Research Article

Comparative Analysis of Dual-Task and Single-Task Balance Exercises in Improving Static Balance in Individuals with Anterior Cruciate Ligament Reconstruction

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ABSTRACT

Introduction: Various balance exercises have been employed to enhance functional stability and balance in individuals who have undergone anterior cruciate ligament (ACL) reconstruction; however, no study has explored the use of dual-task balance exercises for these patients. This study compares the effects of dual motor task balance exercises and single-task exercises on the static balance indices of individuals with ACL reconstruction.

Materials and Methods: In a single-blind randomized controlled trial, 27 subjects who had undergone ACL reconstruction were randomly divided into two groups: Dual-task and single-task balance exercises. Both groups performed their exercises three days a week for one month. Static balance indicators were assessed at the beginning and end of the treatment.

Results: The results demonstrated that after the treatment, there was a statistically significant decrease in various center of pressure variables, including mean displacement in the anterior-posterior and medial-lateral directions, total path length, mean velocity of displacement, root mean square of displacement, and velocity. Furthermore, the knee injury and osteoarthritis outcome score significantly increased in both groups (P<0.05). However, when comparing the two groups, no significant difference was observed after the treatment (P>0.05).

Conclusion: Dual-task and single-task motor exercises improve static stability and knee function levels in patients who have undergone ACL reconstruction. Meanwhile, the effectiveness of these exercise types does not significantly differ from each other.

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Introduction

Anterior cruciate ligament (ACL) reconstruction is a common procedure to address mechanical knee instability in individuals with ACL deficiency. While this surgery restores mechanical stability, it often results in proprioception impairment due to decreased sensory input from mechanoreceptors to the central nervous system (CNS). This impairment can negatively affect postural control, balance, and functional stability [1]. Consequently, balance training plays a crucial role in the rehabilitation of individuals undergoing ACL reconstruction. Extensive evidence supports the inclusion of balance training in ACL reconstruction rehabilitation programs as it has the potential to enhance dynamic stability, improve postural balance, and restore functional ability by stimulating mechanoreceptors and increasing muscle spindle sensitivity in joint structures [2-5].

Existing evidence also highlights the presence of postural control impairment in both limbs following a unilateral ACL injury [6]. This bilateral postural control disorder suggests the involvement of central factors [7]. ACL injury causes reorganization of the CNS due to changes in the ascending pathway to the CNS [8]. Individuals with ACL reconstruction exhibit increased activity in the frontal lobe, secondary somatosensory region, and lingual gyrus during task completion when compared to their healthy counterparts. These areas involve complex integration of multiple sensory afferents, including vision, sensory processing, attention, and memory [8, 9]. Electroencephalography (EEG) studies in individuals who have undergone ACL reconstruction have revealed alterations in sensory information processing, increased reliance on cortical information, and heightened attentional focus during task performance [10]. In other words, ACL injury affects not only the peripheral musculoskeletal system but also the CNS, potentially leading to additional deficits [10, 11].

Recent studies have shown that directing attention toward external sources allows individuals to transfer motor skills and enhance the activity of subcortical autonomic areas [12]. This promotes a higher level of automaticity in the movement system, resulting in more efficient performance and a more natural state [13]. When a secondary task, whether motor or cognitive, is added to the primary task, such as balance, to direct attention to external sources, it is referred to as a dual-task state [14]. Exercising in a dual-task condition can enhance the automaticity of the primary task, allowing the processing system to allocate fewer attentional resources for optimal performance of the primary task [15, 16]. Following treatment, individuals who engage in dual-task exercises exhibit reduced neural activity in specific brain areas involved in dual-task performance, which can be attributed to reduced processing demands [13, 17, 18]. Dual-task exercises expedite information processing, and evidence suggests that the response selection phase shortens with practice [19].

Some studies have suggested that performing balance exercises under dual conditions yields additional and superior effects compared to single balance exercises in improving individuals' balance levels; however, no study has explored the effects of dual-task balance exercises in postoperative rehabilitation programs for individuals with ACL reconstruction. Therefore, this study investigates the impact of dual-task balance exercises on the static balance of these individuals.

Materials and Methods

Study participants

A total of 49 individuals who had undergone ACL reconstruction surgery were referred to the physiotherapy clinic of the Rehabilitation Faculty at Tabriz University of Medical Sciences by an orthopedic surgeon. A qualified physiotherapist conducted assessments to determine eligibility based on inclusion and exclusion criteria. The inclusion criteria encompassed individuals who had undergone unilateral primary hamstring autograft ACL reconstruction, aged between 18 and 45 years. Meanwhile, the exclusion criteria included a history of neurological, vestibular, vision, or other conditions affecting balance, additional knee ligament injuries or surgeries on the operated limb, previous injuries or surgeries to both ankle and hip joints, contralateral knee joints, and the spine. Additionally, the participants with a pain level exceeding 3 on the visual analog scale during balance tests were excluded. Eight individuals among the referrals chose to withdraw from the study, and 12 subjects were excluded due to not meeting the inclusion criteria. Eventually, 29 individuals met the eligibility criteria, participated in the study, and provided informed consent for testing. However, during the study, two participants dropped out. The study was conducted with a final sample size of 27 individuals, consisting of one female and 26 males, who were selected using a non-probability convenience sampling method. Group assignments were determined randomly by an individual not involved in the study, using random allocation software, with the allocation concealed from both the assessors and the participants (Figure 1).
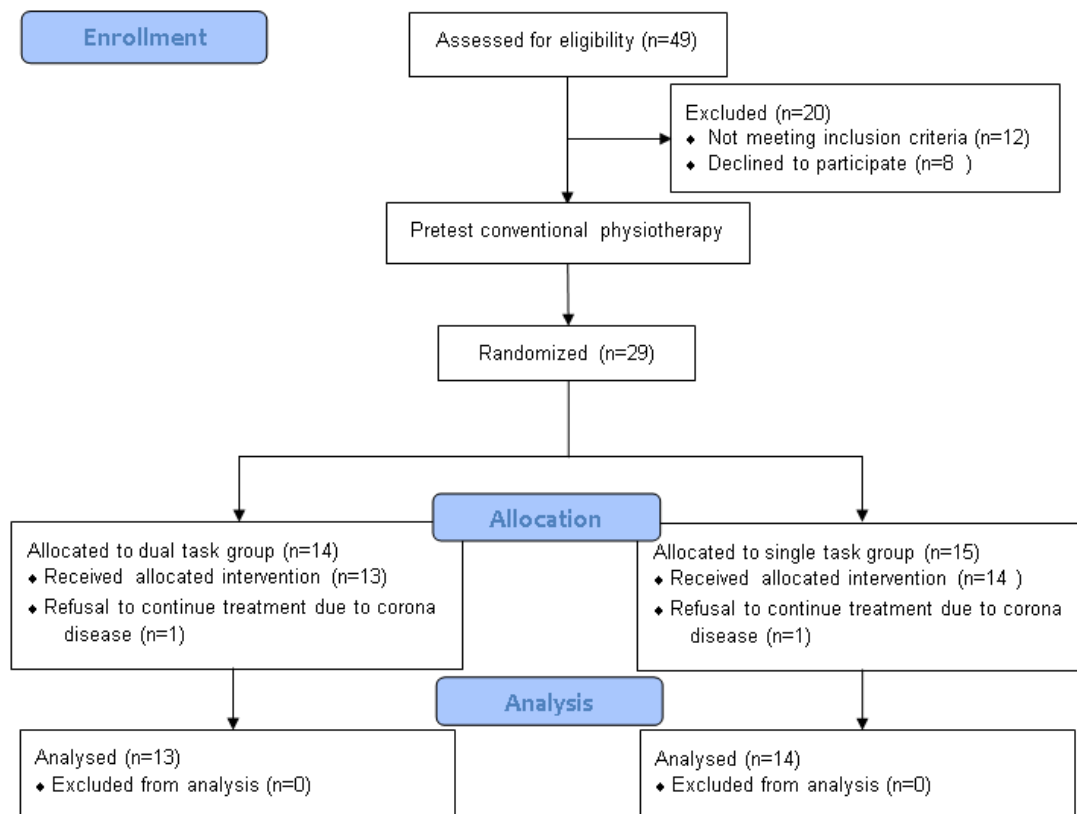
Figure 1. Flow chart illustrating search and study selection

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Study design

Our study follows a randomized controlled trial design and adheres to the relevant CONSORT guidelines. To minimize bias, both the assessor physiotherapist, and the data analyst were blinded to the group assignments.

Study procedure

Initially, personal characteristics and information related to variables, including age, gender, height, weight, dominant leg, injured leg, and the time elapsed since the injury and surgery, were carefully recorded (Table 1 and Table 2).

The treatment plan for the participants consisted of two key components as follows: Conventional physiotherapy and balance exercises. All participants underwent conventional physical therapy before the allocation stage. Once the subjects achieved the necessary neuromuscular control to bear weight on the operated leg without experiencing pain or instability in the knee and demonstrated an active range of motion of 120 degrees of knee flexion, they were instructed to perform the static balance assessment. Additionally, they were asked to

complete the Persian version of the knee injury and osteoarthritis outcome score (KOOS) questionnaire [20].

Subsequently, the participants were divided into two groups the single-task (control) balance exercise group and the dual-task (intervention) balance exercise group. They commenced the main balance exercise regimen, which spanned 12 sessions over one month.

In the control group, the participants received single-task balance exercises, while the intervention group engaged in dual motor task balance exercises. Following the completion of the exercise program, the participants were once again asked to undergo the static balance assessment and to complete the KOOS questionnaire under the conditions that prevailed during their last session.

Conventional physiotherapy

The participants initiated the conventional physiotherapy program within a maximum period of one week following their surgical procedure, adhering to established references in the field of physical therapy [21-23]. This comprehensive program encompassed electrical stimulation, cold therapy, and exercise therapy.

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Table 1. Demographic characteristics of groups

Demographic Data	Mean±SD		P
	Single-task Group (n=14)	Dual-task Group (n=13)	
Age (y)	34.2±6.20	29.92±7.68	0.12
Height (cm)	173.29±6.21	176.15±5.09	0.20
Weight (kg)	75.06±8.97	76.67±9.55	0.65
Body mass index (kg/m^2)	24.94±1.95	24.71±2.88	0.81
Injury and surgery interval (m)	6.5±8.96	11.77±22.92	0.64

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In the electrical stimulation component, transcutaneous electrical nerve stimulation current with a frequency of 120 Hz and a pulse width of 60 μs was applied for 15 min. Electrodes were strategically positioned on both sides of the knee joint, with participants in a supine or long sitting position. The current intensity was set to a level that was well-tolerated by the patients [22]. Additionally, functional electrical stimulation current was utilized with parameters, including a 55 Hz frequency, 300 μs pulse width, a 4-s contraction hold time, and an 8-s rest time, all for 15 min. This was employed to strengthen the quadriceps muscle. The cathode electrode was positioned on the nerve in the upper third of the quadriceps muscle, and the anode electrode was placed in the muscle bulk, directed toward the vastus medialis oblique muscle. The current intensity was adjusted to the maximum tolerable limit for the patients [22]. To address inflammation and joint effusion control, the participants were instructed to apply an ice pack around the patella for 10 min both before and after their exercise sessions.

Therapeutic exercises were introduced in the very first session and encompassed a range of activities, including muscle strength and stretching exercises, as well as exercises for improving knee joint range of motion (Table 3). During each session, new exercises or increased resistance were incorporated based on individual participant conditions and the physical therapist's assessment. The participants were encouraged to replicate these exercises at home, performing them twice a day to optimize their rehabilitation.

Knee injury and osteoarthritis outcome score

KOOS is a validated tool designed to assess patient-relevant outcomes following knee injury. This self-administered questionnaire is structured into five sections and comprises a total of 42 questions, presented in the following sequence: Pain (9 items), symptoms (7 items), daily activity performance (17 items), performance in sports and recreational activities (5 items), and the quality of life (QoL) (4 items). Scores obtained from the questionnaire are converted to a 0–100 scale, where a score of 0 indicates the presence of severe knee problems, and a score of 100 signifies an absence of knee problems [24, 25].

Table 2. Descriptive statistics of groups and comparing before intervention

Variables		No. (%)		P
		Single-task	Dual-task	
Gender	Male	14(100)	12(92.3)	0.48
	Female	0(0)	1(7.7)	
Involved knee	Right	7(50)	3(23.1)	0.23
	Left	7(50)	10(76.9)	
Menisci injury	Intact	5(35.7)	4(30.8)	1.00
	Repaired	9(64.3)	9(69.2)	

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Table 3. Conventional physiotherapy exercises

Number of Repetitions and Sets	Type of Exercise
30 repetitions in 3 sets	Ankle pumps
30 repetitions in 3 sets	Quadriceps setting in a sitting position
30 repetitions in 3 sets	Quadriceps setting in standing position
30 repetitions in 3 sets	Hamstring setting
5 repetitions for 30 s	Gastrocnemius stretching
30 repetitions in 3 sets	Wall slide
30 repetitions in 3 sets	Heel slide
30 repetitions in 3 sets	Knee flexion with a Swiss ball
30 repetitions in 3 sets	Straight leg raising with hip flexion
30 repetitions in 3 sets	Straight leg raising with hip abduction
30 repetitions in 3 sets	Straight leg raising with hip adduction
30 repetitions in 3 sets	Knee flexion in prone
30 repetitions in 3 sets	Foot press
30 repetitions in 3 sets	Terminal knee extension
30 repetitions in 3 sets	Squat
10 min with the least amount of resistance	Bicycle
10 min forward and 5 min backward walking	Treadmill
30 repetitions in 3 sets	Step

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Static balance test

The static balance of all participants was evaluated using a foot pressure tool, specifically the Zebris FDM pressure platform. This device can record the coordinates (X, Y) of the center of pressure (COP) with a sampling rate of 100.

For the static balance assessment, the participants were instructed to stand barefoot on the FDM platform, separately on the operated and non-operated legs. During each leg test, the participants maintained a specific posture, with their arms crossed on their chest, the weight-bearing knee flexed at 20 degrees, and the non-weight-bearing leg flexed at 45 degrees in both the knee and hip joints. The degrees of flexion were accurately controlled using a goniometer, and the participants were required to sustain this posture during the test. If a subject was unable to maintain the described position and balance, the test was repeated. Each test session had a duration of 20 s, during which participants focused on a marked point located at eye level on the opposite wall at a distance of 1.4 m. The test was performed three times for each participant, with a 1-min break given between repetitions to prevent fatigue. The average of the three repetitions was used for subsequent analysis.

Balance exercises

Upon random assignment to their respective groups, participants in the control group commenced single-task balance exercises, while those in the intervention group initiated dual motor task balance exercises, as outlined in Tables 4 and 5. These exercises were organized in an ascending order of difficulty, with the requirement that the previous exercise had to be completed successfully before progressing to the next one. Initially, all exercises on the balance boards were performed using both legs. As

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Table 4. Balance exercises related to the single-task group

Exercises
Standing on the ground with the operated leg
Standing on a two-directional balance board in the medial-lateral direction
Standing on the two-directional balance board in the anterior-posterior direction
Standing on the operated leg on a foam board with a thickness of 10.5 cm
Standing on a multi-directional balance board
Standing on a 10.5 cm thick foam board placed on a two-directional balance board, in the medial-lateral direction
Standing on a 10.5 cm thick foam placed on a two-directional balance board, in the anterior-posterior direction
Standing on a 10.5 cm thick foam placed on a two-directional balance board, in the anterior-posterior direction
Standing on a 10.5 cm thick foam placed on a multi-directional balance board

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the participants' conditions improved, they transitioned to performing these exercises on the operated leg.

Each participant individually executed these exercises under the supervision of a physiotherapist, with three sessions per week over 4 weeks. Each session had a duration of 30 min. All exercises were conducted in the same environment setting for consistency among all participants.

In the intervention group, the balance exercises were performed in the same order as the control group, besides that the participants had to perform another motor task with balance exercise simultaneously.

Statistical analysis

The software of the device used was unable to directly calculate all the variables for our study. Raw data ex-tracted from the FDM pressure platform included coordinates of the COP in both the X and Y axes at a sampling rate of 100. To address this, a knowledgeable medical engineer proficient in MATLAB software developed a computerized algorithm using MATLAB software, version R2022B. This algorithm was capable of calculating various COP variables, including the average displacement of the COP (mm), the average displacement of the COP in both the anterior-posterior and medial-lateral directions (mm), the root mean square of the displacement of the COP, the total path of the COP (mm), the average velocity of the COP (mm/s), the root mean square of the velocity of the COP, and the elliptical area of the COP (mm^2) based on the provided COP coordinates. The data from the MATLAB software was then imported into the SPSS software, version 25 for the subsequent statistical analysis, maintaining a significance level of 0.05. To ensure the normality of data distribution, the Kolmogorov–Smirnov test was employed. The analysis involved us-

Table 5. Balance exercises related to the dual task group

Exercises
Moving a ball between two hands alternately
Moving some water between glasses on hands alternately
Following the lines of the special shapes embedded on the wall with a laser pointer
Catching a ball thrown toward the subject
Throwing a tennis ball to the target marked on the wall
Passing a ball with a non-operated leg

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Table 6. Comparison of center of pressure variables within and between groups

Variables	Single Task		P (Within Group)	Dual Task		P (Within Group)	ANCOVA (Between Group)
	Mean±SD			Mean±SD			
	Before Intervention	After Intervention		Before Intervention	After Intervention		
Displace of COP (mm)	0.36±0.05	0.30±0.05	0.001	0.28±0.03	0.24±0.03	0.001	0.93
Displace of COP in AP (mm)	0.23±0.04	0.19±0.03	0.001	0.19±0.02	0.16±0.02	0.001	0.38
Displace of COP in ML (mm)	0.23±0.02	0.19±0.03	0.04	0.17±0.01	0.15±0.02	0.02	0.73
Total path of the COP (mm)	716.96±101.13	593.68±107.47	0.001	562.35±67.35	488.99±77.50	0.001	0.94
COP velocity (mm/s)	35.84±5.05	29.65±5.31	0.001	28.13±3.36	24.46±3.87	0.001	0.91
RMS of COP displacement	0.47±0.06	0.38±0.07	0.001	0.36±0.03	0.31±0.05	0.001	0.99
RMS of COP velocity	46.29±6.61	37.90±7.00	0.001	36.11±3.81	31.22±5.07	0.001	0.99
An elliptical area of COP (mm^2)	227.77±5979	149.32±39.69	0.001	175.50±57.41	145.51±14.03	0.06	0.80

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Abbreviations: COP: Center of pressure; AP: Anterior-posterior direction; ML: Medial-lateral direction; SD: Standard deviation; RMS: Root mean square; ANCOVA: Analysis of covariance.

ing the independent t-test to compare the averages of the variables between the two groups at both the study's outset and conclusion. Additionally, the paired t-test was applied to compare the averages within each group before and after the intervention. The analysis of the covariance test was utilized to control for the baseline effect of the variables. To investigate the relationship between the balance test variables and the scores of the KOOS questionnaire before and after the intervention, the Pearson correlation coefficient was calculated.

Results

The results of the Kolmogorov–Smirnov test indicated that the distribution of all variables in the study was normal.

Regarding the within-group comparisons of static balance variables and questionnaire subscales, in the control group, all static balance variables exhibited a significant reduction after engaging in balance exercises (P<0.05), as presented in Table 6. In the dual-task motor group, all static balance variables displayed a significant decrease after the treatment (P<0.05). The only exception was the elliptical area of the COP (mm^2), which did not exhibit a significant difference (P=0.06), as indicated in Table 6.

Regarding the questionnaire, in both groups, the balance exercises had a significant impact, leading to a significant increase in the scores of all questionnaire subscales (P<0.05), as shown in Table 7.

The results of the between-group comparison of static balance variables and questionnaire subscales, using the analysis of covariance test to neutralize the baseline effect, demonstrated no significant differences (P>0.05) between the effects of the two types of intervention for static balance variables, as presented in Table 6. Furthermore, there were no statistically significant differences (P>0.05) in questionnaire subscales between the two groups before and after the interventions (Table 7).

The results of the correlation analysis between static balance variables and questionnaire subscales revealed that in the group that engaged in dual motor task exercises, none of the questionnaire subscales exhibited a statistically significant correlation with any of the investigated static balance indicators before or after the interventions.

In contrast, within the single-task exercise group, the variable representing the elliptical area of the COP (mm^2) displayed a significant moderate negative correlation with the subscales related to sports activity and QoL before the therapeutic interventions (r=-0.58, P<0.05 and r=-0.54, P<0.05, respectively). After the completion of the balance exercises, only the average displace-

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Table 7. Comparison KOOS questionnaire subscales within and between groups

Variables	Single Task			Dual Task			P (Between Group After Intervention)
	Mean±SD		P (Within Group)	Mean±SD		P (Within Group)	
	Before Intervention	After Intervention		Before Intervention	After Intervention		
Symptoms	57.29±17.26	69.07±17.09	0.01	59.46±10.57	75.85±11.21	0.001	0.23
Pain	60.36±16.73	71.43±18.71	0.04	58.92±17.96	71.46±13.99	0.001	0.99
Performance in ADLs	66.14±16.38	80.86±12.46	0.001	57.08±19.34	73.46±13.83	0.001	0.15
Performance in sports	14.64±3.22	43.57±19.05	0.001	18.46±8.52	41.54±23.39	0.001	0.80
QoL	64.28±19.24	37.07±17.26	0.001	28.62±19.76	43.85±16.50	0.001	0.30

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Abbreviations: KOOS: Knee injury, and osteoarthritis outcome score; ADLs: Activities of daily living; SD: Standard deviation.

ment of the COP in the anterior-posterior direction (mm) demonstrated a significant relatively moderate positive correlation with the subscales associated with sports and recreational activities (r=0.59, P<0.05).

Discussion

This study investigated the impact of dual motor task balance exercises on static balance and knee function, comparing it with the effects of single-task balance exercises. The study observed a general reduction in variables related to the displacement and speed of the COP in both the dual motor task and single-task exercise groups after a period of exercise in individuals who had undergone ACL reconstruction surgery. This decrease in the COP's displacement and velocity parameters suggests an enhancement in balance, improved postural control, and increased stability [26-28].

Previous research by Conceição et al. and Konak et al. in 2016 explored the effects of dual motor tasks and single-task exercises on individuals with ankle instability and osteoporosis, respectively. Their findings align closely with the results of the present study [17, 29]. Evidence suggests that balance training on an unstable surface can heighten muscle spindle sensitivity through gamma motor neurons, thereby enhancing motor function and stability [30]. Furthermore, training programs enable motor skills to operate automatically, reducing the demand for attention. This, in turn, allows individuals to allocate more attention capacity to other concurrent actions [31]. It is widely acknowledged that as a task becomes more automated, the occurrence of errors decreases, and task execution becomes more aligned with natural functioning [13].

Based on the between-group results of this study, no significant difference was observed between dual motor and single-task balance exercises. Unfortunately, the authors could not find any previous studies that specifically investigated the impact of dual-task balance exercises on individuals with ACL reconstruction. However, in studies involving different subject groups, such as Onegh's research on individuals with functional ankle instability in 2020 [32], Konak's study on individuals with osteoporosis in 2016 [17], and Sinaei's investigation on elderly individuals in 2016 [33], no significant differences were identified between dual and single-task balance exercises. In the author's previous study, which examined the effect of cognitive dual-task in anterior cruciate ligament reconstruction patients, no significant difference was seen between the dual and single groups [34].

In the present study, similar to Onegh's research, balance assessments were not conducted under dual-task conditions while exercises were performed with the inclusion of a secondary task. It is plausible that if patients were assessed in a dynamic condition while concurrently performing a secondary task, the treatment group might have demonstrated a more substantial improvement compared to the control group. The transferability of the effects of dual-task exercises may be limited when evaluations are conducted solely in a single-task condition.

Additionally, the relatively small number of participants and the limited follow-up assessments post-treatment, akin to the study by Sinaei [30], may have influenced our results. Therefore, to achieve different outcomes in future research, it is advisable to increase the number of participants and implement more extensive follow-up assessments after treatment.

In a study by Elhinidi et al. in 2016, it was reported that dual-task exercises had a more pronounced effect on balance compared to single tasks, particularly in children with hemiparesis. They conducted a 30-session training program, each lasting 1 h, and observed a significant decrease in the swing area and swing rate in the dual-task group compared to the control group. They hypothesized that dual-task exercises lead to greater activation of new pathways in the cerebellum, sensory-motor cortex, and premotor cortex, as well as more substantial changes in brain neuroplasticity compared to the control group [18].

Similarly, Shin's study in 2014 reported a superior effect of dual motor task exercises on balance compared to single balance exercises in independent elderly women. The subjects underwent 45-min balance exercise sessions, spanning 6 weeks. The study highlighted the simultaneous and complex involvement of various brain centers, including vision, somatosensory, vestibular, and attention centers, in dealing with gravity, body movements, and the environment, which contributed to the superiority of dual-task exercises [35].

In contrast to this study, the two aforementioned studies employed a longer treatment duration. Accordingly, dual-task exercises may require more consistent repetition to achieve their full effectiveness. Therefore, despite the results of this study, the authors believe in the greater potential and efficacy of dual-task balance exercises. They suggest that the dual-task group could yield superior results compared to the single-task group if the number of treatment sessions and the overall treatment duration were increased.

Regarding the questionnaire, the results of this study demonstrate an increase in the scores of the KOOS questionnaire in both the dual and single-task exercise groups. Some studies interpret an increase in these questionnaire scores as an indicator of improved knee function [24, 25]. In the present study, a statistically significant increase in post-treatment scores was observed, suggesting an overall improvement in knee function among the participants. However, the dual-task balance exercise did not exhibit a superior effect on questionnaire scores, and consequently, knee function did not significantly differ between the two groups.

Furthermore, there was generally no significant correlation between static balance variables and the questionnaire subscales. A similar finding was reported in a study conducted by Wang et al. in 2021, where no correlation was identified between static balance variables and the questionnaire in patients who had undergone total knee replacement surgery. They emphasized that an improvement in pain perception and knee function does not necessarily indicate an improvement in postural control performance after treatment [36].

Conclusion

Both dual motor and single-task balance exercises have demonstrated the ability to enhance static balance indices and reduce levels of knee functional disability. However, this study did not find a significant superiority of one exercise type over the other throughout 12 sessions within a one-month timeframe.

Study limitations

Several limitations of this study should be acknowledged. First, post-treatment follow-up assessments were not conducted to evaluate the durability of the treatment effects, which could provide valuable insights into the long-term impact of these exercises. Secondly, the sample size in this study was relatively small, which may have contributed to the lack of a significant difference in results between the two exercise groups. The short duration of the treatment plan could also be a limiting factor, as a longer exercise regimen may yield more pronounced differences. Lastly, it is worth noting that the majority of the participants in this study were men, which may restrict the generalizability of the results to the broader population.

Ethical Considerations

Compliance with ethical guidelines

Our study has been registered with the Iranian Registry of Clinical Trials (IRCT) (Code: IRCT20180925041138N2) and the study received approval from the Ethics Committee of Tabriz University of Medical Sciences (Code: IR.TBZMED.REC.1397.946).

Authors' contributions

Data collection: Fatemeh Oraei Eslami, Masumeh Hallaj Mazidluie; Data analysis and interpretation: Fatemeh Oraei Eslami, Jalal Ahadi and Tabassom Ghanavati;

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References

[1] Naghizad J, Meibodi MKE, Dalvand H, Shamsoddini A. Comparison of knee proprioception between athletes with anterior cruciate ligament injury and healthy athletes. Journal of Modern Rehabilitation. 2023; 17(2):142-8. [DOI:10.18502/jmr.v17i2.12412]

[2] Cooper RL, Taylor NF, Feller JA. A systematic review of the effect of proprioceptive and balance exercises on people with an injured or reconstructed anterior cruciate ligament. Research in Sports Medicine. 2005; 13(2):163-78. [DOI:10.1080/15438620590956197] [PMID]

[3] Mostafaee N, Yazdi MJS, Negahban H, Goharpey S, Mehravar M, Pirayeh N. Responsiveness of static and dynamic postural balance measures in patients with anterior cruciate ligament reconstruction following physiotherapy intervention. Arch Bone Jt Surg. 2017; 5(3):153-67. [PMID] [PMCID]

[4] Pezzullo DJ, Fadale P. Current controversies in rehabilitation after anterior cruciate ligament reconstruction. Sports Medicine and Arthroscopy Review. 2010; 18(1):43-7. [DOI:10.1097/JSA.0b013e3181cdb5d3] [PMID]

[5] Akbari A, Ghiasi F, Mir M, Hosseinifar M. The effects of balance training on static and dynamic postural stability indices after acute ACL reconstruction. Global Journal of Health Science. 2015; 8(4):68-81. [DOI:10.5539/gjhs.v8n4p68] [PMID]

[6] Stensdotter AK, Tengman E, Häger C. Altered postural control strategies in quiet standing more than 20 years after rupture of the anterior cruciate ligament. Gait & Posture. 2016; 46:98-103. [DOI:10.1016/j.gaitpost.2016.02.020] [PMID]

[7] Howells BE, Clark RA, Ardern CL, Bryant AL, Feller JA, Whitehead TS, et al. The assessment of postural control and the influence of a secondary task in people with anterior cruciate ligament reconstructed knees using a Nintendo Wii Balance Board. British Journal of Sports Medicine. 2013; 47(14):914-9. [DOI:10.1136/bjsports-2012-091525] [PMID]

[8] Kapreli E, Athanasopoulos S, Gliatis J, Papathanasiou M, Peeters R, Strimpakos N, et al. Anterior cruciate ligament deficiency causes brain plasticity: A functional MRI study. The American Journal of Sports Medicine. 2009; 37(12):2419-26. [DOI:10.1177/0363546509343201] [PMID]

[9] Stone AE, Roper JA, Herman DC, Hass CJ. Cognitive performance and locomotor adaptation in persons with anterior cruciate ligament reconstruction. Neurorehabilitation and Neural Repair. 2018; 32(6-7):568-77. [DOI:10.1177/1545968318776372] [PMID]

[10] Baumeister J, Reinecke K, Schubert M, Weiss M. Altered electrocortical brain activity after ACL reconstruction during force control. Journal of Orthopaedic Research. 2011; 29(9):1383-9. [DOI:10.1002/jor.21380] [PMID]

[11] Mohammadi-Rad S, Salavati M, Ebrahimi-Takamjani I, Akhbari B, Sherafat S, Negahban H, et al. Dual-tasking effects on dynamic postural stability in athletes with and without anterior cruciate ligament reconstruction. Journal of Sport Rehabilitation. 2016; 25(4):324-9. [DOI:10.1123/jsr.2015-0012] [PMID]

[12] Needle AR, Lepley AS, Grooms DR. Central nervous system adaptation after ligamentous injury: A summary of theories, evidence, and clinical interpretation. Sports Medicine. 2017; 47(7):1271-88. [DOI:10.1007/s40279-016-0666-y] [PMID]

[13] Ghai S, Ghai I, Effenberg AO. Effects of dual tasks and dual-task training on postural stability: A systematic review and meta-analysis. Clinical Interventions in Aging. 2017; 12:557-77. [DOI:10.2147/CIA.S125201] [PMID]

[14] Fraizer EV, Mitra S. Methodological and interpretive issues in posture-cognition dual-tasking in upright stance. Gait & Posture. 2008; 27(2):271-9. [DOI:10.1016/j.gaitpost.2007.04.002] [PMID]

[15] Monjezi S, Negahban H, Tajali S, Yadollahpour N, Majdinasab N. Effects of dual-task balance training on postural performance in patients with Multiple Sclerosis: A double-blind, randomized controlled pilot trial. Clinical Rehabilitation. 2017; 31(2):234-41. [DOI:10.1177/0269215516639735] [PMID]

[16] Conradsson D, Löfgren N, Nero H, Hagströmer M, Ståhle A, Lökk J, et al. The effects of highly challenging balance training in elderly with parkinson's disease: A randomized controlled trial. Neurorehabilitation and Neural Repair. 2015; 29(9):827-36. [DOI:10.1177/1545968314567150] [PMID]

[17] Konak HE, Kibar S, Ergin ES. The effect of single-task and dual-task balance exercise programs on balance performance in adults with osteoporosis: A randomized controlled preliminary trial. Osteoporosis International. 2016; 27(11):3271-8. [DOI:10.1007/s00198-016-3644-1] [PMID]

[18] Elhinidi EI, Ismaeel MM, El-Saeed TM. Effect of dual-task training on postural stability in children with infantile hemiparesis. Journal of Physical Therapy Science. 2016; 28(3):875-80. [DOI:10.1589/jpts.28.875] [PMID]

[19] Strobach T, Torsten S. Mechanisms of practice-related reductions of dual-task interference with simple tasks: Data and theory. Advances in Cognitive Psychology. 2017; 13(1):28-41. [DOI:10.5709/acp-0204-7] [PMID]

[20] Salavati M, Mazaheri M, Negahban H, Sohani SM, Ebrahimian MR, Ebrahimi I, et al. Validation of a Persian-version of knee injury and osteoarthritis outcome score (KOOS) in Iranians with knee injuries. Osteoarthritis and Cartilage. 2008; 16(10):1178-82. [DOI:10.1016/j.joca.2008.03.004] [PMID]

[21] Kisner C, Colby LA, Borstad J. Therapeutic exercise: foundations and techniques. Philadelphia: F.A. Davis; 2022. [Link]

[22] Cornwall MW. Electrotherapy explained: Principles and practice. Physical Therapy. 2007; 87(8):1088. [DOI:10.2522/ptj.2007.87.8.1088]

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[23] Brotzman SB, Manske RC. Clinical orthopaedic rehabilitation e-book: An evidence-based approach-expert consult. Edinburgh: Elsevier Health Sciences; 2011. [Link]

[24] Roos EM, Roos HP, Lohmander LS, Ekdahl C, Beynnon BD. Knee injury and osteoarthritis outcome score (KOOS)--development of a self-administered outcome measure. The Journal of Orthopaedic and Sports Physical Therapy. 1998; 28(2):88-96. [DOI:10.2519/jospt.1998.28.2.88] [PMID]

[25] Roos EM, Lohmander LS. The Knee injury and Osteoarthritis Outcome Score (KOOS): From joint injury to osteoarthritis. Health and Quality of Life Outcomes. 2003; 1(64):1-8. [DOI:10.1186/1477-7525-1-64]

[26] Palmieri RM, Ingersoll CD, Stone MB, Krause BA. Center-of-pressure parameters used in the assessment of postural control. Journal of Sport Rehabilitation. 2002; 11(1):51-66. [DOI:10.1123/jsr.11.1.51]

[27] Eils E, Rosenbaum D. A multi-station proprioceptive exercise program in patients with ankle instability. Medicine and Science in Sports and Exercise. 2001; 33(12):1991-8. [DOI:10.1097/00005768-200112000-00003] [PMID]

[28] Kidgell DJ, Horvath DM, Jackson BM, Seymour PJ. Effect of six weeks of dura disc and mini-trampoline balance training on postural sway in athletes with functional ankle instability. Journal of Strength and Conditioning Research. 2007; 21(2):466-9. [DOI:10.1519/R-18945.1] [PMID]

[29] Conceição JS, Schaefer de Araújo FG, Santos GM, Keighley J, Dos Santos MJ. Changes in postural control after a ball-kicking balance exercise in individuals with chronic ankle instability. Journal of Athletic Training. 2016; 51(6):480-90. [DOI:10.4085/1062-6050-51.8.02] [PMID]

[30] Kim D, Ko J, Woo Y. Effects of dual task training with visual restriction and an unstable base on the balance and attention of stroke patients. Journal of Physical Therapy Science. 2013; 25(12):1579-82. [DOI:10.1589/jpts.25.1579] [PMID]

[31] Pellecchia GL. Dual-task training reduces impact of cognitive task on postural sway. Journal of Motor Behavior. 2005; 37(3):239-46. [DOI:10.3200/JMBR.37.3.239-246] [PMID]

[32] Onegh A, Akbari A, Ghiasi F, Hosseinifar M, Asgari A. The effect of dual-task training on dynamic postural control in the subjects with functional ankle instability. Journal of Biochemical Technology. 2020; 11(3):115-22. [Link]

[33] Sinaei E, Kamali F, Nematollahi A, Etminan Z. [Comparing the effects of balance training with and without cognitive tasks on the quality of life and balance performance in community-dwelling older adults: A single-blind randomized clinical trial (Persian)]. Journal of Rehabilitation Sciences & Research. 2016; 3(4):91-6. [DOI:10.30476/jrsr.2016.41106]

[34] Hallaj Mazidluie M, Ahadi J, Oraei Eslami F, Ghanavati T, Moradi A. Comparison of the effects of cognitive dual-task and single-task balance exercises on static balance among people with anterior cruciate ligament reconstruction: A randomized controlled trial. The Archives of Bone and Joint Surgery. 2024; 12(5):349-56. [PMID]

[35] Shin SS, An DH. The effect of motor dual-task balance training on balance and gait of elderly women. Journal of Physical Therapy Science. 2014; 26(3):359-61. [DOI:10.1589/jpts.26.359] [PMID]

[36] Wang J, Severin AC, Mears SC, Stambough JB, Barnes CL, Mannen EM. Changes in mediolateral postural control mechanisms during gait after total knee arthroplasty. The Journal of Arthroplasty. 2021; 36(9):3326-32. [DOI:10.1016/j.arth.2021.04.038] [PMID]

Oraei Eslami F, et al. Dual-Task Balance Exercises in ACL Reconstruction. JMR. 2024; 18(3):347-357.

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