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The Electromyographic Activity of Lower Limb Muscles in the Elderly during Walking on the Treadmill: An Emphasis on the Effect of Virtual Reality

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Original Article

Abstract

Introduction: The aim of this study was to assess the effects of virtual reality (VR) on the electromyographic (EMG) activity of the lower limb muscles during gait on the treadmill in the elderly.

Materials and Methods: 12 elderly male subjects participated in this study voluntarily. Using an EMG-USB2+ multichannel system (Bioelettronica, Italy) (sampling frequency of 1000 Hz) and bipolar surface electrodes, the electrical activity of tibialis anterior (TA), rectus femoris (RF), and biceps femoris (BF) muscles were recorded bilaterally during walking with the preferred speed with and without VR environment on the treadmill. The maximal voluntary isometric contraction (MVIC) method was used for the normalization of signals. The gathered signals were processed using OT BioLab software with a bandpass filter of 10-350 Hz and a notch filter of 50 Hz. The data were processed using repeated measures analysis of variance (ANOVA) and paired sample t-test in SPSS software at a significance level of 0.050.

Results: The findings showed that during walking in VR environment, the EMG activity of bilateral RF muscles and right TA muscle of the elderly subjects were significantly higher than normal walking with about 1.97 ($P \leq 0.005$), 1.91 ($P \leq 0.003$), and 2.03 ($P \leq 0.002$) times, respectively. But the differences between EMG activity of right ($P \leq 0.280$) and left ($P \leq 0.990$) BF and left TA ($P \leq 0.080$) muscles were not significant during walking with and without VR. Overall, VR had the main effect on the muscle activity of the elderly subjects ($P \leq 0.007$). Moreover, there was a significant interaction between VR and muscle factors ($P \leq 0.036$).

Conclusion: The results indicated that VR increases the EMG activity of lower extremity muscles among the elderly, thus it can be recommended strongly in the rehabilitation of lower extremity muscles in the elderly.

Keywords: Walking; Virtual reality; Electromyography; Elderly

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Introduction

More than two-thirds of the population in developing countries, including Iran, are elderly, and are projected to increase by more than 300% by 2025 (1). Thus, the elderly health care systems will have a tough fight ahead to meet the growing needs they face in caring for them (2). One of the major challenges to the elderly's general health is the problem of falling (3). Research suggests that one in three elderly people over the age of 65 falls at least once a year (4). This rate increases rapidly with age and as the person becomes weaker (3,5). More than 50% of falls occur in the elderly while walking (6). Therefore, falls in the elderly, the factors affecting it, reducing the frequency of repetitions, and rehabilitation methods have been considered by many researchers who study the injuries and consequences of falls in these people (7). The use of the virtual reality (VR) environment is one of the newest methods in the rehabilitation, training, and learning in these people (8). VR is a

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technology that allows the user to be in a virtual simulated environment by the computers and see the different angles of the environment and current events in it, hear the sounds in the environment according to their position, and affect events with their behavior and movements (9). VR motion rehabilitation often uses play therapy; So that during the activity in the virtual environment, the patient's involvement in the presented activity is increased and fatigue and boredom are minimized, in addition to increasing the patient's motivation and adherence to the rehabilitation process. Another advantage of VR is to provide information on the real position, body part in real time, or even the position of the center of pressure. This information enables patients to set up virtual motor rehabilitation systems and provides important information about the patient progress (10). As a rehabilitation tool, VR provides a challenging but safe and credible environment and can provide different levels of stimulus types (11). However, due to the lack of tactile feedback, this method may lead to patterns that differ from what actually exists (12).

Virtual environments have become very common in walking rehabilitation. VR rehabilitation is a combination of physical therapy and virtual environment that reduces pain and increases satisfaction in the patient (13). In this regard, Forkan et al. in their study of elderly people with balance disorders, showed that a virtual exercise program increases walking speed in these people (14).

Mirelman et al., in their study of the effect of exercise in a virtual environment on the biomechanics of gait in patients with myocardial infarction (MI), found that the virtual environment group had more power produced and ankle range of motion (ROM) compared to the control group, but in kinematics or kinetics of the hip joint, no difference was observed between the two groups. In the knee joint, the VR group showed more changes in ROM (15). Powell and Stevens also reported that when walking on a treadmill in a virtual environment, different factors affecting virtual reality such as visual cues (lines inside VR and virtual reality locations such as forest, desert, or street) and different auditory cues, affected the speed of walking differently (16). Moreover, the findings of the study by Deutsch et al. revealed that cycling in VR increases VO_2 max in individuals with MI and can be used as a treatment with mobility exercises to improve patients with this problem (17).

A review of previous studies showed that activity in a virtual environment can affect a person's gait and improve its quality, but it is not yet clear how activity in a VR can change muscle activity. And the effect of VR on the intensity of different muscle activity has never been reported. Knowledge on how VR affects the activity of different muscles can be a good guide in designing training and rehabilitation programs for the elderly for doctors, physiotherapists, and physical education instructors. Therefore, the present study is carried out with the aim to determine the effect of activity in a VR on electrical activity of lower limb muscles in the elderly when walking on a treadmill.

Materials and Methods

This was a quasi-experimental and causal-comparative study conducted with an applied purpose. The statistical population of the study consisted of healthy elderly men in Tabriz, Iran, of whom 12 people participated in the study voluntarily using the purposive sampling method as a statistical sample. Using the G*Power software, for the test power of 0.95, $\alpha = 0.05$, and the effect size of 0.65, 10 samples were obtained to be sufficient. Before the subjects participated in the study, the test objective was explained to them and a written consent form was obtained from them. The study was reviewed at Tabriz University and approved with the ethics code IR.TABRIZU.REC.1399.023. The study inclusion criteria for the elderly included physical health, no history of falls, independence in daily activities, and the ability to walk independently. Having a history of neuromuscular and musculoskeletal disorders, pain limiting daily activities, hearing, vision, and atrial system problems, Parkinson's disease (PD), balance disorders, Alzheimer's disease, fractures, and any lower limb injury or surgery affecting their gait pattern (18-21) were also considered as the exclusion criteria.

To record the electrical activity of the muscles, an 80-channel electromyography (EMG) device (USB2 +, Italy) with a sampling frequency of 1000 Hz and bipolar gel-layered surface electrodes with an inter-electrode distance of 1.7 cm was utilized. The electrodes were placed on the rectus femoris, biceps femoris, and tibialis anterior muscles of the right and left legs according to the Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles (SENIAM) standard protocol. For the rectus femoris muscle, the electrode was located one-third of the distance between the anterior superior iliac spine to the upper edge of the patella (22), the biceps femoris electrode was on the largest part of the biceps and in the middle of the line connecting the ischial tuberosity to the knee lateral condyle (23), and the tibialis anterior muscle electrode was located on one third of the line between the fibula head and the tip of the medial malleolus (24).

Methodology: First, the study objective and the desired skill were introduced and taught to the subjects and a written consent to participate in the test was obtained from them. Then, to record the EMG activity of the muscles, the skin of the subjects was first prepared according to the European Recommendations for Surface ElectroMyoGraphy. In this way, after determining the exact location of the electrodes, it was shaved using a Gillette razor and the excess hair was removed. Then, using cotton and alcohol, their skin surface was thoroughly cleaned and the surface electrodes were positioned on the muscles parallel to the muscle fibers, according to the standard method mentioned earlier, and fixed with anti-allergy glue and bandage to prevent noise due to the electrode moving on the skin. Furthermore, to prevent noise, the wires were collected and tied to the person's body using a bandage. The reference electrode was also connected to the individual's wrist. After preparing the skin and installing the electrodes, the subject stood on the treadmill and walked at the preferred speed on the treadmill with the "Go" command. In order for the subject to get acquainted with the treadmill and to determine his preferred walking speed, they were asked to start walking at a slow speed of 1 km/hour. Then the speed of the treadmill gradually increased by 0.1 km/hour, and these increases continued until the person announced that he had reached a speed at which he could walk comfortably (neither slowly nor fast). After specifying this speed, the speed of the treadmill was increased and decreased by 0.5 km/hour again to confirm the desired speed of the person (25-27). After determining the preferred speed, the subjects rested for 3 minutes. The muscle activity was then recorded for 3 minutes while walking at the preferred speed with and without VR. To walk with VR, a VR program was played by a projector on a screen mounted 2.5 meters from the treadmill, and the subjects were asked to walk on the treadmill while watching the video. In this video, the virtual environment was surrounded by mountains, forests, and various landscapes along the way. There was also a 5 minute break between walking with and without VR. To normalize the EMG data, the electrical activity during maximum voluntary isometric contraction (MVIC) for each of the rectus femoris (28), biceps femoris (23), and tibialis anterior muscles (29) was recorded based on the methods mentioned in the articles cited. After collecting the EMG signals, the OT BioLab software was employed to process the signals. Thus, the EMG signals were first filtered using a 10-350 Hz band-pass filter and a 50 Hz Notch filter. Then, their root mean square (RMS) was extracted. To normalize the data, the RMS obtained for each muscle was divided by the RMS obtained from the MVIC activity of the same muscle and calculated as a percentage. Besides, the Shapiro-Wilk test was used to examine the normality of data distribution and repeated measures analysis of variance (ANOVA) and paired t tests to evaluate the intra-group differences. Finally, the data were analyzed in SPSS software (version 24, IBM Corporation, Armonk, NY, USA). $P < 0.05$ was considered as the significant level.

Results

12 people with a mean age of 61.8 ± 3.9 years, mean height of 167.9 ± 5.1 cm, and mean weight of 75.1 ± 11.5 kg participated in the study.

Table 1 represents the results related to the assimilated activity intensity of the rectus femoris, biceps femoris, and tibialis anterior muscles in two modes of walking in virtual environment and preferential walking. Accordingly, the assimilated activity intensity of the right and left thigh muscles and the right tibialis anterior muscle when walking in the virtual environment was significantly about 1.97 (P = 0.005), 1.91 (P = 0.003), and 2.03 (P = 0.002) times more than that of walking without VR, respectively. However, there was no difference between walking with and without VR in the assimilated activity intensity of the right biceps femoris (P = 0.280) and left biceps femoris (P = 0.990) muscles. A similar result was observed in the left tibialis anterior muscle (P = 0.088).

The factor analysis results suggested that regardless of the effect of other factors, in general, the assimilated activity intensity of the muscles in walking conditions with VR was higher than normal walking (P = 0.007) (Figure 1).

Table 1. Assimilated activity intensity results of rectus femoris, biceps femoris, and tibialis anterior muscles

Muscle		Normal walking (mean ± SD)	Walking in virtual environment (mean ± SD)	P
Rectus femoris	Right	34.3 ± 14.2	67.6 ± 19.3	*0.005
	Left	37.5 ± 17.5	72.1 ± 16.5	*0.003
Biceps femoris	Right	32.5 ± 13.4	39.7 ± 25.4	0.280
	Left	39.3 ± 17.9	39.2 ± 22.9	0.990
Tibialis anterior	Right	32.7 ± 10.1	66.6 ± 23.0	*0.002
	Left	34.6 ± 8.5	49.0 ± 20.9	0.088

SD: Standard deviation

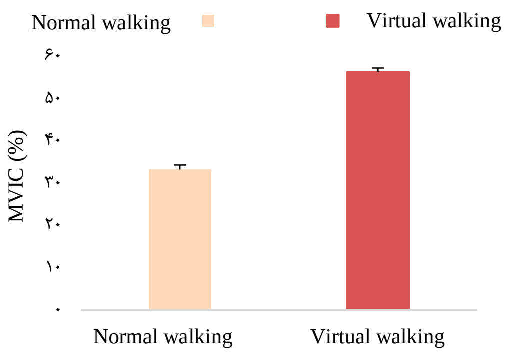

Figure 1. Comparison of the assimilated muscle activity intensity in normal walking and walking in a virtual environment
MVIC: maximum voluntary isometric contraction

The results showed that walking in VR environment increased the assimilated activity of the tibialis anterior and rectus femoris muscles significantly more than the biceps femoris muscle and a significant interaction was observed between the VR factor and muscle (P = 0.036) (Figure 2).

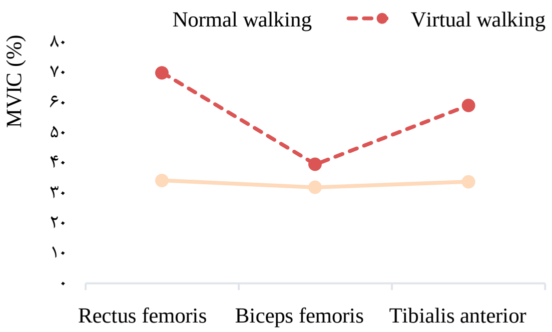

Figure 2. Virtual reality (VR) and muscle interaction
MVIC: maximum voluntary isometric contraction

The effect of VR on the intensity of activity of the rectus femoris, biceps femoris, and tibialis anterior muscles was similar on both right and left sides of the body and no significant interaction was observed between the muscle, VR, and body side factors (P = 0.310).

Discussion

The aim of this study was to investigate the effect of VR on EMG activity of the rectus femoris, biceps femoris, and tibialis anterior muscles when walking on a treadmill. The findings indicated that in general, walking in a virtual environment increases the assimilated muscle activity intensity, and the activity of the rectus femoris and tibialis anterior muscles when walking in a virtual environment was significantly higher than walking without VR. Based on a review of the research literature, the EMG activity of muscles when walking with and without VR was reported for the first time in the present study. Therefore, no study was found to directly compare its results with those of the present study. Only in a study by Park et al., which examined the activity of the tibialis anterior, gastrocnemius, erector spinae, and rectus abdominis muscles in young people before and after six weeks of VR and non-VR balance exercises, it was found that the balance training group in VR had higher activity of the tibialis anterior and gastrocnemius muscles (30); this was consistent with the findings of the present study in the tibialis anterior and rectus muscles when walking in a virtual environment. Additionally, in confirmation of the findings of the present study, Sharifmoradi and Farahpour showed that in healthy elderly with PD, in general, the intensity of muscle activity while walking with visual task was significantly higher than it during normal walking (31). Elhami and Yazdani also concluded that in people with cerebral palsy (CP), dual visual task while walking had a significant effect on increasing the intensity of muscle activity (32). Performing two tasks at the same time (walking and watching a video on the wall) leads to interference in tasks when walking in a virtual environment and requires a division of attention between the two tasks. Hence, due to the competition between cognitive demands of the dual task while walking, more attention may be required and make it difficult for the person to control his balance while walking (33). Therefore, the individual’s muscle activity may increase as a compensation to maintain balance while walking while performing the dual task. On the other hand, Park et al. indicated that balance training in a virtual environment increases the stability of the ankle joint and also changes the movement of the center of pressure of the foot in the anterior-posterior and internal-external directions (30).

Since the tibialis anterior muscle plays an important role in ankle strategy and is one of the most important muscles in maintaining balance, with increasing muscle stability and calling for more movement units, with increasing the stability of the ankle and controlling the movement of the center of pressure, the person can maintain dynamic balance when walking in a virtual environment. Studies on the effect of a VR training course also support the effective role of these exercises in improving balance (34), increasing ankle joint stability (30), and increasing ankle strength

(35,36). Dunning et al. (35) and Mirelman et al. (15) reported in their studies that practicing in VR, by increasing the strength of the ankle, can affect the kinematics of walking and increase the speed and rhythm of walking (35,36), step length (36), and ROM of the ankle (35) in patients with stroke.

The results of previous investigations have shown that virtual environment programs lead to more dynamic movement, which in turn will require more muscle activity (30). In this regard, Mirelman et al. in a study on the effect of exercise in a virtual environment on the biomechanics of gait in patients with MI, reported that the virtual environment group had more power production and ankle ROM, as well as more knee ROM compared to the group without a virtual environment, but they did not observe any difference in kinematics or kinetics between the two groups (15). Therefore, in addition to the above, increasing the activity of the rectus femoris and tibialis anterior muscles when walking in a virtual environment can be attributed to the role of these muscles in increasing power production and higher increase in the ankle and knee ROM when exercising in a virtual environment.

Other causes of the increased muscle activity when walking in a virtual environment include the role of the virtual environment in providing visual feedback. In their study of patients with stroke, Quaney et al. found that the virtual environment could increase brain activity by providing compensated visual feedback and, by increasing muscle activity, increase the ability to grasp in patients with stroke (36).

In the study of muscle activity in the elderly with impaired balance when walking with dual tasks, Azadian et al. concluded that the activity of the tibialis anterior and vastus lateralis muscles in these conditions was significantly less than normal walking (33), which contradicted the findings of the present study. In a study by Sharifmoradi and Farahpour, it was found that the secondary cognitive task factor had a significant effect on reducing the intensity of lower extremity muscle activity in the stance and swing phases of gait (31). In the study of Elhami et al., in general, no difference was observed between the intensity of muscle activity of healthy youth when walking with and without dual tasks (32). The inconsistency of the results of the present study with the abovementioned ones can be attributed to the type of subjects studied, age, type of task presented while walking, and the type of variable extracted from the EMG signals. In the studies of Azadian et al. (33) and Sharifmoradi and Farahpour (31), the elderly with poor balance and the elderly with PD were studied, respectively. Most of these people walk more slowly during the secondary task and have a small length of step due to the fear of falling, which can be a reason for the decrease in muscle activity in these people during dual tasks. Moreover, in the study of Sharifmoradi and Farahpour, the mean assimilated integrated electromyography (IEMG) of muscles in millivolts per second was calculated as the logarithm to base 10 and analyzed (31); while in the present study, RMS of the signals was extracted.

The results of the present study indicated that walking in VR environment increased the assimilated activity of the tibialis anterior and rectus femoris muscles significantly more than that of the biceps femoris muscle and had no effect on the activity of the biceps femoris muscle. In confirmation of the findings on the biceps femoris muscle, Park et al. did not observe any change in the activity of the erector spinae and rectus abdominis muscles after balance exercises in the virtual environment (26). Based on the above result, it can be claimed that activity in the virtual environment does not have the same effect on the intensity of activity of different muscles, and training in the virtual environment can change the activity of some muscles more than others.

Limitations

In the present study, the effect of VR on the muscular activity of the elderly while walking was investigated. Therefore, the results obtained cannot be generalized to other functional activities. Furthermore, in the present study, only the male elderly were examined. Investigating the effect of VR on EMG activity in men and women may have interesting results that are recommended to be performed in future studies.

Recommendations

In the present study, the intensity of muscle activity when walking in the virtual environment was investigated without considering other biomechanical parameters such as kinematics and kinetics of the joints as well as the ground reaction force (GRF); while the study of movement from different aspects can provide a more complete understanding and be a more appropriate treatment guide. Therefore, it is recommended that in future studies, the effect of VR on the kinematics and kinetics of joints and the body be investigated.

Conclusion

Since walking in a virtual environment can increase the activity of the tibialis anterior and rectus femoris muscles, its use is highly recommended as an easy, low-cost, and relatively new training method in designing a suitable exercise program for the elderly with weak lower limb.

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Authors' Contribution

Shirin Yazdani: study design and ideation, study support, executive, and scientific services, providing study equipment and samples, collection, analysis, and interpretation of results, specialized statistics services, manuscript preparation and specialized evaluation of manuscript in terms of scientific concepts, manuscript approval for final submission to the journal office, responsibility for maintaining the integrity of the study process from beginning to publication, and responding to the referees' comments; Saba Mohammadalinezhad: study design and ideation, study support, executive, and scientific services, providing study equipment and samples, and manuscript preparation; Sahanad Eslami: study design and ideation, study support, executive, and scientific services, providing study equipment and samples, and manuscript preparation; Heydar Sajedi, study design and ideation, study support, executive, and scientific services, and data analysis.

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Conflict of Interest

The authors do not have a conflict of interest. Dr. Shirin Yazdani has been working as an assistant professor of sports biomechanics since 2004 (since 2004 as a coach and since 2014 as an assistant professor) at the University of Tabriz. Saba Mohammadalinezhad has been an MSc student in movement learning and control since 2019 and Sahand Eslami has been an MSc degree student in sports psychology at the School of Physical Education and Sport Sciences of Tabriz University since 2019. Dr. Heydar Sajedi has been working as an assistant professor of sports medicine at Ibrahim Chechen University, Turkey since 2019.

References

1. Azim Zadeh E, Faghihi V, Ghasemi A. The effect of dual-task training on balance of elderly women: with the motor and cognitive approach. Research in Sport Management and Motor Behavior 2018; 8(15): 103-10. [In Persian].
2. Barak Y, Wagenaar RC, Holt KG. Gait characteristics of elderly people with a history of falls: A dynamic approach. Phys Ther 2006; 86(11): 1501-10.
3. Lockhart TE, Woldstad JC, Smith JL. Effects of age-related gait changes on the biomechanics of slips and falls. Ergonomics 2003; 46(12): 1136-60.
4. Voermans NC, Snijders AH, Schoon Y, Bloem BR. Why old people fall (and how to stop them). Pract Neurol 2007; 7(3): 158-71.
5. Lamoth CJ, van Deudekom FJ, van Campen JP, Appels BA, de Vries OJ, Pijnappels M. Gait stability and variability measures show effects of impaired cognition and dual tasking in frail people. J Neuroeng Rehabil 2011; 8: 2.
6. Priest AW, Salamon KB, Hollman JH. Age-related differences in dual task walking: A cross sectional study. J Neuroeng Rehabil 2008; 5: 29.
7. Callisaya ML, Blizzard L, Schmidt MD, Martin KL, McGinley JL, Sanders LM, et al. Gait, gait variability and the risk of multiple incident falls in older people: A population-based study. Age Ageing 2011; 40(4): 481-7.
8. Annetta LA. Video Games in Education: Why they should be used and how they are being used. Theory Pract 2008; 47(3): 229-39.
9. Laver KE, George S, Thomas S, Deutsch JE, Crotty M. Virtual reality for stroke rehabilitation. Cochrane Database Syst Rev 2011; (9): CD008349.
10. Saposnik G, Teasell R, Mamdani M, Hall J, McIlroy W, Cheung D, et al. Effectiveness of virtual reality using Wii gaming technology in stroke rehabilitation: A pilot randomized clinical trial and proof of principle. Stroke 2010; 41(7): 1477-84.
11. Keshner EA. Virtual reality and physical rehabilitation: A new toy or a new research and rehabilitation tool? J Neuroeng Rehabil 2004; 1(1): 8.
12. Martin O, Julian B, Boissieux L, Gascuel JD, Prablanc C. Evaluating online control of goal-directed arm movement while standing in virtual visual environment. Comput Animat Virtual Worlds 2003; 14(5): 253-60.
13. Hoffman HG, Garcia-Palacios A, Kapa V, Beecher J, Sharar SR. Immersive virtual reality for reducing experimental ischemic

pain. Int J Human Computer Interact 2003; 15(3): 469-86.
14. Forkan R, Pumper B, Smyth N, Wirkkala H, Ciol MA, Shumway-Cook A. Exercise adherence following physical therapy intervention in older adults with impaired balance. Phys Ther 2006; 86(3): 401-10.
15. Mirelman A, Patritti BL, Bonato P, Deutsch JE. Effects of virtual reality training on gait biomechanics of individuals post-stroke. Gait Posture 2010; 31(4): 433-7.
16. Powell WA, Stevens B. The influence of virtual reality systems on walking behaviour: A toolset to support application design. Proceedings of 2013 International Conference on Virtual Rehabilitation (ICVR); 2013 Aug 26-29; Philadelphia, PA, USA. p. 270-6.
17. Deutsch JE, Myslinski MJ, Kafri M, Ranky R, Sivak M, Mavroidis C, et al. Feasibility of virtual reality augmented cycling for health promotion of people poststroke. J Neurol Phys Ther 2013; 37(3): 118-24.
18. Bahram ME, Akasheh G, Shabanzadeh Fini M. The effect of 10 weeks of pilates exercises on static and dynamic balance and psychological factors in elderly men. J Fasa Univ Med Sci 2017; 7(3): 416-27. [In Persian].
19. Farajzadeh MM, Ghanei GR, Sayehmiri K. Health related quality of life in iranian elderly citizens: A systematic review and meta-analysis. Int J Community Based Nurs Midwifery 2017; 5(2): 100-11.
20. Jeste DV, Blazer DG, First M. Aging-related diagnostic variations: need for diagnostic criteria appropriate for elderly psychiatric patients. Biol Psychiatry 2005; 58(4): 265-71.
21. Browne JP, O'Boyle CA, McGee HM, Joyce CR, McDonald NJ, O'Malley K, et al. Individual quality of life in the healthy elderly. Qual Life Res 1994; 3(4): 235-44.
22. Simoes EC, Moraes AC, Okano AH, Altimari LR. Behavior of EMG activation of rectus femoris, vastus lateralis and vastus medialis muscles during maximum contraction before and after a series of repeated efforts. Electromyogr Clin Neurophysiol 2008; 48(8): 377-84.
23. Contreras B, Vigotsky AD, Schoenfeld BJ, Beardsley C, Cronin J. A comparison of gluteus maximus, biceps femoris, and vastus lateralis electromyography amplitude in the parallel, full, and front squat variations in resistance-trained females. J Appl Biomech 2016; 32(1): 16-22.
24. Merletti R, Rainoldi A, Farina D. Surface electromyography for noninvasive characterization of muscle. Exerc Sport Sci Rev 2001; 29(1): 20-5.
25. Hollman JH, Childs KB, McNeil ML, Mueller AC, Quilter CM, Youdas JW. Number of strides required for reliable measurements of pace, rhythm and variability parameters of gait during normal and dual task walking in older individuals. Gait Posture 2010; 32(1): 23-8.
26. Ghanavati T, Salavati M, Karimi N, Negahban H, Ebrahimi Takamjani I, Mehravar M, et al. Intra-limb coordination while walking is affected by cognitive load and walking speed. J Biomech 2014; 47(10): 2300-5.
27. Hollman JH, Kovash FM, Kubik JJ, Linbo RA. Age-related differences in spatiotemporal markers of gait stability during dual task walking. Gait Posture 2007; 26(1): 113-9.
28. Lin HT, Hsu AT, Chang JH, Chien CS, Chang GL. Comparison of EMG activity between maximal manual muscle testing and cybex maximal isometric testing of the quadriceps femoris. J Formos Med Assoc 2008; 107(2): 175-80.
29. Tabard-Fougere A, Rose-Dulcina K, Pittet V, Dayer R, Vuillerme N, Armand S. EMG normalization method based on grade 3 of manual muscle testing: Within- and between-day reliability of normalization tasks and application to gait analysis. Gait Posture 2018; 60: 6-12.
30. Park J, Lee D, Lee S. Effect of virtual reality exercise using the nintendo wii fit on muscle activities of the trunk and lower extremities of normal adults. J Phys Ther Sci 2014; 26(2): 271-3.
31. Sharifmoradi K, Farahpour N. Assessment of range of motion and lower limb muscle activity in Parkinson patients and normal elderly subject (A case study). J Sport Biomech 2017; 3(1): 25-36. [In Persian].
32. Elhami M, Yazdani S. Electromyographic activity of lower extremity and trunk muscles in patients with cerebral palsy during normal walking and walking with visual, motor and cognitive dual task [MSc Thesis]. Tabriz, Iran: University of Tabriz; 2019. [In Persian].
33. Azadian E, Taheri H R, Saberi Kakhki A, Farahpour N. Effects of dual-tasks on spatial-temporal parameters of gait in older adults with impaired balance. Salmand Iran J Ageing 2016; 11(1): 100-9. [In Persian].
34. Walker ML, Ringleb SI, Maihafer GC, Walker R, Crouch JR, Van Lunen B, et al. Virtual reality-enhanced partial body weight-supported treadmill training poststroke: Feasibility and effectiveness in 6 subjects. Arch Phys Med Rehabil 2010; 91(1): 115-22.
35. Dunning K, Levine P, Schmitt L, Israel S, Fulk G. An ankle to computer virtual reality system for improving gait and function in a person 9 months poststroke. Top Stroke Rehabil 2008; 15(6): 602-10.
36. Quaney BM, He J, Timberlake G, Dodd K, Carr C. Visuomotor training improves stroke-related ipsilesional upper extremity impairments. Neurorehabil Neural Repair 2010; 24(1): 52-61.