Stillness Moves: Exploring Body Weight-Transfer Learning in Physical Training for Tai-Chi Exercise

Han Hong Lin

Graduate Institute of Networking
and Multimedia
National Taiwan University
Taiwan, ROC
stanley538@gmail.com

Ping Hsuan Han

Graduate Institute of Networking
and Multimedia
National Taiwan University
Taiwan, ROC
pinghsuan.han@gmail.com

Kuan Yin Lu

Dept. of Computer Science and
Information Engineering
National Taiwan University
Taiwan, ROC
r_2123b@hotmail.com

Chia Hung Sun

Taiwan Taichi Academy
Taiwan, ROC
Johnny05311@yahoo.com

Pei Yi Lee

Taiwan Taichi Academy
Taiwan, ROC
taichihung@gmail.com

Yao Fu Jan

Dept. of Computer Science
National Chengchi University
Taiwan, ROC
joshuachan6988@gmail.com

Amy Ming Sui Lee

Graduate Institute of Networking
and Multimedia
National Taiwan University
Taiwan, ROC
mslee@csie.ntu.edu.tw

Wei Zen Sun

Health Science and Wellness
Center
National Taiwan University
Taiwan, ROC
wzsun@ntu.edu.tw

Yi Ping Hung

Graduate Institute of Animation
and Film Art
Tainan National University of the
Arts
Taiwan, ROC
hung@csie.ntu.edu.tw

ABSTRACT

Body weight-transfer plays an important role in many exercises. The correlation of the body posture, movement, and weight-transfer will mutually affect the trainee to do well in performances such as Tai-Chi exercise. According to the traditional way of learning Tai-Chi, we proposed Stillness Moves, a physical training system for Tai-Chi, which captures and records users' skeleton movement and weight-transfer information for offering real-time and summary visual feedback. Based on above, we provide a gradual learning program in physical training, which combines body movement and weight-transfer learning. We evaluated our system and compared the performance without and with weight-transfer guidance in the user study. The result demonstrated that weight-transfer guidance is beneficial for trainee learning the Tai-Chi moves. For difficult moves, the trainee should learn the weight-transfer first, then, learning the body movement.

KEYWORDS

Weight-Transfer Learning; Movement Guidance; Visualization; Tai Chi Chuan

ACM Reference format:

Han Hong Lin, Ping Hsuan Han, Kuan Yin Lu, Chia Hung Sun, Pei Yi Lee, Yao Fu Jan, Amy Ming Sui Lee, Wei Zen Sun and Yi Ping Hung. 2018. Stillness Moves: Exploring Body Weight-Transfer Learning in Physical Training for Tai-Chi Exercise. In 1st International Workshop on Multimedia Content Analysis in Sports (MMSports'18), Oct. 26, 2018, Seoul, Republic of Korea. ACM, NY, NY, USA, 9 pages. DOI: <http://dx.doi.org/10.1145/3265845.3265856>

1 INTRODUCTION

Tai Chi (TC) is a famous physical activity in martial arts, and it can be an exercise in daily life [1]. In the traditional way of learning TC, trainees will follow the master who demonstrates the moves in the classroom. The concept of proper weight-transfer is always emphasized in practice TC exercise [2]. Usually, the master of TC has many trainees to take care of in the classroom. Those trainees not only has different learning progress, but also across all ages. Without any master instruction or supervision, it is very easy to do the wrong posture or movement when trainees doing their practice, especially, the

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than ACM must be honored. Abstracting with credit is permitted. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. Request permissions from Permissions@acm.org.

MMSports'18, October 26, 2018, Seoul, Republic of Korea.

© 2018 Association of Computing Machinery.

ACM ISBN 978-1-4503-5981-8/18/10...\$15.00.

DOI: <http://dx.doi.org/10.1145/3265845.3265856>

weight-transfer in the moves procedure. When standing on the ground with feet, the different posture will change the body weight center. In fact, the complete moves consist of correct posture, movement and weight-transfer. Therefore, weight-transfer learning should be accompanied with body movement training.

The first problem is that after users obtain the instruction, they can only be aware of their proportion of their body weight on both legs by themselves. Then, they adjust the body posture to change the proportion of the weight on the feet. Simultaneously, in the body movement part, the change of the weight-transfer is continuous, and those transfers need to cooperate with the change of the body posture. Therefore, it is very hard for trainees to imagine by themselves. Secondly, in order to know whether the weight-transfer is correct or not, in addition to their own awareness, is usually by observing the outside shape of the user's physical action through the master's vision. Therefore, without the master around the trainee, it makes the trainees' practice inefficient. Specially, trainees may get used to the wrong physical action when they practice by themselves.

In this paper, we consulted TC experts and proposed a physical training system for TC, which captures users' 3D movements by a Microsoft Kinect and plantar pressure distribution (PPD) that pressures sensing shoes. Then, various feedbacks such as sensors' visualized information, guidance hints, and summary feedback with a record review browser presented. Finally, our system provides multiple stages for gradual learning.

2 RELATED WORK

Our work is influenced by prior work in many areas, such as physical activity training, movement guidance, and body weight-transfer.

2.1 Physical Activity Training

There has been a push to use technology for physical training in physical therapy. These typically focus on retraining simple movements and improving range of motion. For example, Anderson et al. [3] introduced multi-touch tabletop (technology-based) rehabilitation methods in opposition to traditional table-based therapy methods. Another example is Physio@Home [4], which addressed several aspects of corrective guidance, including plane and range of movement, joint positions, angles, and extent of movement. There are several research projects supporting physical activity training with motion demonstration and evaluation, which used skeletal tracking technology such as motion capture or Microsoft Kinect mostly. Motion capture technology collects full-body skeletal data with high accuracy. Chan et al. [5] proposed a virtual reality based dance training application using motion capture technologies, and Hachimura et al. [6] proposed similarly but using head-mounted display. However, Microsoft Kinect benefits from being readily available, easy to setup, and low-cost; thus, it has been widely used in researches lately. Alexiadis et al. [7] introduced a novel system

using Kinect-based human skeleton tracking, which evaluates dance performances against standard performance and provides visual feedback. MotionMA [8] uses the Kinect to focus on movement interpretation and feedback for performing repetitions. YouMove [9] is a system for learning full body movements that trains the users through a series of stages that gradually reduce the user's reliance on guidance and feedback.

Within the domain of physical activity training, TC learning has researched on as well. Chua et al. [10] presented a wireless virtual reality system rendered in the head mounted display and a prototype of full body Tai Chi training application. The Kinect-based system Jin et al. [11] proposed can evaluate a Tai Chi trainee's performance and provide correction feedback in real-time. Hsieh et al. [12] also used the Kinect to track Tai Chi motions for physical rehabilitation. However, those researches and fitness courses focus on body posture and movement. They do not considerate the body weight-transfer. In contrast, we explore the body weight-transfer in physical activity, and the relation between weight-transfer and body movement.

2.2 Movement Guidance

Based on previous section, systems within the HCI literature have focused on movement guidance. Several researches explored the AR technology for guiding users through repairing laser printer [13] or completing procedural tasks [14]. Flagg and Rehg uses projection-based AR for guiding users through painting task [15]. White et al. uses tangible AR for guiding user discovery and completion of hand gestures [16]. Motokawa and Saito uses AR display for guiding user playing guitar [17]. LightGiode [18] uses on-body projected hints, such as arrow and path, to guide users' hand through 3D space. The movement guidance provides user visual hints for doing the physical actions or gestures.

Serval movement guidance in the training system, Physio@Home [4] and YouMove [9] are closest to our work. Previous provides contextualized movement guidance with movement arc, directional arrow, and the nearest arm figure. The others progress through stages including posture guide and movement guide. The posture guide stage helps trainees refine their body position by pausing the movement at each keyframe until they hold a stable position for seconds.

2.3 Body Weight-Transfer

In order to note the user's weight-transfer, the system needs to collect the information by providing foot pressure guidance. Nintendo Wii Fit [19] provides a balance board for measuring player's center of pressure. Although it is a great technology product that be used for guiding user's weight-transfer, users must stand on the board for measurement. Additionally, plantar pressure distribution can measure the user's data without standing on the fixed place. It has utilized for TC gait analysis [20, 21] and TC movement analysis [22]. Mao et al. [23] compared plantar pressure distribution during one-leg stance with normal working, and found that practicing TC benefits balance control. Wu et al. [24] concluded that Tai Chi gait had a

low impact force, an evenly distributed body weight between the forefoot and rear-foot regions.

Figure 1. The design of Stillness Moves

3 STILLNESS MOVES DESIGN

Based on our observations and a review of previous work, we have developed a set of design goals to guide the implementation of our system.

3.1 Knowledge-Driven Feedback

The experts know which postures in the movement trainees should practice and how to evaluate trainees' performance. Then, the training system should make trainees practice those emphases, and provide feedback for them to revise their body movement and weight-transfer. Based on above, the recorded information of instructor's physical actions can be considered as a good performance. In several previous works [5, 7, 8, 11], they used it for standard performance through evaluating the trainee's performance by comparing it with standard performance. Therefore, finding a suitable matching algorithm and scoring standard would be the main concern.

After aggregating the experts' knowledge, providing feedback would help users examine their own performance. Anderson and Bischof designed and evaluated various gesture guides, and found that high guidance can hinder learning of the motor action [25]. Several research projects provided guidance along with correction feedback [5, 8, 9, 11, 18]: real-time feedback can help users fix their errors immediately, and summary feedback allow users to see systemic errors in their performances and their process of improvement, which could be encouraging for them. In the design of guiding system, OctoPocus [26] and ShadowGuides [27] provides a real-time feedback and feedforward mechanisms for guiding users gestural tasks. Interpretation of feedback should be simple and easy to understand. Users should make little effort on reading these feedbacks while practicing.

Then, learning procedure should divide into various parts, with gradual increase in difficulty. The user, especially, beginner,

would struggle with too much information given at the same time when they are in practice. With gradually adding new elements from stage to stage, the learning process would go through more smoothly. Users can focus on one element at a time instead of learning all the elements at the same time. Moreover, users can choose which element to learn considering users' learning progress and weaknesses. Finally, with learning to a certain extent, guidance should gradually reduce. The reason is that when the guides take away, we still want users to remember the physical activity they had learned.

3.2 Guided Learning

Although each coach has different sequence in which they teach the TC moves, the main idea is to let the trainees know the complete appearance of the moves with each emphasis, then, trainee will start to practice and correct their own actions. Therefore, following the gradual learning design and referring to [9], our system provides five training stages of learning process: Posture Guide, Weight Transfer Guide, Movement Guide, Self-Practice, and Self-Quiz.

3.2.1 Posture Guide. The posture guide stage (Figure 1a) helps users refine their body posture on each keyframe. When learning a new movement, we must practice the important postures in the movement first. The keyframe of movement are pre-select by the instructor; it can also be select automatically by using keyframe selection algorithm [28]. The instructor's skeleton align to the user, which can guide users to match their posture with it. The system halts the movement at each keyframe and provides real-time feedback on their errors. The pause-and-play procedure has used in tutorial systems, and it has been found to improve users' experience with video tutorial [29]. The stage pauses until the user holds a stable posture for three seconds. Errors in posture shown on the corresponding bones of the instructor's skeleton the more error on the bone, the much red it turns (Figure 2a).

Figure 4. The system used to teach the TC moves in the Guided Learning mode (Dark Green), and allow users to review their performance with a learning result browser in the Record Review mode (Light Green). The hardware configuration of our system: (a) PC, (b) pressure sensing shoes, (c) a Microsoft Kinect, (d) an iOS device, and (e) a screen.

3.2.2 Weight Transfer Guide. The weight transfer guide stage (Figure 1b) instructs users to refine their plantar pressure distributions. After learning the important postures, the focus should be on the plantar pressure distribution. Similar to the posture guide stage, the stage pauses until the user holds the correct center of body weights. A slide bar represents the user's plantar pressure distribution, and red arrows point to the instructor's. With the visualization UI design (Figure 2b), users can see their difference from the instructor's PPD.

Figure 2. The real-time feedback in our system: (a) Errors in posture are indicated on the instructor's bone; the more error on the bone, the more red it turns. (b) The red arrow shows the instructor's body weight center, and the blue spot shows the user's body weight center.

3.2.3 Movement Guide. The movement guide stage (Figure 1c) provides upcoming movement hints for guiding the movement. The upcoming movement hints display the 3D trajectories of hands and feet a second ahead of the current frame. Since users might find a hard time following the guidance at first, the movement will pause if users did not catch up. It still encourages users to follow the instructor's movements at full speed.

3.3 Self-Practice

The Self-Practice stage (Figure 1d) encourages users to focus on their reflections including PPD, without any visual guidance and feedback. Since there is no guidance including demonstration

video, users are allowed to perform at their own paces instead of memorizing the timing and speed. With this consideration, there is no standard speed for TC. Finally, speed recognition used for users to cue the system that they finished the movement.

3.4 Self-Quiz

The Self-Quiz stage (Figure 1e) tests users on the TC movement. Just like the real test, users can only rely on what they have learned without seeing their reflections. Same as the Self-Practice stage, users can perform at any speed and stop the quiz when finished.

After each of the training stages, users can view the scores of their overall performance (Figure 1f). The performance scored based on postural and plantar pressure distributional correctness. The three error curves of scoring components (Figure 3e) represent performance on each component throughout the process. Users can move to the next training stage, practice again in the same stage, or review the detailed record of their performance.

Figure 3. The UI design of summary feedback in our system: (a) instructor video, (b) comparing user's skeleton with instructor's skeleton, (c) comparing user's weight-transfer with instructor's weight-transfer, (d) the playback bar with error tags, (e) the graphs of user error.

3.5 Record Review

The record review browser (Figure 3) shows the detailed record of users' previous performances by giving user a summary feedback. Users can navigate through the learning process to see their posture and PPD for each frame. Both trainee and instructor's skeletons are align to the recorded video of trainee so users can easily see the difference between them. For all the visualization data, blue ones represent the trainee's data and red ones represent the instructor's. The error curves (Figure 3e) and error tags (Figure 3d) used in summary feedback are used for helping users find the parts they made errors. After reviewing the performance record, users can learn from their mistakes and correct them the next time they perform.

4 STILLNESS MOVES IMPLEMENTATION

In this section, we demonstrate the implementation details of our physical training system for TC exercise.

4.1 System Overview

There are two modes in our system (Figure 4): (1) In the Guided Learning mode, users provided with guidance and feedback based on the comparison between standard data and users' data retrieved from sensors. We collected the color data and skeleton data from Kinect and PPDs data from pressure sensing shoes. After being processed, the data compared with the standard data for correction feedback, and recorded into the database for reviewing it later. We used this mode to record standard data. (2) In the Record Review mode, users can review their performance by accessing their performance data from database. The database contains color data saved as a video file, skeleton data, and PPD data saved as text files. Those data compared with standard data in order to get the evaluation result including scores. Eventually, the information presented in a browser for users to browse their whole performances.

4.2 Skeleton Alignment

Scaling the skeleton is necessary since users have different age, height, and weight from the instructor. Each bone in the instructor's skeleton resized to match the size of corresponding bone in the user skeleton. Starting from the spine base, the bones connected to the joint are scaled to the length of corresponding bones of user skeleton, then the position of joints on the other side are updated. This bone resizing has done hierarchically to change joint positions throughout the skeleton. After scaling the skeleton, users can try to match the scaled instructor's skeleton to imitate the posture and movement.

4.3 Skeletal Similarity

As most of the joints have more than one degree of freedom, the joint angle should be measured three-dimensionally instead of as planar angle. For each joint angles, we define a coordinate system with the origin at the joint, and normalize the two bone vectors into unit vectors that the joint angle is in between. Both vectors are multiplied with the same rotation matrix that makes one of the vectors on x-axis, and then the joint angle has defined

by the other vector's coordinate. After defining joint angles, we measure the similarity between two joint angles by their dot product. The example shown in figure 5.3.

We calculate the similarity between two skeleton frames as the weighted average of the score of components. Part of the joint angles are involved in the similarity measurement, including the neck, L/R shoulder, L/R elbow, L/R wrist, L/R hip, L/R knee, and the L/R ankle.

The score of each joint angle is calculated using Gaussian function as the following formulas:

$$\theta = \cos^{-1}(j, j_i), S_j = \exp\left(-\frac{\theta^2}{2\sigma_j^2}\right) \quad (1)$$

, where j and j_i are the user and instructor's joint angle, S_j is the score of the joint angle j , and σ_j is the Gaussian RMS width, which is used to control the tolerance of error.

4.4 Shoes Data Processing

We put the distribution of plantar pressures in a pair of Kong-Fu Shoes proposed. Inside of DPP, there are 16 high resolutions (0-2 bar) force sensors under each shoe insole. The data retrieved from sensor is the weight that sensor carried, which is scaled from 0 to 200. As we are interested in the distribution of two feet, we summed up the sensors data for each foot and calculate the weight ratios of both feet which scaled from 0 to 10 (Figure 5). We calculate the score of plantar pressure distribution correctness score S_{PI} with Gaussian function as well:

$$d = \frac{|p - p_i|}{10}, S_{PI} = \frac{1}{2}(\exp(-\frac{d_L^2}{2\sigma^2}) + \exp(-\frac{d_R^2}{2\sigma^2})) \quad (2)$$

, where d is the difference between trainee and instructor's PPD p and p_i , the left and right foot difference in PPDs are denoted as d_L and d_R , and σ is the Gaussian RMS width which is used to control the tolerance of error.

Figure 5. The PPD of two feet could be interpreted as numerical scale for guiding user's weight-transfer.

4.5 Scoring and Dynamic Time Warping

Each frame of the user's movement scores as the weighted mean of the scores of postural and plantar pressure distributional correctness. We calculate the score S as follows:

$$S = \omega_{pj}S_{pj} + \omega_{pl}S_{pl} \quad (3)$$

, where the weights of postural and plantar pressure distributional correctness score are $\omega_{pj}(= 0.5)$, $\omega_{pl}(= 0.5)$ respectively. In order to allow small errors in timing, we searched a window on each side of the target frame to find the best scores. However, users are allowed to perform at their own paces for some training stages in our system.

The speed inconsistency problem can be achieved by using the dynamic time warping algorithm [30]. Dynamic time warping is an algorithm for measuring similarity between two temporal sequences vary in time or speed. After going through dynamic time warping process with locality constraint, users' movement sequence will match the instructor's movement sequence for speed variance. Therefore, the performance can be evaluated without any timing constraint.

5 EVALUATION

We conducted a controlled study to compare our system with and without PPD feedback since we focused on how having weight-transfer guidance and feedback improve the performance of learning TC movements. Effectiveness of TC instruction was compared using the scores after learning. Subjects also provided suggestion and feedback on our learning system, which will be archive to the consideration of design.

Figure 6. TC movements used in our study: (a) Jin-Gang-Hou-Lyu, and (b) Shen-Ma-Fen-Zong.

● Experiment 1: Participants

We recruited 14 participants (8 males and 6 females) between 20 and 33 years old (mean = 23.71 years, std = 3.53) to be our subjects in this experiment, which are external to the research group. No participants had experience with the study or system, or a TC background.

● Experiment 1: Study Moves

Participants would complete the learning process of TC movement while following an onscreen guide. The TC Silk

Reeling moves (Figure 6) were recorded for the study, which were selected by the expert that indicated those are difficult for trainees to perform well. We invited a TC senior student, which is external to the research group and had 5 years of TC experience. This Study moves (Figure 6a) included one arm and upper body movement, and containing weight-transfer and feet change.

● Experiment 1: Condition

The two conditions for the study were training stages without and with PPD feedback. Subjects in the training stages without PPD feedback condition (Interface A) can access most of the stages we provided except the 'Weight-Transfer Guide' stage, and the PPD information is shown only for demonstration rather than lets them view their own data. However, subjects in the training stages with PPD feedback condition (Interface B) can access all stages in our system and receive all guidance we provided.

● Experiment 1: Design

This user study was conducted as a repeated-measures design, which each participant learning one move using two different interfaces in our Stillness Moves. The condition order was fully counterbalanced across all 14 participants.

● Experiment 1: Procedure

Before the experiment starts, we give users approximately 5 minutes for experiment introduction and system training. Then, the experiment begins with a pre-test phase, in which participant watch demonstrations of the movement twice, and then perform the TC movement five times in the 'Self-Quiz' stage. Then the participant will separate in two groups. Each of the group needs to practice two kinds of interfaces with different sequence. Each interface takes 15 minutes for trainee learning the TC moves 1, after completing the practices, participants take a post-test by watching the demonstration twice and performing the movement five times in the 'Self-Quiz' stage. After they have done with the first interface, the participants move on to practice the other one, and do the post-test for that one. The contents of PPD feedback and guidance depend on the condition (interface) in which the subjects are. During practices and tests, we collect Kinect data and pressure sensing shoes data in our system. Finally, after completing the tasks, we will hold a short interview to participants to draw qualitative response. The study takes approximately one hour for each groups to complete.

● Experiment 1: Result

We analyzed the study result with the independent variables: condition (Training Stages without and with PPD Feedback). The PPD correctness score on Pre-Test and Post-Test shown in Figure 7, which using equation 2 describe in previous section. The blue line presented the user sequence using the Interface A first, and then using Interface B. The change from Pre-Test to Post-Test 1 and Post-Test 1 to Post-Test 2 in blue line with Stillness Moves scores improving by average of 0.93 and 1.98 points. In red line, the improving by average of 1.66 and -0.12 points.

Figure 7. The PPD score of pre-test, post-test 1, and post-test 2 for moves 1 in two different interfaces.

The postural score of Pre-Test, Post-Test shown in Figure 8, and the total score of Pre-Test, Post-Test shown in Figure 9. Those color lines presented the same meaning as Figure 7's line. The change from Pre-Test to Post-Test 1 and Post-Test 1 to Post-Test 2 in blue line with Stillness Moves scores improving by average of 0.37 and 1.48 points. In green line, the improving by average of 4.65 and -0.35 points.

Figure 8. The postural score of pre-test, post-test 1, and post-test 2 for moves 1 in two different interfaces.

In the total score, the change from Pre-Test to Post-Test 1 and Post-Test 1 to Post-Test 2 in blue line with Stillness Moves scores improving by average of 3.46 and 9.76 points. In green line, the improving by average of 19.88 and -1.50 points.

Figure 9. The total score of pre-test, post-test 1, and post-test 2 for moves 1 in two different interfaces, which combining postural and PPD scores after we normalized.

● Experiment 2: Participants

We recruited 14 participants (8 males and 6 females) between 20 and 29 years old (mean = 22.33 years, std = 2.35) to be our subjects in experiment 2, whom are external to the research group. No participants have had experience with the study or system, or a TC background.

● Experiment 2: Study Moves

In experiment 2, participants would complete the learning process of TC movement while following an onscreen guide same as experiment 1. However, with different kinds of TC Silk Reeling moves (Figure 6b) were recorded for the study, which were selected by the same expert and recorded by the same TC senior student. The moves 2 (Figure 6b) included both arm and upper body movement, and contained weight-transfer and feet change. The moves 2 is more difficult than the previous one, because trainee needs to give more attention to the other arm movement.

● Experiment 2: Condition, Design, and Procedure

The experiment 2 condition, design, and procedure is same as experiment 1, but with different participants and moves.

● Experiment 2: Result

We analyzed the study result same as Experiment 1. In PPD score (Figure 10), the change from Pre-Test to Post-Test 1 and Post-Test 1 to Post-Test 2 in blue line with Stillness Moves scores improving by average of 0.60 and 2.64 points. In green line, the improving by average of 2.05 and 1.07 points.

Figure 10. The PPD score of pre-test, post-test 1, and post-test 2 for moves 2 in two different interfaces.

In postural score (Figure 11), the change from Pre-Test to Post-Test 1 and Post-Test 1 to Post-Test 2 in blue line with Stillness Moves scores improving by average of 2.25 and 0.37 points. In green line, the improving by average of 2.39 and 2.35 points.

Figure 11. The postural score of pre-test, post-test 1, and post-test 2 for moves 2 in two different interfaces.

In the total score (Figure 12), the change from Pre-Test to Post-Test 1 and Post-Test 1 to Post-Test 2 in blue line with Stillness Moves scores improving by average of 7.97 and 6.55

points. In green line, the improving by average of 11.39 and 9.25 points.

Figure 12. The total score of pre-test, post-test 1, and post-test 2 for moves 2 in two different interfaces. The scoring is same as previous experiments 1.

6 DISCUSSION

We were pleased with the result overall, as there is improvement from pre-test to post-test when using our Stillness Moves system in two different kinds of moves (Figure 9 and Figure 12).

For body weight-transfer learning in moves 1, all the participants using our system had improved, and participants improved even more with PPD feedback due to the fact that PPD feedback helps users revise their posture, such as squatting lower and transferring their body weight center.

As Figure 7 post-test1 shown, with interface B, the PPD score grown faster than interface A. When post-test1 to post-test2 in green line, trainee's score had drop a little bit, but not too much. The change from Pre-test to Post-Test1 is bigger than Post-Test1 to Post-Test2. This explain that after learning the weight-transfer, the trainee can still remember the weight-transfer. Finally, after two post-tests, they will be the proximate same learning outcome regard less of which interface comes first. In moves 2 (Figure 10), the blue line with higher score at the beginning improves less than the green line with lower score. In green line, after removing the weight-transfer guidance, the score keeps improving. This shows that after learning the weight-transfer, there may be an improvement of score if the beginning score is not very high. It make sense that the change from post-test1 to post-test2 is improving, but the improving score in moves 2 is less than moves 1 after using interface B in post-test2,. This can be shown that after reaching a higher score, it is very difficult to improve even further.

For PPD information, we provide demonstration video, ratio of two feet, and a slide bar representing in our system. The participants using Posture Guide and Movement Guide stage in both interface focus on the instructor's movement the most, they pay less of an attention to the ratio of two feet. Sometimes they will peak a look when they think they can do well on body movement. However, participants using our system regarded this information while observing the transition of body weight center. The participants often used the Weight-Transfer Guide stage to check whether they had the same PPD as instructor. In the future, our system can without PPD by using body posture information from Kinect or other vision-based methods [31].

For body movement learning, as Figure 8 shown, the beginning score in green line is worse than blue line, but the PPD score (Figure 7) is higher than blue line. Overall, the improving thread in PPD and Postural scores are mostly with same curve, which improves a lot and then decreases a little. The blue line shown in the same result. For the experiment 2, as Figure 11 shown, the green line improving curve is same as PPD score, but without weight-transfer guidance, the Postural score grows higher, and blue line Postural score decreases after using weight-transfer guidance. I seems that with weight-transfer guidance, it has had bad effect when trainee learns moves 2. This result is opposite of learning moves 1. In comparison, the interview with participants, we found that it is hard for the trainee to follow both body movement and weight-transfer with difficult moves. Because the wrong weight-transfer in weight-transfer guide stage will cause the video to pause for a long time, the trainee's make their choice correct the weight-transfer first. Therefore, it will cause the bad affect to body movement learning. Going back to the description at the beginning, it makes sense that after removing the weight-transfer guidance, trainees can keep improving their Postural score.

7 CONCLUSION

We have presented our physical training system for TC. Our work contributes a TC training system with body movement and weight-transfer guidance using body tracking sensor, and the evaluation methods for postural and plantar pressure distributional correctness score. The user studies we conducted shows using our system resulted in an interesting change from using different interface with two TC moves, and finds that weight-transfer guidance can help trainee learning the Tai-Chi moves. For difficult moves, the trainee should learn the weight-transfer first, then, learning the body movement. Record Review Browser can intuitively help users identify the details in the moves that they cannot do well. Overall, no matter what interface, the result shows that our system is beneficial for beginner to learning TC.

ACKNOWLEDGMENTS

We thank our TC teacher, TC expert, and participants. This work was partially supported by the Ministry of Science and Technology of Taiwan under the Grant MOST 104-2627-E-002-001.

REFERENCES

- [1] Hong, Y., & Li, J. X. (2007). Biomechanics of Tai Chi: a review. *Sports biomechanics*, 6(3), 453-464.
- [2] Hong, Y., & Li, J. X. (2006). Characteristics of foot movement in Tai Chi exercise. *Physical therapy*, 86(2), 215-222.
- [3] Anderson, F., Annett, M., & Bischof, W. (2012). Tabletops in motion: the kinetics and kinematics of interactive surface physical therapy. In *CHI EA*, 2351-2356.
- [4] Tang, R., Tang, A., Yang, X. D., Bateman, S., & Jorge, J. (2015, April). Physio@Home: Exploring visual guidance and feedback techniques for physiotherapy exercises. In *CHI*, 4123-4132.
- [5] Chan, J. C., Leung, H., Tang, J. K., & Komura, T. (2011). A virtual reality dance training system using motion capture technology. In *IEEE Transactions on Learning Technologies*, 4(2), 187-195.

- [6] Hachimura, K., Kato, H., & Tamura, H. (2004). A prototype dance training support system with motion capture and mixed reality technologies. In ROMAN IEEE International Workshop, 217-222.
- [7] Alexiadis, D. S., Kelly, P., Daras, P., O'Connor, N. E., Boubekeur, T., & Moussa, M. B. (2011). Evaluating a dancer's performance using kinect-based skeleton tracking. In ACM MM, 659-662.
- [8] Velloso, E., Bulling, A., & Gellersen, H. (2013). MotionMA: motion modelling and analysis by demonstration. In CHI, 1309-1318.
- [9] Anderson, F., Grossman, T., Matejka, J., & Fitzmaurice, G. (2013). YouMove: enhancing movement training with an augmented reality mirror. In UIST, 311-320.
- [10] Chua, P. T., Crivella, R., Daly, B., Hu, N., Schaaf, R., Ventura, D. & Pausch, R. (2003). Training for physical tasks in virtual environments: Tai Chi. In Virtual Reality, 87-94.
- [11] Jin, Y., Hu, X., & Wu, G. (2012). A tai chi training system based on fast skeleton matching algorithm. In ECCV Workshops and Demonstrations, 667-670. Springer Berlin Heidelberg.
- [12] Hsieh, C. H., & Lin, T. Y. (2014). A Kinect-based Tai Chi exercises evaluation system for physical rehabilitation. In ICCE, 177-178.
- [13] Feiner, S., Macintyre, B., & Seligmann, D. (1993). Knowledge-based augmented reality. Communications of the ACM, 36(7), 53-62.
- [14] Henderson, S. J., & Feiner, S. K. (2011). Augmented reality in the psychomotor phase of a procedural task. In ISMAR, 191-200.
- [15] Flagg, M., & Reh, J. M. (2006). Projector-guided painting. In UIST, 235-244.
- [16] White, S., Lister, L., & Feiner, S. (2007). Visual hints for tangible gestures in augmented reality. In ISMAR, 1-4.
- [17] Motokawa, Y., & Saito, H. (2006). Support system for guitar playing using augmented reality display. In ISMAR, 243-244.
- [18] Sodhi, R., Benko, H., & Wilson, A. (2012). LightGuide: projected visualizations for hand movement guidance. In CHI, 179-188.
- [19] Nintendo. Wii Fit Plus. <http://wiifit.com/>
- [20] Morris, S. J., & Paradiso, J. (2002). Shoe-integrated sensor system for wireless gait analysis and real-time feedback. In EMB. Proceedings of the Second Joint, Vol. 3, 2468-2469.
- [21] Wu, G., & Millon, D. (2008). Joint kinetics during Tai Chi gait and normal walking gait in young and elderly Tai Chi Chuan practitioners. Clinical Biomechanics, 23(6), 787-795.
- [22] Li, J. X., & Hong, Y. (2006). Plantar pressure distribution during Tai Chi exercise. Archives of physical medicine and rehabilitation, 87(6), 814-820.
- [23] Mao, D. W., Li, J. X., & Hong, Y. (2006). The duration and plantar pressure distribution during one-leg stance in Tai Chi exercise. Clinical Biomechanics, 21(6), 640-645.
- [24] Wu, G., & Hitt, J. (2005). Ground contact characteristics of Tai Chi gait. Gait & posture, 22(1), 32-39.
- [25] Anderson, F., & Bischof, W. F. (2013). Learning and performance with gesture guides. In CHI, 1109-1118.
- [26] Bau, O., & Mackay, W. E. (2008). OctoPocus: a dynamic guide for learning gesture-based command sets. In UIST, 37-46.
- [27] Freeman, D., Benko, H., Morris, M. R., & Wigdor, D. (2009). ShadowGuides: visualizations for in-situ learning of multi-touch and whole-hand gestures. In ACM International Conference on Interactive Tabletops and Surfaces, 165-172.
- [28] Togawa, H., & Okuda, M. (2005). Position-based keyframe selection for human motion animation. In Parallel and Distributed Systems, 2005. Proceedings. 11th International Conference on, Vol. 2, 182-185.
- [29] Pongnumkul, S., Dontcheva, M., Li, W., Wang, J., Bourdev, L., Avidan, S., & Cohen, M. F. (2011). Pause-and-play: automatically linking screencast video tutorials with applications. In UIST, 135-144.
- [30] Kruskal, J. B., & Liberman, M. (1983). The symmetric time-warping problem: from continuous to discrete. Time Warps, String Edits and Macromolecules: The Theory and Practice of Sequence Comparison, 125-161.
- [31] Tomoya K., Shohei M., Hideo S., Kosuke T., Dan Mikami, Mariko I. & Hideaki K. (2018) Estimation of Center of Mass for Sports Scene Using Weighted Visual hull, in Proc. CVPR workshop (CVSports).