Health Promotion Community Support for Vitality and Empathy: Visualize Quality of Motion (QoM)

Takuichi Nishimura[1(✉)], Zilu Liang[1], Satoshi Nishimura[1], Tomoka Nagao[1], Satoko Okubo[1], Yasuyuki Yoshida[2], Kazuya Imaizumi[3], Hisae Konosu[4], Hiroyasu Miwa[5], Kanako Nakajima[5], and Ken Fukuda[1]

[1] National Institute of Advanced Industrial Science and Technology, AI Research Center, Tyoto, Japan
takuichi.nishimura@aist.go.jp
[2] Tokyo Institute of Technology, Graduate School of Decision Science and Technology, Tokyo, Japan
[3] Faculty of Healthcare, Tokyo Healthcare University, Tokyo, Japan
[4] Japan Dance Sport Federation, Tokyo, Japan
[5] Human Information Research Institute, National Institute of Advanced Industrial Science and Technology, Tokyo, Japan

Abstract. Nowadays approximately 30 % of the population is suffering from lifestyle-related diseases in Japan. Both individuals and the government are becoming more and more health-conscious and are taking various measures to improve personal health and to prevent lifestyle-related diseases. Among all the measures, improving trunk stability has been given special attention as it is vital for improving physical strength, preventing injury, 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 evaluating two trunk torsion standard movements. We also developed a mobile application named "Axis Visualizer" based on the proposed trunk torsion model, which gives higher score to users who rotate the shoulders or hips smoothly with axis fixed and high frequencies. 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.

Keywords: Health promotion · Community support · Quality of motion

1 Introduction

The rapidly aging population imposes a heavy burden to the social welfare system in Japan. The number of old people reached historical peak 33 million in 2014, which is equivalent to 26.0 % of the whole population [1]. In 2012, the national healthcare cost

V.G. Duffy (Ed.): DHM 2016, LNCS 9745, pp. 253–263, 2016.
DOI: 10.1007/978-3-319-40247-5_26

was more than 39 trillion Japanese Yen, which increased about 627 billion Japanese Yen compared to that in previous year. In addition, long-term care insurance sharply increased to 8 trillion Japanese Yen. Moreover, it is expected that the social welfare for nursing and healthcare will roar in 2025 as the baby boom generation ages beyond 75-year-old. Various efforts have been made, including cooperation between health industry (e.g., private sports clubs) and medical institutions or local governments, preventive healthcare measures advocated by health insurance unions, regional comprehensive care system designed for supporting independence of local residents. As nowadays lifestyle-related chronic diseases are more common than infectious diseases, it is imperative to promote healthy lifestyles in order to extend healthy life expectancy. Actively improving physical strength is widely acknowledged as a very important aspect of healthy lifestyles.

Under such background, special attention has been given to body trunk for the purpose of prevention injuries and fall, and many core training methods [2–5] have been introduced to increase trunk muscle mass. In dance sports, however, it is widely considered that the strength of body trunk is not characterized by the amount of muscle but by the cooperative use of body trunk and limb. Therefore, in order to support more integrative evaluation on trunk strength, we developed a mobile application named Axis Visualizer based on our proposed trunk torsion model for evaluating the smoothness of truck torsion movements. A user can obtain high score if he or she coordinately rotates shoulders and hips smoothly, with low vibration and high frequency.

The rest of the paper is organized as follows. The related work on trunk strength and movements is discussed in the next section. In Sect. 3, we present our proposed trunk torsion spring model and the evaluation measures of body trunk strength. In Sect. 4, we describe the implementation of the mobile application Axis Visualizer and a demo of the evaluation on users' torsion. We then give an overall picture of the health promotion community support that we are working on. The paper is concluded in Sect. 6.

2 Related Work

2.1 Definition of Trunk Strength

In order to discuss the body trunk strength, we first describe the definition of posture, movement, motion, action in kinematics.

- *Posture*: a posture consists of two elements: attitude and position. Attitude represents the relative positional relationship among each part of the body such as head, trunk, limb, and it can be measured through joint angle. On the other hand, position is used to represent the relationship between the body axis and gravity, and it can be indicated by standing, supine (face up), and so on.
- *Movement*: a movement refers to temporal change of posture. In other words, it is described as a change of attitude and position.
- *Motion*: a unit that analyzes the behavior as a task that is specifically carried out by a movement.
- *Action*: a unit when taking into consideration the context of the meaning and intention shown by a movement.

Body trunk is the torso which has the following three roles: (1) supporting and maintaining postures, (2) the foundation for producing movement, (3) serving as an axis. Several methods were proposed to increase the mass of surface muscle group (e.g., rectus abdominis muscle) and deep muscle groups (e.g., transverse abdominal muscle) [6–8], such as plank, elbow-to, and breathing techniques.

It is worth mentioning that the quality of movement is more important than the amount of movement, which is a key point in improving people's healthy life expectancy in the super-aged society in the future. Bad motion patterns caused by bad postures may lead to musculoskeletal pain syndrome. The prevention and treatment of pain is directly related to the activity in everyday life, therefore it is a very effective and efficient means for health promotion and preventive care. Based on this rationality, the MSI (Movement System Impairment) approach was proposed, which reduces mechanical stress by correcting the movements and motions and thereby enables the prevention and treatment of pain [9]. In addition, Shumway-Cook and Woollacott proposed a system theory which advocates that movement is not simply the result of muscle-specific exercise program or uniform reflection, but rather the result of the dynamic interaction among perception system, cognition system, and musculoskeletal system [10]. This theory has been applied in rehabilitation and has been proved effective in practice. For instance, the capability of independent walking in the elderly was improved after motion control exercise with repeated movement such as walking, even though muscle strength was not really improved, the capability of independent walking was increased. In physically expressive sports such as dance sports, it is widely known that smooth usage from deep muscles to the surface muscles is more important than muscle mass. And the core stability is the result of motion control and the muscle function of the Lumbar spine, pelvis, and hip joint complex.

Therefore, it is considered that system theory as well as MSI approach should be applied to health promotion and preventive medicine. In other words, rather than evaluating single function, such as muscle strength and range of motion, it is important to establish an easy and proper approach to evaluate and visualize the quality of movement pattern in a comprehensive manner by considering neuromuscular coordination. In this way, it will become possible to learn and acquire the optimal movement pattern without injury or secondary dysfunction. However, many services of health promotion and prevention activities still solely put emphasis on strength training.

2.2 Typical Trunk Movement

According to the WDSF technique book "Rumba" [11], there are four types of trunk movement.

1. *Left and right horizontal movement of pelvis* (Fig. 1 left). While keeping the pelvis and shoulder line horizontal, move pelvis left and right horizontally.
2. *Left and right tilt of pelvis* (Fig. 1 center). The left side of the body is compressed vertically while the right side of the body is stretched. Keep the left shoulder close to the left hip and the right shoulder away from the right hip. The right side is the same.

3. *Back and forward tilt of pelvis* (Fig. 1 right). For forward tilt, tilt the pelvis forward by moving the upper part of the pelvis forward and the bottom part backward, and vice versa for back tilt.
4. *Trunk torsion*. While keeping the pelvis and shoulder line horizontal, rotate around the vertical axis of the trunk.

The trunk can also make various movements by opening and closing the chest. In the case of standard dance, many movements involve the conjunction move of limbs and head. In the case of Latin dance, many movements only move the lower part of the body smoothly while keeping the upper part instable. In this paper, we focus on trunk torsion that may occur in walking and rotational motion, which in characterized by the angle change in the vertical axis of the shoulder line and the hip line.

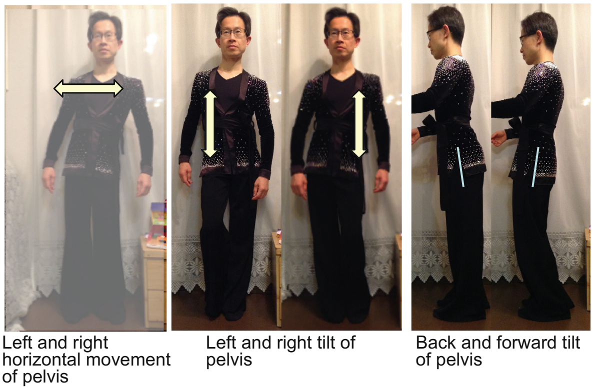

Fig. 1. Examples of trunk movements in dance sports.

2.3 Existing Trunk Models

The most detailed trunk model is the musculoskeletal model [12]. 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.

3 Proposal of Trunk Torsion Spring Model and Evaluation Method

3.1 Overview of the Proposal

In this paper, we propose a method for evaluating the smoothness of trunk movement. First, we propose the trunk torsion spring model. We selected the standard movements of trunk torsion as shown in Fig. 2 for easy evaluation on trunk movements. Second, we propose a method to use accelerometer on mobile phone for evaluating trunk movement. This method could be used more widely in comparison with motion capture systems or floor reaction force systems that are only available in laboratories.

3.2 Trunk Torsion Basic Movements

We selected two beginning and one intermediate movement for easy evaluation of trunk torsion. Since advanced movement such as Kuka Racha can only be performed smoothly by advanced dancers, we will not cover it in this paper. 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.

Fig. 2. Basic body torsion movements.

- Slow shoulder torsion(legs open)

Separate the legs at shoulder width while standing, as is shown in Fig. 2 (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 Fig. 2 (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 Fig. 3 (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.

3.3 Proposed Trunk Torsion Spring Model

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

$$F = -k\theta \tag{1}$$

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 rotation 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 rotation of the deep muscles, it may also be affected by muscle activity while the frequency of rotation 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 Eq. (2).

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

where M is the rotation moment. The Axis Index in the proposed model is defined as follows:

$$\mathit{Axis\,Index} : f(\mathit{Naturalness}, \mathit{Elasticity}, \mathit{Position}) \tag{3}$$

- *Naturalness:* if only deep muscles were used and surface muscles were not used, the movement satisfies Eq. (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 Axis Visualizer 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 rotational 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 Implementation of Axis Visualizer

4.1 Overview

Axis Visualizer is a iOS app that evaluates the smoothness of trunk movements based on the proposed trunk torsion spring model described in Sect. 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 Fig. 3, the measurement procedure is as follows: physical condition check → practice of movement → practice of measuring method → measurement (12 s) → visualization of results → data export. In particular, the measurement method in step 4 can use two of the methods described in Sect. 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.

4.2 Measurement: Sound Feedback

We implemented sound feedback during measurement to enhance the naturalness of movements. When the acceleration of the movement is greater than a fixed threshold value, the sound of "wheel" is played. If the timing deviates, the sound will not play. In the next step, we plan to refine the system to dynamically set the threshold value according to the motion of the user. One of the methods is to use the *th%* of the maximum value of the past *N* seconds. We will also conduct experiments to clarify the conditions for users to feel that the sound is played at good timing depending on their movement. Figure 4 presents two screenshots of the Axis Visualizer. Users simply need to input measurement duration (12 s by default) and nickname. The measurement starts when users tap the start button and stops when timer ends.

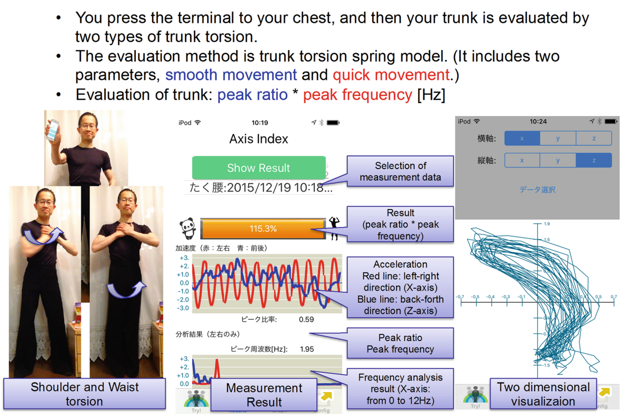

Fig. 3. Overview of Axis Visualizer.

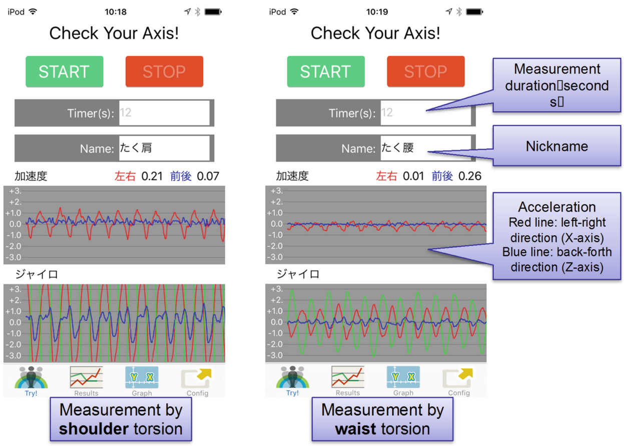

Fig. 4. The use of Axis Visualizer.

4.3 Result: Peak Ratio * Peak Frequency [Hz]

During a measurement, the sampling rate, FFT and sampling time are set to 50 Hz, 512 taps, and 10.24 s respectively. As is shown in Fig. 5, 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 5 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 Fig. 5 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 0.5 Hz 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 %.

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.

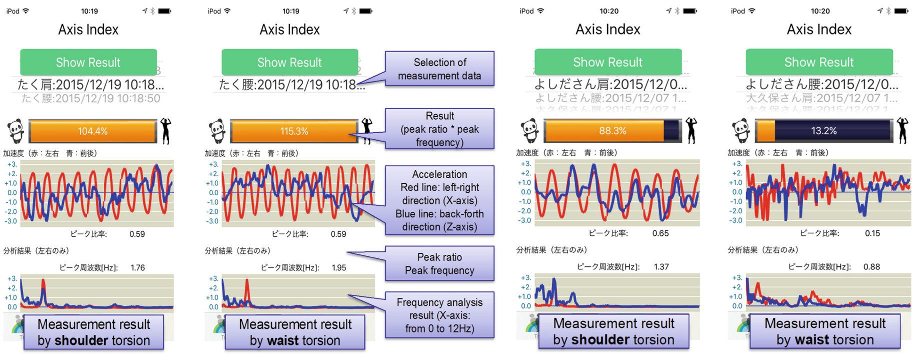

Fig. 5. Screenshots of measurement results.

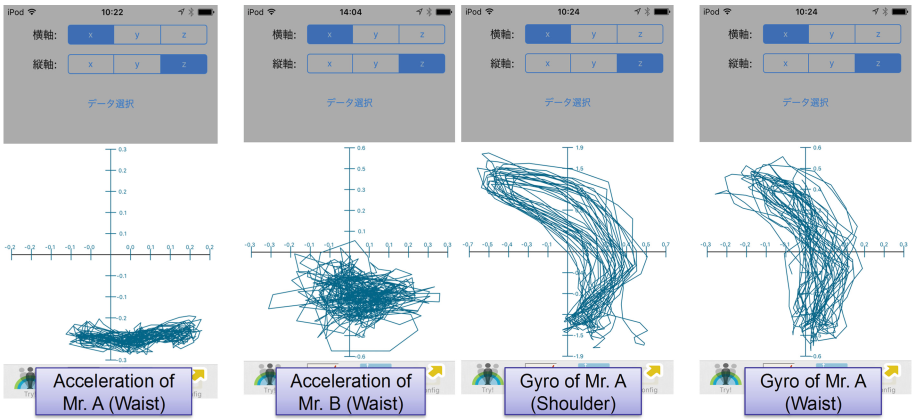

Fig. 6. Two dimensional trajectory of accelerometer.

5 Health Promotion Community Support

In this section, we describe our on-going health promotion community support, and shows the positioning of the implemented Axis Visualizer. As is shown in Fig. 7, health promotion community support refers to the repetitive cycle of performing physical activities within the organization, measuring, analyzing, visualizing, and re-designing (making strategic decision on tailored behavior change for better activity and better health state) the activity of community members. Health promotion communities can stay active by repeating this cycle. Furthermore, the measurement data and the insight of redesign can be aggregated in a database. After necessary processing such as anonymization, it is possible to share health community information /knowledge with other organizations. As a result, the useful information and knowledge obtained in one of the community can be utilized in other communities, and therefore the overall quality of health promotion community can be improved nationwide.

Within the framework of such health promotion community support, Axis Visualizer is positioned as a tool for measuring the intensity of the trunk of the participants. Trunk strength is one of the indicators to measure whether the activities were carried out without injury and whether the activities were carried out effectively in a wide variety of physical activities such as dance sports. Axis Visualizer makes it possible to autonomously measure trunk strength in each community and thereby contributes to the prosperity of the entire health promotion community.

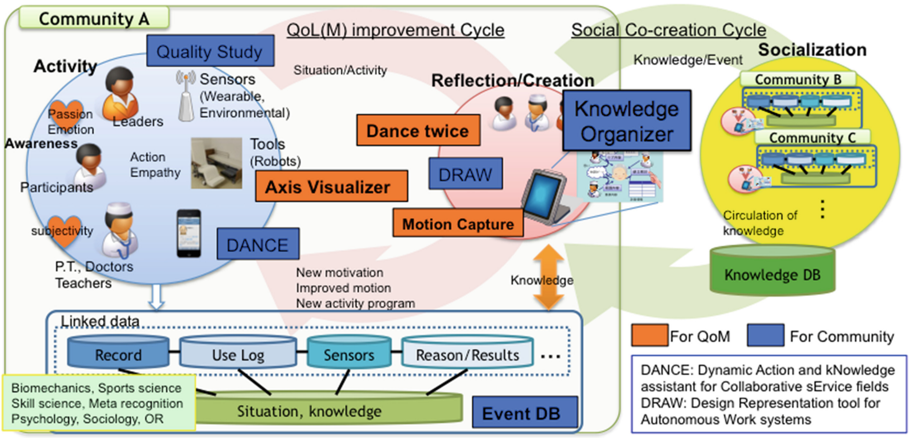

Fig. 7. Health promotion community support

6 Conclusions

In this paper, we proposed trunk torsion model to evaluate the smoothness of trunk movement. Based on the proposed model, we implemented and preliminarily evaluated a trunk movement evaluation application called Axis Visualizer. 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. We also plan to improve the real-time biofeedback in Axis Visualizer and to calibrate the constants in the proposed model. We will continue improve the trunk torsion model, the visualization of the analysis results, and the way to save and share the results after applying our system in practical use. 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.

Acknowledgment. This study was partly supported by Japanese METI's "Robotic Care Equipment Development and Introduction Project",NEDO's Artificial Intelligence Research Project and JSPS KAKENHI Grant Numbers 24500676 and 25730190. We would also like to thank the member of the health promotion project in Odaiba and Tsukuba for their kind support.

References

1. White Paper in 2015, Cabinet Office, Government Of Japan. http://www8.cao.go.jp/kourei/whitepaper/w-2015/html/zenbun/index.html [in Japanese]
2. Cowley, P.M., Fitzgerald, S., Sottung, K., Swensen, T.: Age, weight, and the front abdominal power test as predictors of isokinetic trunk strength and work in young men and women. J. Strength Cond. Res. **23**(3), 915–925 (2009)
3. Biering-Sørensen, F.: Physical measurements as risk indicators for low-back trouble over a one-year period. Spine **9**(2), 106–119 (1984)
4. McGill, S.M.: Low back stability: from formal description to issues for performance and rehabilitation. Exerc. Sport Sci. Rev. **29**(1), 26–31 (2001)
5. Baechle, T.R.: Essentials of strength training and conditioning, 3rd edition. National Strength and Conditioning Association (NSCA) (2008)
6. Behm, D.G., Drinkwater, E.J., Willardson, J.M., et al.: The use of instability to train the core musculature. Appl. Physiol. Nutr. Metab. **35**(1), 91–108 (2010)
7. Panjabi, M.M.: The stabilizing system of the spine. J. Spinal Disord. 5(4), 390–397
8. Majewski-Schrage, T., Evans, T.A., Ragan, B.: Development of a core-stability model: a delphi approach. J. Sport Rehabil. **23**(2), 95–106 (2013)
9. Sahrmann, S.A.: Diagnosis and Treatment of Movement Impairment Syndromes, Mosby (2002)
10. Shumway-Cook, A., Woollacott, M.: Motor Control: Translating Research into Clinical Practice, 2nd Edition (1999)
11. WDSF Latin Technique Books and DVD, The World DanceSport Federation. https://www.worlddancesport.org/WDSF/Academy/Technique_Books
12. Nakamura, Y., Yamane, K., Suzuki, I., Fujita, Y.: Somatosensory computation for man-machine interface from motion capture data and musculoskeletal human model. IEEE Trans. Rob. **21**(1), 58–66 (2004)