Quantifying and Visualizing Trunk Strength using Mobile Devices

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Nowadays many people are becoming aware of the importance of improving physical strength in preventing life-style related chronic diseases. Among all the measures of physical strength, trunk stability is given special attention as it is vital for improving physical strength, preventing fall, and extending healthy life span. Many traditional trunk strength evaluation methods were designed to assess core muscle mass. Less emphasis, if any, was given to the stability of the trunk, which could be represented by the smoothness of trunk movement. In this paper, we proposed a new trunk torsion model for the purpose of quantifying trunk strength in terms of the smoothness of trunk movement. In order to make it possible for end users to easily evaluate and visualize their trunk strength, we also developed a mobile application named "AxisVisualizer" based on the proposed trunk torsion model, which gives higher score to users who perform the trunk torsion movements smoothly with fixed axis and high frequency. This application can support trainers and coaches to visualize the smoothness of trunk movement and to increase training outcome, as well as support health promotion community to easily evaluate the effectiveness of group exercise.

1. Introduction

The age structure of Japanese population is undergoing rapid reorganization with sharp increase in the number of seniors [Japanese Government, 2015]. The corresponding roaring national healthcare cost imposes a big challenge to the social welfare system. In order to reduce nursing and healthcare cost, there is a need for an integrative research effort among the fields of geriatrics, exercise science, and physiotherapy to address age-related and cost-intensive health care problems (e.g., high prevalence of falls) [Gillespie LD, 2012]. Balance and mobility are paramount for fall prevention in older adults, and they are uniquely linked to trunk muscle composition [Hicks GE, 2005 (a)]. Poor trunk muscle composition, as manifested by a higher ratio of fat and decreased trunk strength and endurance, is associated with both balance and mobility decline even after controlling for deficiencies in leg muscle composition [Hicks GE, 2005 (b)] as well as associated with the occurrence of low back pain [Nourbakhsh MR, 2002]. Therefore, trunk strength is of paramount importance to balance, functional performance and fall prevention in older adults [Granacher U, 2013]

Functionally, the body trunk is a kinetic link that facilitates the transfer of torques and angular momenta between upper and lower extremities during the execution of whole-body movements as part of sports skills, occupational skills, fitness activities, and activities of daily living [Behm DG, 2010]. It is difficult to establish precise methods for trunk strength evaluation, as the evaluation per se should be specific to the demands imposed by sports, fitness activities and daily activities [Behm DG, 2010]. In this paper, we propose a new trunk torsion model for the purpose of quantifying trunk strength in terms of the smoothness of trunk movement. In addition, we develop a mobile application named "AxisVisualizer" based on the proposed trunk torsion model, so that end users could easily evaluate and visualize their trunk strength using mobile devices.

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2. Related Work

2.1 Existing Trunk Models

The most detailed trunk model is the musculoskeletal model [Nakamura Y, 2004]. As it models trunk components in great details, it can be used to describe complex movements. However, it is difficult to apply this on torsion movements due to large number of parameters involved. In addition, the trunk model for walking focuses on the waist and the lower limbs, which is not suitable for the purpose of our study. Even in the case of whole body models, the trunk is usually modeled as mass-point or cylinder, and there is no model of trunk torsion movements. Although there are models for body torsion while walking, they cannot be applied to the cases of repeated trunk torsions.

2.2 Basic Trunk Torsion Movements

We selected two beginning and one intermediate movement for easy evaluation of trunk torsion. All the selected movements require stretching the body up and down by using abdominal muscle and abdominal oblique muscle as well as rotating trunk around the vertical axis naturally.

Beginning movement□shoulder torsion□legs open□□ Intermediate movement□waist torsion□legs closed□□

Fig. 1. Basic Body Torsion Movements.

- Slow shoulder torsion（legs open）: separate the legs at shoulder width while standing, as is shown in Figure 1 (left). Slowly rotate the shoulder while keeping the head still (the waist is also rotated naturally). The shoulders and waist are almost in the same phase.
- Quick shoulder torsion（legs open）: separate the legs at shoulder width while standing, as is shown in Figure 1 (left). Quickly rotate the shoulder while keeping the head still (the waist is also rotated naturally). The shoulders and waist are almost in the opposite phase.
- Quick waist torsion（legs closed）: close the legs while standing, as is shown in Figure 1 (right). Rotate the waist so as not to move the upper chest. In practice the chest is also rotating slightly and is almost in the opposite phase as the waist.

3. Proposal of Trunk Torsion Spring Model and Quantifying Trunk Strength

3.1 Proposed Trunk Torsion Spring Model

Our proposed trunk torsion spring model is described by Equation (1).

$$F = -k\theta \quad (1)$$

where

F: the force in the vertical axis direction.

θ: torsion angel（rotating angle of the shoulder line to the pelvis）.

k: spring constant (k_p + k_a).

k_p: the constant that characterizes the passive return of the trunk torsion to its original posture.

k_a: the constant that characterizes the force around the trunk axis generated by deep muscles, which is in the reverse direction of the torsion force.

The rationality of this model is that smooth body torsion movement is generated by the deep inner muscles along the body axis rather than the active linear force of outer muscles. The movement is supported by the passive restoring force caused by the torso, which is squeezed vertically by inner muscles. It is considered that k_p increases with the activities of the deep muscles, and we plan to measure it in the future. We will modify the model if the relationship was non-linear. Though k_a also increases with torsion force that accelerates the torsion of the deep muscles, it may also be affected by muscle activity while the frequency of torsion gradually changes. We plan to improve the accuracy of the model based on measurement using motion capture systems and floor reaction force meter. In this model, oscillation frequency can be calculated using Equation (2).

$$f = 1/2\pi\sqrt{(k/M)} \quad (2)$$

where M is the torsion moment.

3.2 Quantifying Trunk Strength

Based on the trunk torsion spring model described in the previous section, we proposed Axis Index to quantify trunk strength in terms of the smoothness of trunk movement. The Axis Index is defined as follows:

Axis Index: f (Naturalness, Elasticity, Position) (3)

- *Naturalness:* if only deep muscles were used and surface muscles were not used, the movement satisfies Equation (1) and is close to sine wave. It becomes coordinated motion and from chest to foot the body can move in harmony. In the implemented mobile app AxisVisualizer which will be described in the next section, peak ratio (the power of peak divided by the total power) is used to approximate *Naturalness*.
- *Elasticity:* refers to the oscillation frequency, or the square root of the restoring force (spring constant). The unit is [Hz] or [s-1]. High frequency of torsion movement indicates stronger force to restore. Since it is in proportion to the square root of the value obtained by dividing the spring constant against the torsional moment of the trunk, stronger force is required if the body is large.
- *Position:* depending on the posture, the torsion center could shift forward or backward. This can be understood by plotting the trajectory of the sensor.

4. Visualizing Trunk Strength

In order to make it possible for end users to evaluate and visualize their trunk strength, we implemented an iOS app named AxisVisualizer based on the approach proposed in Section 3. This app uses the imbedded accelerometer of mobile terminals and it performs simple analysis function with two types of visualization.

This app has the following three main characteristics: (1) adopting the evaluation method based on trunk torsion spring model; (2) offering easy measurement without the need of special devices; (3) providing straightforward visualization of the measurement results. As is shown in Figure 2, the measurement procedure is as follows: physical condition check → practice of movement → practice of measuring method → measurement (12 seconds) → visualization of results → data export. In particular, the measurement method in step 4 can use two of the methods described in Section 3.3. If one becomes familiar with those methods, step 2 and 3 can be omitted. Similarly, step 6 is optional. In the following subsections, we will describe in detail the design of the application in step 4 and the data visualization in step 5.

Fig. 2. Measurement procedure.

4.1 Measurement with Sound Feedback

We implemented sound feedback during the measurement to enhance the naturalness of movements. When the acceleration of the movement is greater than a fixed threshold value, the sound of "wheel" will be played [Nishimura T, 2016]. In order to solve this problem, we use the following equations to determine the upper and lower bound of the threshold value.

Upper bound:

$$\theta_{max} = min[0.5, a_{max} - (a_{max} - a_{min}) \cdot \theta_r] \quad (4)$$

Lower bound:

$$\theta_{min} = max[0, a_{min} + (a_{max} - a_{min}) \cdot \theta_r] \quad (5)$$

where a_{max} and a_{min} are the maximum and minimum acceleration during the past *N* seconds (*N*=2 in the implementation). The sound will play when the acceleration is higher than θ_{max} or lower than θ_{min}. We also validated that th=0.2 is a proper value for the sound to play whenever the user changes torsion direction regardless of the absolute acceleration. Figure 3 presents two screenshots of the application. Users simply need to input measurement duration (12 seconds by default) and nickname. The measurement starts when users tap the start button and stops when timer ends.

4.2 Result: peak ratio * peak frequency [Hz]

During a measurement, the sampling rate, FFT and sampling time are set to 50Hz, 512 taps, and 10.24 seconds respectively. As is shown in Figure 4, the final result that is given to the end user is the the value obtained by multiplying the peak frequency to the peak ratio of the movements. Figure 4 shows screenshots of measurement results. The percentage value shown on the top of the figure is a value obtained by multiplying the peak frequency to the peak ratio, which makes it easy to understand the measurement results. The graph in the center in Figure 4 shows the acceleration. The red line indicates the acceleration in the left-right direction (X-axis), and the blue line indicates the acceleration in the back-forth direction (Z-axis). The value of the peak ratio and the peak frequency is presented below it. The graph at the bottom shows the frequency analysis results, illustrating which frequency components are often obtained during measurement. The fewer the peaks are, the more stable the torsion movement is. Peak ratios are obtained by dividing the peak power over full power. For this application, the peak power is calculated by summation from -2 to 2 taps, this means about 0.5Hz width, of the FFT power result. The two screenshots on the right shows the evaluation of bad movements. The body axis shakes during waist torsion, generating both low frequency and high frequency. Therefore, the result was as low as 13.2%.

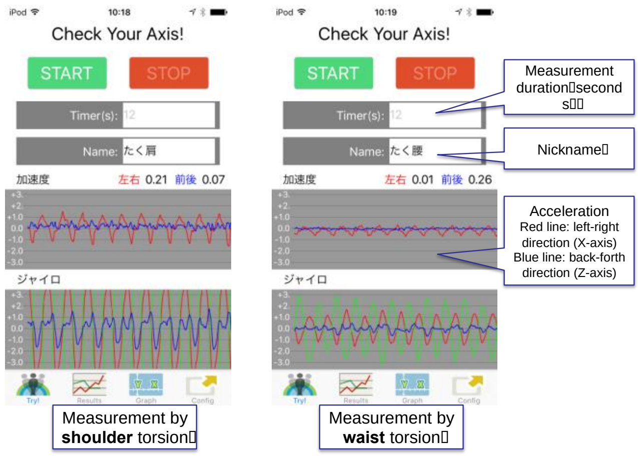

Fig. 3. The Use of Axis Visualizer.

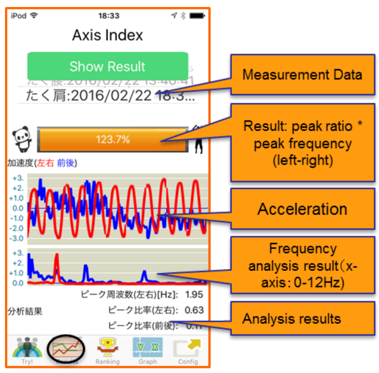

Fig. 4. Screenshots of measurement results.

4.3 Ranking Function

As is shown in Figure 5, we also implemented a ranking function for users to compare results with others. A ranking is generated based on the descending order of the scores stored in local memory. This function can help users (1) track the change in their quality of movement, (2) understand the difference of between their movement and others', and (3) be motivated for further improvement in core stability.

Fig. 5. Image of ranking results.

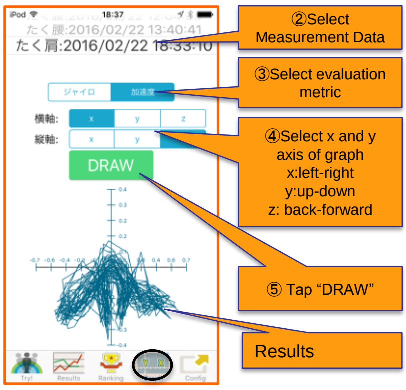

Fig. 6. Two dimensional trajectory of accelerometer.

4.4 Visualization of Analysis

The simple visualization function allows users to select two axis out of the X-axis, Y-axis, and Z-axis, and plot a graph of either acceleration or gyros on a two dimensional plane. The visualization helps users understand their movements straightforwardly. Figure 6 illustrates the plots of acceleration and gyros respectively on a two-dimensional plan with X-axis and Z-axis. This function not only helps users understand their own movements but also makes it possible to compare to previous measurement or the measurement results of others.

5. Conclusions

In this paper, we proposed a trunk torsion model and evaluation criteria for the purpose of quantifying trunk strength in terms of the smoothness of trunk movement. Based on the proposed model, we implemented a mobile application named AxisVisualizer for end users to evaluate and visualize their trunk strength. In the next step, we will refine the trunk torsion model based on measurement using motion capture systems or floor force plate systems, as well as assessing the model against users' subjective evaluation. In addition, we will build the modeling and evaluation techniques for other trunk movements and by doing so we will eventually promote the health promotion community support.

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