Designing Digital Games for Reflecting the Performance of Dynamic Balance

Wen-Shou Chou and Hsuan-Liang Lin

***Abstract*—Digital games have been applied to study the performance of human dynamic balance. However, how to design the balance games, or how the mechanics of games affect the performance of dynamic balance are still lack of research reports. This study developed a serial of game prototypes to explore the design principles of balance games. The experimental results show that when a balance game is designed, if the moving of object under control is more predictable, the moving of player's weight center is more regular, and the game has suitable challenge designed, the player's ability of dynamic balance can be more correlated to the game scores.**

Keywords-balance game; balance measurement; dynamic balance; game design; computer game

I. INTRODUCTION

Digital contents have been integrated into the balance training and measuring systems. For examples, integrating the golf training system with virtual reality contents can improve the performance of balance capability [1]; Based on the training of virtual reality balance game (VRBG) can reduce the risk and fear of falls among the elder peoples [2]. In these studies of integrating digital contents and balance systems, some research investigated how to apply the interactive peripherals (such as the Nintendo Wii@ balance board) to develop novel methods for measuring balance capability [3]. Some study discussed the development of rehabilitation games for the training of dynamic balance [4]. These studies either compared the novel method of measuring balance capability to traditional methods [3], or applied the commercial games to investigate the balance training effects. However, instead of measuring the balance ability by using corresponding instruments, how to design the balance games such that the balance ability of game players can be judged directly by using the game score is rare studied.

In this study, we tried to explore the design principles of balance games by developing a serial of game prototypes. It was expected that the performance of players' dynamic balance could be judged directly from the game scores. Through the testing and modification of game prototypes, we expected the design principles and application notes for developing such balance games could be discovered.

II. MEASURING THE PERFORMANCE OF BALANCE CONTROL

Balance control is the basic capability of human in everyday life. The balance capability can be divided into static balance and dynamic balance. The former is the ability to keep one's body not fall down when he (she) does not move, it includes the ability to keep one's standing or sitting gestures. The ability of dynamic balance is to recover from an unbalanced gesture, or not to fall down when one is moving.

Traditional methods for measuring the performance of one's balance capability include measuring the time of passing a balance beam, or using the Star Excursion Balance Test (SEBT) [5]. In the SEBT test, one should stand by using his (her) leg of common usage in central place, and try to let another leg reach to the most distant place in each 8 directions (Anterior, Anterior-lateral, Lateral, Posterior-lateral, Posterior, Posterior-medial, Medial, and Anterior-medial), then stretch the leg back to the central place. The ratio of averaged, reaching distances and the length of leg is used to estimate the ability of dynamic balance.

In addition to the traditional methods, electronic instrument has been applied to evaluate the performance of dynamic balance, such as using the force plate to measure the variations of Center of Pressure (COP) during motion tests [6]. In one of these tests, the tester moves a ball (representing tester's COP) on the screen repeatedly to reach points shown on the left and right ends of screen respectively. Another test is to let the tester move the ball to follow a circular motion. The variations of moving paths and time spanned are analyzed to evaluate the ability of dynamic balance.. With similar principles, the KAT2000 [7] measured one's balance capability by letting the tester control his (her) center of mass to follow the moving of a cross mark shown on the screen.

Digital games have been applied to develop the measuring or training system of balance. The game controller such as the Wii@ balance board was applied to measure the performance of balance capability in some of these balance games [3, 8, 9]. Some of these studies declared that the use of Wii@ balance board can have the similar measurement results as those measured by the use of force plate [8]. However, some research indicated the Wii@ balance board can't support a valid balance measurement [9].

When a player plays a balance game, the playing performance (usually evaluated by the game score) seems intuitively to be affected by the game design method. So, when we consider to use the game score to represent the player's ability of balance control, what design principles should be followed? As far as we know, there are rare studies till now have discussed the effects of game design to the measurement or training effects of balance control.

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III. PROTOTYPES OF THE BALANCE GAMES AND EXPERIMENT DESIGN

Three prototypes of balance games were developed to explore the game design principles and to investigate the effects of game mechanism to the performance of dynamic balance. In order to study whether or not the game scores can reflect the player’s capability of dynamic balance, one more experiment was built to test the performance of dynamic balance before the tester played those balance games. The game scores got by players were analyzed with their performances of dynamic balance, in order to explore the relationships between game scores and the performance of dynamic balance..

A. Measuring the Performance of Dynamic Balance

As far as we know, there is no standard method till now to measure the ability of human dynamic balance by applying the electronic instrument or balance games. The measuring methods as briefly reviewed in the previous session are all not “standard”, that is to say, we should apply those instruments, such as the KAT2000, to establish a reference dataset for the target testers first, then use the same instrument to compare the testing result to the reference dataset, in order to judge the balance performance of testers.

In order to “measure” the balance performance of testers in this study, we referred to the measuring principles of KAT2000 and the method of motion tests proposed by Nichols [6], but simplified the moving directions to lateral direction only. As shown in Fig.1, a wireless gyro was attached to the balance platform to provide the lateral axis angles under balance control. These angles were transformed to the movements of objects shown on the screen. The system was calibrated such that one degree of gyro axial value was transformed to 25 units of objects moving on the screen. The platform with gyro can be tilted left or right 6 degrees respectively. That will cause the object move from the left end to the right end of screen with total moving length of 300 units.

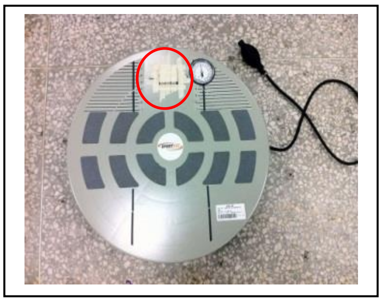

Figure 1.The wireless gyro (indicated by red circle) and balance platform.

In the test, tester stand on the platform with hands crossed in front of chess, and tried to keep the white ball follow the yellow ball as best as possible by moving his (her) body (Fig. 2). The yellow ball would move from the right end of screen to the left end in 2 seconds with equal velocity, then move back to the right end in 2 seconds. This process repeated for 60 seconds. Distance between the white and yellow balls was recorded 50 times per second. The performance of dynamic balance was evaluated as the mean distance during these times. If the mean distance is smaller, the balance performance is better.

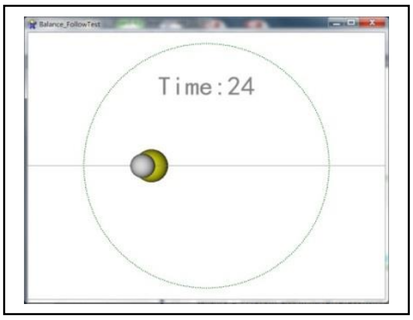

Figure 2. Tester tried to move the white ball to follow the yellow ball.

B. Balance Game 1 (Capturing Fruits)

The first balance game changed the visual feedback from “ball following” designed in the performance measurement to “capturing fruits” (Fig. 3). The fruits would drop sequentially from right to left, then from left to right, similar to the moving process of yellow ball designed in the performance measurement. The falling time between the fallings from the right end to the left end (and vice versa) was set 2 seconds. And, the gaming time was also set to 60 seconds. Each time the player “captured” the fruit, the score was increased by a fixed number. It was expected that the player has better balance performance also has higher game scores.

Figure 3. Screen shot of the “Capturing Fruits” balance game.

10 undergraduate students were invited to test the game prototype of “Capturing Fruits” after testing their performance of dynamic balance. The relationship between game scores and the averaged distances was shown in Fig. 4. The Pearson correlation coefficient was -0.884 (p=0.001). It should be noted that the smaller the distance is in Fig. 4, the better the balance performance is achieved.

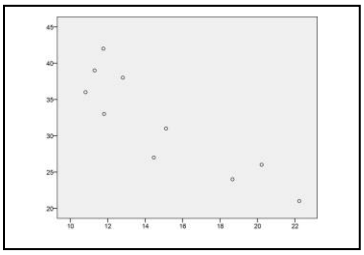

Figure 4. Relationship between the game scores (vertical axis) and the averaged distances (horizontal axis) in dynamic balance.

C. Balance Game 2 (Avoding Obstacles)

The sequence of "dropping fruits" in the "Capturing Fruits" game is similar to the moving of yellow ball in the dynamic balance test. Testers playing the game are "forced" to move the basket in game sequentially, similar to move the white ball in dynamic balance test. What will be the result if player doesn't have to move sequentially while playing the game?

The second balance game was designed to increase the flexibility of player's balance control as compared to the first game. In this game, each time when the player wanted to avoid hitting the obstacles, he (she) can freely move the balloon left or right (Fig. 5). Each time the balloon was hit, the score was decreased by a fixed number. The gaming time was also set to 60 seconds. It was expected to know whether or not a player played the balance game without the need to move sequentially can yield similar results.

Figure 5. Screen shot of the "Avoiding Obstacles" balance game.

20 undergraduate students (not including the 10 students in game 1) were invited to play the game "Capturing Fruit" and the game "Avoiding Obstacles" respectively after testing their performance of dynamic balance. The Pearson statistical correlation coefficient of game scores and the averaged distances of dynamic balance test were -0.738 ($p<0.01$) for "Capturing Fruit" and -0.673 ($p<0.01$) for "Avoiding Obstacles" respectively. It showed that players who have better balance performance will basically yield better performance in playing both the games. However, in a more strict sense, playing the "Avoiding Obstacles" game could reflect the performance of players' dynamic balance less than playing the "Capturing Fruit" game. Possible reasons may include: (1) The players have to make decisions to move the balloon left or right first in playing the game, it may affect the reflectivity of balance control. As compared to playing the "Capturing Fruit" game, wherein players only have to move the basket sequentially from left to right and vice versa. It seemed that the balance control for playing the "Capturing Fruit" game was more intuitively and more directly. (2) Appearances of "holes" in the "Avoiding Obstacles" game are not as predictable as dropping fruits in the "Capturing Fruit" game. (3) The movements of weight center of players in the "Avoiding Obstacles" game are not as regular as in the "Capturing Fruit" game. (4) The "Avoiding Obstacles" game is more difficult than the "Capturing Fruit" game.

D. Balance Game 3 (Hitting Bricks)

Comparing the results of playing the "Capturing Fruits" game and the "Avoiding Obstacles" games, we speculated that there were four possible clues that may affect the correlations between the balance control performance and game score. The "Hitting Bricks" game (Fig. 6) was developed to further test these conjectures. In playing the game, player has to control the rectangular box below the screen to reflect the white ball, in order to hit the bricks shown above. As compared to the previous two games, this game has the following characteristics: (1) Similar to the "Avoiding Obstacles" game, players have to make decisions before they move. (2) Movements of weight center of players are more un-regular and less guided. (3) The falling positions of white ball are more un-predictable. (4) It seems to be more difficult to get high scores. It was expected that the degree of correlation coefficient between game score and dynamic balance performance will be less than those of the two previous games.

Figure 6. Screen shots of the "Hitting Bricks" balance game**.**

The gaming time was again set to 60 seconds. Each time when the white ball hit the bricks above, the game score will increase one point. And when the white ball falls below the controlled box, the game score will decrease two points (game will continue).

IV. EXPERIMENT RESULTS

50 undergraduate students (students had attended in game 1 or game 2 were excluded) were invited to attend the test. Each student played the "Capturing Fruits", the "Avoiding Obstacles" and the "Hitting Bricks" games respectively after testing his (her) performance of dynamic balance. And answered the questionnaire consisted of the following four questions for each of the three games:

1. I have to think how to move when I play the game.
2. I can predict the moving way of the controlled target.
3. I feel the movements of my body's weight center are regular when I play the game.
4. I feel this game is difficult.

The scattering plots of game scores and the averaged distances of dynamic balance test were shown in Figure 7. Pearson statistical correlation coefficients between the balance test and the three games were shown in Table 1. The results showed that the "Capturing Fruits" game has the highest correlation degree, next is the "Avoiding Obstacles" game, and the "Hitting Bricks" game has the lowest correlation degree. The conjectures made in previous section for designing the "Hitting Bricks" game seemed to be true.

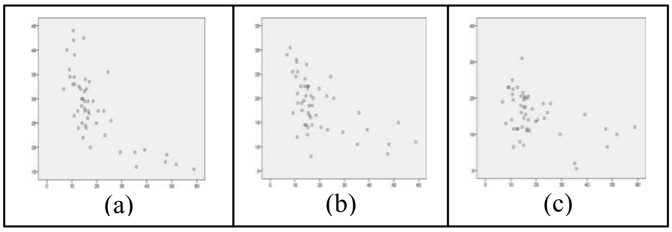

Figure 7. Relationship between the game scores (vertical axis) and the averaged distances (horizontal axis) in dynamic balance test: (a) the "Capturing Fruits" game (b) the "Avoiding Obstacles" game (c) the "Hitting Bricks" game.

Table 1. The correlation coefficients between balance test and three games

	Balance Test	*Capturing Fruits*	*Avoiding Obstacles*	*Hitting Bricks*
Balance Test	1	-.726**	-.568**	-.451**
Capturing Fruits		1	.703**	.431**
Avoiding Obstacles			1	.328*

** p < 0.01 , * p < 0.05

The mean values and standard deviations of questionnaire (Likert with 5 scales) for the three games were summarized in Table 2. The ANOVA analysis was applied to compare the means of three games for the four questions (Table 3). It showed that the means of question 1 (Q1) were not significantly different between three games, and the other three questions needed to be analyzed further (Table 4).

Table 2. The mean values and standard deviations of questionnaire for the three games

Questions for the three games		*Mean*	*S.D.*
Q1：I have to think how to move when I play the game.	Capturing Fruits	3.80	1.07
	Avoiding Obstacles	3.62	1.05
	Hitting Bricks	3.86	0.99
Q2：I can predict the moving way of the controlled target.	Capturing Fruits	4.28	0.78
	Avoiding Obstacles	4.30	0.65
	Hitting Bricks	3.72	1.13
Q3：I feel the movements of my body's weight center are regular when I play the game.	Capturing Fruits	3.64	1.16
	Avoiding Obstacles	3.84	1.13
	Hitting Bricks	3.20	1.09
Q4：I feel this game is difficult.	Capturing Fruits	3.44	0.91
	Avoiding Obstacles	4.34	0.75
	Hitting Bricks	3.24	0.87

Table 3. The ANOVA analysis for comparing the means of three games

Questions for the three games	*Sum of Squares*	*df*	*F*	*Sig.*
Q1：I have to think how to move when I play the game.	1.56	2.00	0.73	0.485
Q2：I can predict the moving way of the controlled target.	10.84	2.00	7.07	0.001**
Q3：I feel the movements of my body's weight center are regular when I play the game.	10.72	2.00	4.23	0.016*
Q4：I feel this game is difficult.	34.22	2.00	24.11	0.000**

**p < 0.01 , * p < 0.05

The results were summarized as followings:

1. For the question 2 (Q2), the mean value of "Hitting Bricks" game was smaller than those of "Capturing Fruits" and "Avoiding Obstacles" games and the difference both reached statistically significant. It was the hardest to predict the moving of controlled target for playing the "Hitting Bricks" game.
2. For the question 3 (Q3), whether the movements of body's weight center was regular or not during playing the game. The "Avoiding Obstacles" game was the most regular, next was the "Capturing Fruits" game, the least was the "Hitting Bricks" game. The difference between the "Avoiding Obstacles" game and the "Hitting Bricks" game reached statistically significant.
3. For the question 4 (Q4), The "Avoiding Obstacles" game was more difficult than "Capturing Fruits" and "Avoiding Obstacles" games, and the difference between them both reached statistically significant. There was no difference between the "Capturing Fruits" and "Avoiding Obstacles" games.

When playing the "Avoiding Obstacles" game, some of the players were used to move to the left or right single direction, this might be the reason why the players felt the movements of their body's weight center were more regular when playing this game. In order to discuss the possible reasons of making differences between the three questions (Q2 ~Q4), and their effects on the correlation relationships between balance test and three games, we summarized the experimental results in Table 5. Wherein the correlation relationships and the effects caused by the three questions were classified into high, middle, and low three classes. Using the Q2 classification as an example, since the mean value of "Hitting Bricks" game was smaller than those of "Capturing Fruits" and "Avoiding Obstacles" games and their differences reached statistically significant, and the difference between the "Capturing Fruits" and "Avoiding Obstacles" games was not statistically significant, the "Hitting Bricks" was given "Low" class, and the other games were classified as "High". Based on the observations, if we want to have high correlations between the balance test and the game score, the game design should be: (1) Motion of the controlled target in games should be predictable. (2) The game should not be too difficult to the players. (3)

Movements of the player's weight center should be moderate regular while playing the game.

Table 4. Multiple Comparisons with 95% Confidence Interval

	I	J	Mean Difference (I - J)	Std. Error	Sig.
Q2: I can predict the moving way of the controlled target.	Capturing Fruits	Avoiding Obstacles	-0.02	0.175	0.909
		Hitting Bricks	0.56*	0.175	0.002*
	Avoiding Obstacles	Capturing Fruits	0.02	0.175	0.909
		Hitting Bricks	0.58*	0.175	0.001*
	Hitting Bricks	Capturing Fruits	-0.560*	0.175	0.002*
		Avoiding Obstacles	-0.580*	0.175	0.001*
Q3：I feel the movements of my body's weight center are regular when I play the game.	Capturing Fruits	Avoiding Obstacles	-0.2	0.225	0.376
		Hitting Bricks	0.44	0.225	0.053
	Avoiding Obstacles	Capturing Fruits	0.2	0.225	0.376
		Hitting Bricks	0.64*	0.225	0.005*
	Hitting Bricks	Capturing Fruits	-0.44	0.225	0.053
		Avoiding Obstacles	-0.64*	0.225	0.005*
Q4：I feel this game is difficult.	Capturing Fruits	Avoiding Obstacles	-0.9*	0.169	0.000*
		Hitting Bricks	0.2	0.169	0.238
	Avoiding Obstacles	Capturing Fruits	0.9*	0.169	0.000*
		Hitting Bricks	1.1*	0.169	0.000*
	Hitting Bricks	Capturing Fruits	-0.2	0.169	0.238
		Avoiding Obstacles	-1.1*	0.169	0.000*

* $p < 0.05$

Table 5. Experimental Results

	Capturing Fruits	Avoiding Obstacles	Hitting Bricks
Correlated with the balance test	High	Middle	Low
Q2： I can predict the moving way of the controlled target.	High	High	Low
Q3：I feel the movements of my body's weight center are regular when I play the game.	Middle	High	Low
Q4：I feel this game is difficult.	Low	High	Low

V. CONCLUSIONS

To predict or decide the ability of one's dynamic balance by letting him (her) play a balance game and observing the game score is an interested but difficult research topic. Based on the testing and observations of a serial of three balance game prototypes, some design principles for developing such balance games have been explored in this study. It includes the motion prediction of controlled target, the regular movements of players' weight center, and the difficulty of game. We believe this study is just a beginning for discussing the design principles of balance games. For using games to develop a balance training or measuring system, more experiments should be designed to explore the implicated design clues and to find out their impacts.

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