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Motor Learning in Elderly: Effects of Decision Making Time for Self-Regulated Knowledge of Results During a Dynamic Balance Task

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Abstract

Background: Deficiencies in the ability to maintain balance are common in elderly. Augmented feedback such as knowledge of results (KR) can accelerate learning and mastering a motor skill in older people.

Objects: We designed this study to examine whether one session of Wii-Fit game with self-regulated KR is effective for elderly people, and to compare the effect of two different timings of self-regulated KR conditions.

Methods: Thirty-nine community-dwelling elders, not living in hospice care or a nursing home, participated in this study. During acquisition, two groups of volunteers were trained in 10 blocks of a dynamic balancing task under the following 2 conditions, respectively: (a) a pre-trial self-regulated KR (n_1=18), or (b) a post-trial self-regulated KR (n_2=21). Immediate retention tests and delayed retention tests of balancing performance were administered in 15 minutes and 24 hours following acquisition period, respectively.

Results: In both groups, significant improvements of balancing performances scores were observed during the acquisition period. Regardless of the group, mean of balancing performance scores on retention tests were well-maintained from the final session. There were no significant differences between groups in balancing performance scores during the acquisition period ($p>.05$); however, the post-trial self-regulated KR group exhibited significantly higher balancing performance scores in both the immediate retention test and delayed retention test than that of the pre-trial self-regulated KR group ($p<.05$).

Conclusion: Therefore, subjects who regulated their feedback after a dynamic balancing task, during the acquisition period, experienced more efficient motor learning during the retention period than did subjects who regulated their feedback before a dynamic balancing task. Accordingly, in case of presenting the KR of motor learning in clinical settings to elders who reduced dynamic balance abilities, the requesting time of KR is imperative according to self-estimation processes as well as types of KR and practice.

Key Words: Dynamic balance; Elderly; Knowledge of results; Self-regulation.

Introduction

Dynamic balance can be defined as the amount of volitional movement of a person's center of mass within the limits of stability (de Bruin and Murer, 2007). As such, it involves many coordinated neuromuscular processes (Jones, 2000; Stelmach et al, 1989). Control over dynamic balance is regulated by both the central nervous system (CNS) and sensorimotor system. The CNS generates appropriate motor commands and corrects for errors through a feed-forward, feedback mechanism based on sensory information from the visual, vestibular, and somatosensory systems (Diener and Dichgans, 1988).

Sensorimotor functionality degrades with age (Sturnieks et al, 2008). Overall deterioration in vision, function-

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ality of the semicircular canals and otoliths, and proprioception are common age-related ailments. Together, these ailments tend to result in a loss of control over dynamic balance and a degraded ability to recover from moments of imbalance episode such as falling (Agrawal et al, 2012; Barrett and Lichtwark, 2008; Goble et al, 2009; Lord, 2006; Perrin et al, 1997).

Nintendo Wii Fit (Nintendo, Kyoto, Japan), the force plate-controlled virtual reality platform is becoming an increasingly popular therapeutic tool for patients with a variety of illnesses and balancing disorders (Agmon et al, 2011). Because of changes in the center of pressure (COP) experienced on a Wii balance board (WBB) (Nintendo, Kyoto, Japan) which had a good intra-class correlation coefficient=.86～.99 (Chang et al, 2013), it can be considered as comparable to those obtained from a typical force plate (Clark et al, 2010). Therefore, this system could potentially be used to measure and train dynamic balance while standing and moving in elderly (Clark et al, 2010; Holmes et al, 2013). Accordingly, Wii Fit videogames have been adopted in rehabilitation training programs for the elderly population up to now (Young et al, 2011), and many researches have studied its applications in recovering the reduced balancing abilities (Bateni, 2012; Bieryla and Dold, 2013; Nitz et al, 2010).

Knowledge of results (KR) is putative form of augmented feedback in motor learning. KR is the information provided to a learner about the consequences of his or her movement (s) (e.g., temporal or spatial) relative to the goals of the movement (Schmidt and Lee, 2011; Wulf and Shea, 2004). KR also refers to information regarding task success provided to the performer following a pre-determined set of practice trials (Winstein and Schmid, 1990). This information serves as a basis for error correction in subsequent trials, which can, ideally, be instinctively applied to real-world situations (Winstein and Schmid, 1990). Visual biofeedback and force plate systems using KR information are often used to exercise and re-train balance and mobility in the aging population (Lange et al, 2010). Scheduling frequency, timing, KR type, and KR determiner significantly impact performance and motor learning.

Self-regulation is a widely accepted technique used in motor learning studies in which learners determine how to schedule the practice or when to receive the feedback (Schmidt and Lee, 2011). A self-regulated KR involves receiving feedback only when the participant wants to know the results of a given trial, which means learner have an option of receiving KR or not. According to previous researches, self-regulated KR has been found to be a more important component in acquisition and retention when learning a motor skill than other feedback types such as summary KR and Yorked KR (Chiviacowsky and Wulf, 2002; Chiviacowsky and Wulf, 2005; Janelle et al, 1995; Janelle et al, 1997; Wulf et al, 2005). Self-regulated KR gives learners control over their own practice regimes, which serves as a powerful motivator (Bandura, 1993; Boekaerts, 1996). This encourages self-directed strategies (Kirschenbaum, 1984), as well as active involvement of the learner in the motor learning process which can lead to improved information processing (Ferrari, 1996; McCombs, 1989; Watkins, 1984). However, empirical data explaining the cognitive underpinnings of these learning benefits are limited and inconsistent.

Self-regulated KR can be varied by the timing of KR divulgence. In such cases, learners are asked to decide whether they will receive KR before starting a trial (pre-trial, self-regulated KR); whereas, post-trial, self-regulated KR involves learning of KR only after a trial has finished. In either case, there should be no differences in the results in the two groups, as subjects in both groups can regulate feedback delivery (Chiviacowsky and Wulf, 2005). The only difference between two groups' experimental conditions is the timing of their decision-making (Chiviacowsky and Wulf, 2005). However, there are lack of research on the influence of timing in self-regulated KR to date.

We designed this study to examine whether one session playing a virtual reality-based Wii Fit game with self-regulated KR can be effective in motor skill learning in elderly people. Two different self-regulated KR delivery times were compared ('pre-trial self-regulated KR' vs. 'post-trial self-regulated KR').

Methods

Subjects

Twenty-one males and eighteen females, aged 65 ~84, were recruited from an welfare center of community-dwelling elderly in Samcheock, Gangwon-do, South Korea. 'Pre-trial self-regulation KR group' is comprised eighteen elderly participants which are provided the KR feedback of dynamic balance task by requesting before the each acquisition trial. 'Post-trial self-regulation KR group' consisted of twenty-one elderly participants, who are provided with the KR feedback of dynamic balance task by the requests after the each acquisition trial.

Inclusion criteria necessitated being a resident of Samcheock, a Berg Balance Scale (BBS) score of ≥ 40; a Mini-Mental State Examination, Korean version (MMSE-K) score of ≥24; as well as being able to understand verbal instructions and watch a television screen without losing focus. Participants were also required to have the ability to walk independently with or without a device for 10 m. Exclusion criteria were any neurological or medical disorders that can cause seizures, dizziness, fainting, or paralysis; a neurological or vestibular disorder that would prevent a normal range of balance; difficulty standing for more than 5 consecutive minutes; and medications that could affect the ability to balance. All subjects participating in this study were informed of the purposes of and procedures involved in this research. Each participant received credit for their involvement from the center's director, and signed an informed consent from the Institutional Review Board of Yonsei University, Wonju Campus (approval number: 1041849-201511-BM-082-02) prior to participation.

During the first meeting, basic demographic data was gathered from interviews. Afterward, participants took MMSE-K and BBS tests to assess cognition and dynamic balance ability. Participants who completed interviews and assessments were randomly assigned to either the pre-trial self-regulated KR group (10 males, 8 females) or the post-trial self-regulated KR group (11 males, 10 females). Table 1 presents the demographic characteristics of each group. A comparative analysis found no significant differences in age, gender, height, weight, body mass index, MMSE-K, or BBS between the two groups (p>.05).

Table 1. Demographic characteristics of pre-trial KR group and post-trial KR Group (N=39)

Characteristics		Pre-trial self-regulated KR[a] group (n_1=18)	Post-trial self-regulated KR group (n_2=21)	t or χ^2	p
		Mean±SD[b] or number (%)	Mean±SD or number (%)		
Age (year)		73.7±5.1	71.9±3.6	1.263	.214
Height (㎝)		165.2±7.9	163.2±9.8	.687	.496
Weight (㎏)		66.3±8.3	64.4±9.0	.698	.490
BMI[c] (kg/㎡)		24.3±2.8	24.1±2.4	.249	.805
MMSE-K[d] (score)		26.2±1.7	26.9±2.0	-1.133	.264
BBS[e] (score)		51.7±2.1	52.9±2.0	-1.813	.078
Gender	Male	10 (55.6)	11 (52.4)	.039	.843
	Female	8 (44.4)	10 (47.6)		

[a]knowledge of results, [b]mean±standard deviation, [c]body mass index, [d]mini-mental state examination-Korean version, [e]Berg balance scale.

Instruments

1. Wii Fit balance game

A Wii Fit (RVL-001, Nintendo, Kyoto, Japan) comes with a balance board (RVL-021, Nintendo, Kyoto, Japan) for dynamic movements, and includes four strain gauge load sensors (one mounted in each corner of the board) to extrapolate the center of gravity and track motions derived from weight transfer (Agmon et al, 2011). The Wii balance board has four transducers to measure force spreading and consequential motions in the COP. During gameplay, users experience instantaneous feedback on a television screen in order to make corrections to their positioning in real time (Agmon et al, 2011).

2. Berg balance Scale

The BBS was used to measure balance in study participants. The BBS consists of fourteen metrics which are scored on a scale of 0~4. A score of 0 indicates that a subject is incapable of doing a task, while a score of 4 signifies task competency based on the criterion which has been assigned to it. The maximum score on this assessment is 56. The items contained in this scale include both simple mobility tasks (eg, sit-to-stand, standing unsupported, transfers) and demanding tasks (eg, single-leg standing, turning 360°, tandem standing) (Berg et al, 1989).

Procedure

1. Task

'Balance Mii', a virtual reality videogame (RVL-R-RFNK, Nintendo, Kyoto, Japan) which utilizes the Wii Fit platform, exercises dynamic balance in a continuous movement task. Thus, this game was selected from a set of 9 video games included in the category of balance game from the Wii Fit package (Figure 1). During gameplay, the participant is represented as an avatar which is positioned inside a bubble floating on a river. The player has to use his or her body position and movements to guide the

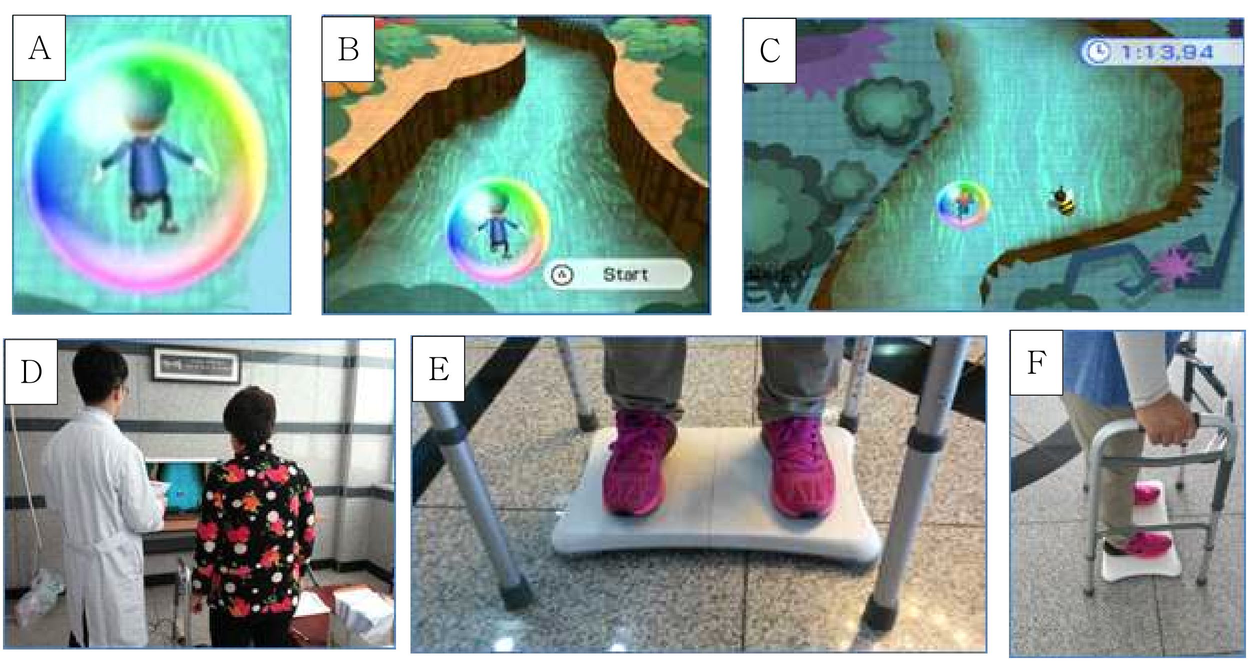

Figure 1. Wii Fit-based dynamic balance tracking game using a Wii balance board: (A) a game character called 'Mii' represented as a participant, (B) tracking pathway, (C) obstacle and time constraint during a game, (D) game trial under the instructions, (E) participant's foot position on a WBB, (F) standard walker for safety.

bubble along the river to its destination (1200 m away from the start point) without hitting the surrounding landscape or obstacles. Each trial has a time limit of 90 seconds. If the bubble does not reach successfully arrive at its destination within the time limit, or if the bubble hits the riverbank, it will burst and the game will end. All subjects from both groups played at the beginner difficulty level.

Each participant was asked to stand erect on the WBB with his or her arms in a comfortable position by his or her sides until the investigator started the game. To move the bubble, the player had to shift their bodies on the WBB by leaning to the left and right, back and forth, looking at the bubble of a television screen. The final score is measured by the total distance floated, from 0 to 1200, it displays on the screen at the end of the game trial. A higher score indicated that bubble was reached in the closer to the goal point, which a subject had a particularly adept sense of dynamic balance. For safety, a standard walker was placed in front of the balance board. Participants were allowed to hold the walker for balance support, but were instructed not to hold the walker if possible.

The final score was used as KR information in this experiment. The KR information was provided only when the participant requested it. Otherwise, the KR information was obscured by hiding the score with a screen in front of the television monitor.

2. Process

A brief summary of the experimental procedures for tests of acquisition and retention of balance tasks is represented in Figure 2. Firstly, participants were shown a demonstration video to explain the nature of the study and how to perform the videogame task. This instructional video was recorded by the investigator while an elderly model subject played the videogame. Whenever necessary, the investigator provided additional verbal instructions on the game. Subsequently, participants performed 2~3 practice trials for familiarization. After the practice trials, participants were administered a pre-test and were not provided with their final scores (KR).

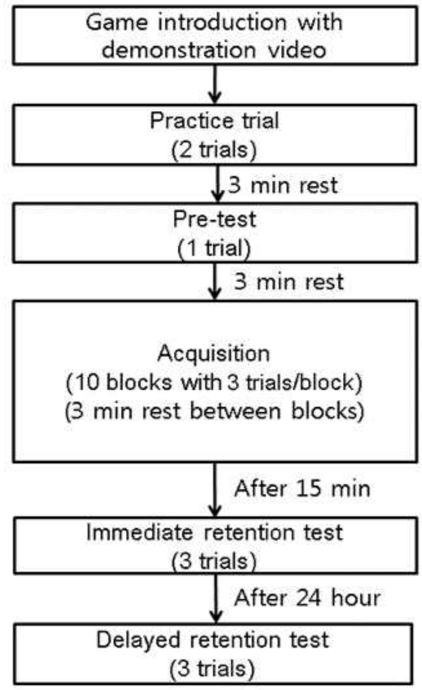

Figure 2. Flowchart of study procedure: Test, acquisition, and retention of the balance tasks with resting and time interval.

After the pre-test trials, participants took part in an acquisition phase consisting of ten blocks in which participants performed 3 trials of the game during each acquisition block. There was a 15 seconds inter-trial interval. Participants in the pre-trial self-regulated KR group were asked to decide whether or not to receive KR before performing each trial. Participants in the post-trial self-regulated KR group were asked to decide whether or not to receive KR after each trial. There were 3 minutes of resting time every 10 blocks during which participants would watch an unrelated video. The verbal instructions associated with each experimental condition are presented in Figure 3.

Subsequently, there were 15 minutes of retention intervals after completing each of the acquisition trials, and immediate retention tests were administered immediately. During the immediate retention tests,

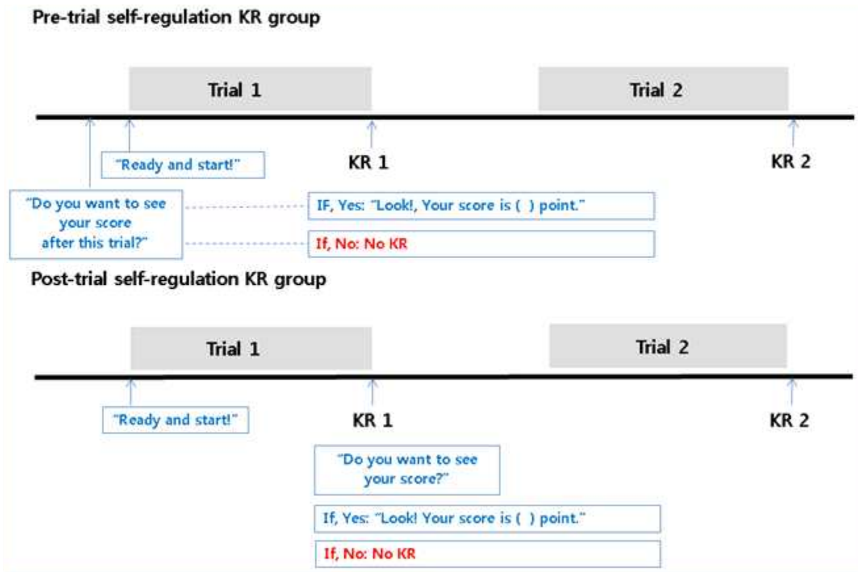

Figure 3. Presentation of KR and verbal commands for each group (KR: knowledge of result).

participants performed three trials of a Wii-based balance task (Balance Mii) in the absence of visual or verbal KR. Delayed retention tests were administered 24 hours after the immediate retention tests, in which participants performed the same three balance tasks in the absence of visual and verbal KR. During the acquisition and retention periods, all participants performed the game tasks in a large, quiet room, individually.

Following the delayed retention tests, a post-experimental interview was conducted to identify participants' strategies for learning and retaining motor skills during the acquisition and retention periods. After each phase, participants answered the question, "What did you think about before and after the trial started?"

Dependent Measures

The dependent measures in this study included balance performance during acquisition and retention. Balance performance was defined as the absolute point value during each trial. The change in mean score during acquisition was calculated by subtracting the performance score on acquisition block 1 from that of block 10. Total mean frequencies of KR requests were calculated by adding the requests for KR feedback during acquisition block 1 and those during acquisition block 10.

Statistical Analysis

The Kolmogorov-Smirnov test was used to confirm the normality of the data. According to whether or not a normal distribution of the data, independent t-test, chi-square analysis, and Mann-Whitney U test were used to examine the balance performance between group differences. A one-way, repeated measure analysis of variance (ANOVA) was used to compare balance performance during 3 motor learning periods (acquisition, immediate retention, and delayed retention) of two different self-regulated KR conditions. After data collection, the data was validated, coded, and analyzed using the SPSS ver. 21.0 (SPSS Inc., Chicago, IL, USA), with statistical significance set at $p>.05$.

Results

Requests for feedback

Table 2 presents comparisons of mean KR request

Table 2. Mean frequencies of requests for KR feedback, by group, during acquisition (N=39)

Acquisition block	Mean frequencies of KR[a] requests±SD[b]		U^c	p
	Pre-trial self-regulated KR group (n_1=18)	Post-trial self-regulated KR group (n_2=21)		
1	1.61±1.20	1.76±1.48	175.50	.683
2	1.78±1.40	1.33±1.32	159.00	.368
3	2.00±1.28	1.33±1.43	141.00	.143
4	2.28±1.23	1.48±1.40	124.50	.044*
5	2.17±1.20	1.38±1.36	127.00	.061
6	2.06±1.31	1.45±1.40	137.50	.176
7	2.17±1.25	1.57±1.33	138.00	.118
8	2.00±1.33	1.48±1.40	150.50	.234
9	1.94±1.39	1.38±1.40	147.50	.201
10	2.17±1.30	1.33±1.43	130.50	.069
Total	20.17±11.31	14.19±13.09	162.00	.440

[a]knowledge of results, [b]standard deviation, [c]Mann-Whitney U-test, *p<.05.

frequencies between groups during the acquisition period. The overall number of KR requests was greater in the ‘pre-trial self-regulated KR group’ than those of the ‘post-trial self-regulated KR group’. However, a comparative analysis found no significant differences in any of the acquisition blocks, excluding acquisition block 4 (p<.05), between the two self-regulated KR groups (p>.05).

Performance changes during acquisition and retention

Figure 4 shows the mean performance scores during acquisition blocks 1~10, 15 minutes immediate retention, and 24 hours retention. Up to block 3, the ‘pre-trial self-regulated KR group’ achieved higher scores than did the ‘post-trial self-regulated KR group’. From block 4 to block 10, the ‘post-trial self-regulated KR group’ performed better than the ‘pre-trial self-regulated KR group’. The mean change in performance during the acquisition period (block 10 score-block 1 score) was significantly greater in the ‘post-trial self-regulated KR group’ (mean changes=407.29, standard deviation; SD=270.95) than the ‘pre-trial self-regulated KR group’ (mean=163.83, SD=324.18) (Table 3). The mean performance scores for immediate retention were significantly greater in the ‘post-trial self-regulated KR group’ (mean=784.56, SD=184.04) than the ‘pre-trial self-regulated KR group’ (mean=593.93, SD=280.54), (p=.015) (Table 3). Delayed retention test scores also indicated that learned dynamic balance in the ‘post-trial self-regulated KR group’ (mean=783.70, SD=217.93) were significantly higher than those of the ‘pre-trial self-regulated KR group’ (mean=623.22, SD=319.90), (p=.036) (Table 3).

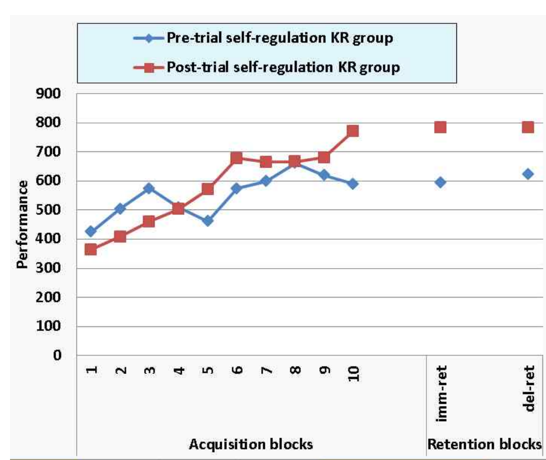

Figure 4. Mean game score for both KR conditions across acquisition blocks and retention tests (higher scores indicate better performance, KR: knowledge of result, imm-ret: immediate retention, del-ret: delayed retention).

Table 3. Mean differences in performance between the pre-trial self-regulated KR group and post-trial self-regulated KR group (N=39)

Characteristics	Pre-trial self-regulated KR[a] group (n_1=18)	Post-trial self-regulated KR group (n_2=21)	t	p
	Mean±SD[b]	Mean±SD		
Pre-test (score)	214.11±203.09	194.57±241.89	.270	.788
Acquisition block 10 (score)	589.48±269.53	771.08±207.10	−2.377	.023*
Mean change score during acquisition (block 10-block 1)	163.83±324.18	407.29±270.95	−2.555	.015*
Immediate retention test (score)	593.93±280.54	784.56±184.04	−2.543	.015*
Delayed retention test (score)	623.22±319.90	783.70±217.93	−1.853	.036*

[a]knowledge of results, [b]mean±standard deviation, *p<.05.

Table 4. Comparisons between acquisition block 10, immediate retention, and delayed retention (N=39)

Group	Mean±SD[a] (score)			F	p
	Acquisition block 10	Immediate retention test	Delayed retention test		
Pre-trial self-regulation KR[b]	589.48±269.53	593.93±280.54	623.22±319.90	.164	.850
Post-trial self-regulation KR	771.08±207.10	784.56±184.04	783.70±217.93	.037	.964

[a]mean±standard deviation, [b]knowledge of results.

The results of the one-way, repeated measure ANOVA showed no significant difference in the performance scores between acquisition block 10 and the immediate retention test (p>.05) between the two groups. Further, no significant difference in the performance scores was found between the immediate retention test and delayed retention test (p>.05). No significant difference was found in the performance scores between acquisition block 10 and the delayed retention test (p>.05) (Table 4).

Discussion

In this study, we examined whether or not one session of a virtual reality-based balance training task, using Nintendo Wii Fit, with a self-regulated KR could be an effective for learning of dynamic balance in older adults. The research further examined the differential effects of two different timings for self-regulated KR ('pre-trial self-regulated KR' vs. 'post-trial self-regulated KR') on motor learning.

The main finding of this study was that one 90-minute supervised session playing a Wii Fit dynamic balance game with self-regulated KR engendered instant improvements in dynamic balance scores during retention tests, and accelerated the acquisition period in elderly subjects. Regardless of the KR presentation timing, improvements in dynamic balance were well-maintained in both the immediate and delayed retention tests. This result is consistent with a previous study, which found that Wii Fit games were effective in improving dynamic balance in an elderly population (Toulotte et al, 2012). However, our research did not evaluate long-term learning and transfer effects of the Wii Fit training to functional tasks which required dynamic balance in real world situations.

According to a previous study (Chiviacowsky and Wulf, 2002), using a sequential timing task, self-regulated feedback schedules engendered learning benefits. These findings were consistent with the results of our study. Another previous study has demonstrated that a self-regulated KR schedule is advantageous for motor learning in elders (Carter and Patterson, 2012); however, the underlying cognitive and sensorimotor mechanisms responsible for these findings were not clearly explained. One possible explanation of these results might be that self-regulation allowed learners to tailor the delivery of KR to suit their immediate performance request (Schmidt and Lee, 2011). According to Chiviacowsky and Wulf (2005), self-regulated KR served a strong motivational role in confirming the learner's hunch about their own performance because they were better able to personalize the subject's temporal needs than in externally controlled feedback schedules.

Compared to the 'pre-trial self-regulated KR group', the subjects in the 'post-trial self-regulated KR group' showed significantly enhanced learning in the final acquisition block, immediate retention period, and delayed retention period. These results are commensurate with those of Chiviacowsky and Wulf (2005), who compared self-regulated KR conditions in which subjects requested KR either before or after the trial while learning a discrete throwing task. The authors found that subjects who requested KR 'after' each trial were significantly better at the throwing task, similar to the results of our study. When a learner can determine after a trial whether to get KR feedback, the decision process probably includes an self-estimation of performance on that trial (Chiviacowsky and Wulf, 2005). Based on the results of this self-estimation process, the learner can then determine whether or not to request KR feedback. These seems to support a interpretation that self-regulated feedback is more effective in motor learning by facilitating a self-estimation process of performance especially when the externally provided KR information works together with the inherent source of feedback received while they performed the given trial. Compared to Chiviacowsky and Wulf (2005) sequential timing task of discrete movement, participants in our study were allowed continuous tracking type task in a virtual reality environment. Therefore, this task provides too much extrinsic feedback with learner during task performance, compared to discrete movement task in many previous study (Chiviacowsky and Wulf, 2002; Janelle et al, 1995; Janelle et al, 1997; Wulf et al, 2005).

According to previous research of motor learning by age group using self-regulated feedback (Carter and Patterson, 2012), the young group showed significantly better motor learning in immediate and delayed retention tests than elderly group. Therefore, the results of our research regarding an elderly population are difficult to generalize to other populations. Further studies into the more clear causes for the advantages of 'post-trial self-regulation KR condition' should lead to the design of more effective feedback conditions and to a better explanation of this absorbing phenomenon.

Conclusion

The goal of the present study was to examine whether one session of Wii-fit game with self-regulation KR is effective for elderly people, and to compare the effect of two different timings of self-regulated KR conditions on Wii-based dynamic balance task in motor learning.

The results showed that one 90 minutes session of a Wii Fit dynamic balance game with self-regulated KR induced significant improvements in dynamic balance scores during retention tests as well as in the acquisition period of motor learning in elderly people. However, subjects in 'post-trial self-regulated KR group' consistently achieved significantly higher scores during the acquisition, immediate, and delayed retention periods. In both groups, improved dynamic balance acquired during the training periods was well-maintained in immediate and delayed retention tests.

Those elderly subjects who regulated their feedback after each dynamic balance task during the acquisition period achieved higher motor learning of dynamic balance during retention periods than those who regulated their feedback before each dynamic balance task. Therefore, in case of presenting the KR of motor learning in clinical settings to the elderly who reduced dynamic balancing ability, requesting time of the KR is imperative according to critical factor such as self-estimation as well as the types of the KR.

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