RESEARCH ARTICLE

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

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Abstract

Objectives: The anterior cruciate ligament (ACL) reconstruction surgery improves mechanical stability; however, functional stability remains impaired. Balance exercises can help improve functional stability. The effect of cognitive dual-task balance exercises has not been studied in people with ACL reconstruction surgery; therefore, this study aimed to compare the effect of cognitive dual-task and single-task balance exercises on the static balance indices in these individuals.

Methods: This study was a randomized clinical trial. After a period of conventional physiotherapy and applying inclusion criteria, 28 patients with ACL reconstruction surgery were randomly divided into two groups of cognitive dual-task and single-task balance exercises. Each group received the relevant exercises for four weeks, three times a week, with each session lasting 20 min. Center of pressure variables, including mean displacement in anterior-posterior and medial-lateral directions, total path length, mean velocity of displacement, root mean square of displacement and velocity, and the elliptical area, were measured using the FDM pressure platform before and after the interventions as the primary outcomes. Knee Injury and Osteoarthritis Outcome Score (KOOS) scale was completed by the participants before and after the interventions.

Results: The measured static balance variables and KOOS subscales had significant differences before and after intervention in both groups ($P<0.05$); however, no statistically significant difference was observed in these variables between the two groups. There was no significant correlation between KOOS subscales and measured static balance variables.

Conclusion: Both cognitive dual-task and single-task balance exercises improved the indicators related to static balance and the level of functional disability of the knee. However, cognitive dual-task balance exercises had no superiority over single-task balance exercises in ACL-reconstructed individuals.

Level of evidence: II

Keywords: Anterior cruciate ligament reconstruction, Balance exercise, Cognitive dual-task, Static balance test

Introduction

Since the anterior cruciate ligament (ACL) protects the knee joint both mechanically and neurally, damage to its fibers may seriously affect lower limb functions, particularly during intense activities.[1-3] Therefore, most people who expect to achieve their pre-injury level of activity undergo ACL reconstruction surgery.[4] The available evidence shows that postural control is impaired in both limbs after unilateral ACL injury and even after its reconstruction.[2] The bilaterality of postural control disorder and the impairment of postural control of the uninjured limbs probably indicate the involvement of a central mechanism.[2] ACL damage is more

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than a simple musculoskeletal peripheral disorder.[5] Central changes that occur following damage to this ligament are shown in electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) studies.[5-7] These changes cause persistent disabilities, failure in surgery, and unfavorable results.[5] EEG studies in ACL reconstructed subjects have shown changes in the theta wave in the frontal cortex and alpha in the parietal cortex indicating a higher focus of attention and a change in the processing of sensory information in the somatosensory cortex, respectively.[5,6] Therefore, people are more dependent on cortical information in task performance following ligamentous injury.[5,6] An fMRI study revealed that during knee extension, patients with ACL deficiency showed increased activity in movement planning, sensory areas, and visual processing compared to healthy subjects.[7] These findings did not improve even after ACL reconstruction surgery, rehabilitation, and return to activity.[8] It has been demonstrated that ACL injuries lead to deficits in cognitive processes, including reaction time, processing speed, and visual and verbal memory, which may decrease neuromuscular control of the knee.[9]

To evaluate the attentional needs of postural control and the effect of higher cognitive control levels on postural control, the dual-task model is used, in which the postural task is performed simultaneously with a cognitive task.[10] In several studies, the effects of cognitive tasks on the postural control of deficient ACL or ACL-reconstructed subjects have been investigated, the results of which have shown that either the postural task or the cognitive tasks have been disturbed.[10-12] If a person with this disorder engages in sports activities or even daily activities (where most of the time, several tasks are performed at the same time), the possibility of re-injury or the risk of primary ligament injury increases and the quality of performing tasks is affected.[11]

Therefore, it seems reasonable that these people should be trained in dual-task conditions. In recent decades, several studies have shown the positive effects of cognitive dual-task exercises on postural control in different groups of patients with postural control disorders, such as people with Parkinson's disease, balance impairment, and older adults.[13-16] However, according to our search, these exercises have not been performed in patients after ACL reconstruction.

Consequently, the primary aim of this study was to compare the effect of cognitive dual-task balance exercises and single-task balance exercises on static balance among people with ACL reconstruction. This research also aimed to find out any differences between functional disabilities affected by the type of exercise. We hypothesized that by performing cognitive dual-task balance exercises, center of pressure (COP) variables will be significantly changed compared to single-task balance exercises.

Materials and Methods

Study Design and Participants

A randomized controlled trial was registered in the Iranian Registry of Clinical Trials (IRCT20180925041138N1). This study was conducted to evaluate the effect of cognitive dual-task and single-task balance exercises on static balance parameters of individuals with ACL reconstruction. This research was approved by the Ethics Committee of Tabriz University of Medical Sciences (IR.TBZMED.REC.1397.865).

Based on a pilot study, the total sample size of the study was calculated to be 26 people with a power of 0.80. Therefore, 50 subjects undergoing ACL reconstruction surgery with hamstring tendon autograft were referred to the Faculty of Rehabilitation Clinic of Tabriz University of Medical Sciences by an orthopedic surgeon. The subjects were selected using a non-probability convenience sampling method from February to November 2020. After the inclusion criteria assessed by a physiotherapist were met following conventional physiotherapy, the participants filled out an informed consent form and entered the study. The inclusion criteria were 1) Age range between 18 and 45 years; 2) Unilateral ACL reconstruction using hamstring tendon graft; 3) Active knee range of 120 degrees; and 4) The ability to bear full weight on the operated leg. The exclusion criteria were 1) A history of neurological, vestibular, and vision disorders as well as other complications affecting balance; 2) A history of other surgeries and spinal injury; 3) Other simultaneous ligament injuries of the knee; and 4) A pain score of > 3 on the numerical pain scale during tests. Twenty-eight eligible subjects were randomly divided into two groups (n=14 in each group) of dual and single-task by an allocator in a random allocation software using the block randomization method [Figure 1]. Block sizes were four and six; nevertheless, the allocator had hidden the randomly used block sizes from the assessor. Therefore, the allocation was kept concealed. The assessor and analyzer were blinded to grouping, while due to the nature of the exercise-based intervention, neither the participants nor the trainer physiotherapist were blinded. Demographic characteristics of individuals in groups and descriptive statistics of groups are described in [Tables 1 and 2].

Conventional Physiotherapy

Prior to starting the main part of the study intervention, all participants had received the conventional post-surgery rehabilitation program based on reliable references of physiotherapy. The program included electrical stimulation, cold therapy, and exercise therapy.[17-19] In the electrical stimulation, high transcutaneous electrical nerve stimulation current with a frequency of 120 Hz and a wavelength of 60 µs for 15 min was used to reduce knee pain, and functional electrical stimulation current with a frequency of 55 Hz, wavelength of 300 µs, duration of current hold time of 4 s, and a rest time of 8 s were used for 15 min to stimulate the quadriceps muscle. To reduce knee joint inflammation, cold packs were used for 10 min on the knee. The exercise therapy included muscle stretching, exercises planned to increase the range of motion of knee flexion and extension, and strengthening of hamstring, quadriceps, and gluteal muscles progressively. The participants were asked to repeat the cold therapy and all exercises at home twice a day.

After the participants acquired the ability to bear the weight on the operated leg without giving up due to pain and could flex the knee 120 degrees actively, a static balance test was done using an FDM pressure platform, and the Persian version of Knee Injury and Osteoarthritis Outcome Score (KOOS) was filled out. Then participants were allocated to groups.

Static Balance Test

Before and after the balance exercises, the static balance of the subjects was evaluated by a foot pressure tool (zebris FDM pressure platform, Germany). This tool records the coordinates (X, Y) of the COP of a subject with a sampling rate of 100.

At first, participants were given full descriptions of how to perform the tests. Each of the participants was asked to stand barefoot on the operated leg on the plate of the FDM pressure platform. The knee of the weight-bearing leg was bent 20 degrees (the stability of the knee is provided by the neuromuscular system and passive joint factors do not have much effect on its stability). Meanwhile, the knee and hip joint of the non-weight-bearing leg were 90 and 45 degrees flexion, respectively, with hands crossed on the chest. The participants were asked to keep their balance for 20 s while looking at a point marked at a distance of 1.4 m on the opposite wall at the level of their eyes. The test was repeated three times for each participant. One-minute rest time was given between the three trials of the test to avoid fatigue. If the participants were unable to maintain their balance, the test was repeated. Finally, the average of the three trials was reported.

All participants completed the Persian KOOS questionnaire before and after the balance exercises. This 42-item questionnaire includes five subscales in the following order and weight: symptoms (7 items), pain (9 items), performance in activities of daily living (17 items), performance in sports and recreational activities (5 items), and quality of life (4 items). The scores in the questionnaire are converted onto a scale ranging from 0 to 100 with higher scores indicating less disability.[20] The questionnaire has the necessary cultural adaptation, reliability, and validity to evaluate Iranian patients with knee injuries.[21]

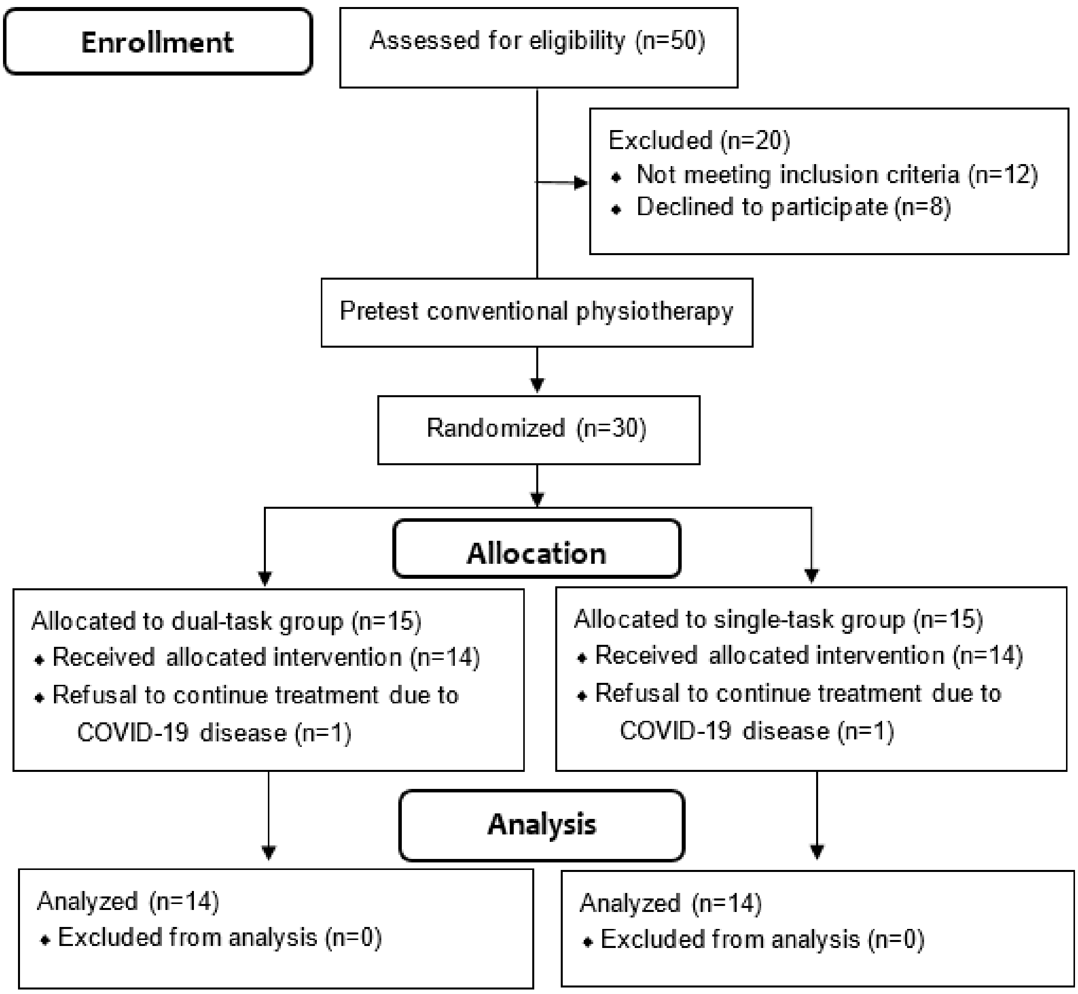

Figure 1. Study flow chart

Table 1. Demographic characteristics of groups

Demographic data (Unite)	Single-task group n=14 Mean (SD)	Dual-task group n=14 Mean (SD)	*P* value
Age (year)	34.2 (6.20)	32.57 (9.30)	0.5
Height (cm)	173.29 (6.21)	174.57 (6.90)	0.6
Weight (kg)	75.06 (8.97)	74.91 (9.33)	0.9
Body Mass Index (kg/m^2)	24.94 (1.95)	24.56 (2.58)	0.6
Injury and surgery interval (Month)	6.5 (8.96)	7.1 (6.53)	0.4

Table 2. Descriptive statistics of groups and baseline comparison

Variable		Single-task group n (%)	Dual-task group n (%)	*P* value
Gender	**Male**	14 (100)	11 (78.6)	0.22
	Female	0 (0)	3 (21.4)	
Involved leg	**Right**	7 (50)	6 (42.9)	0.70
	Left	7 (50)	8 (57.1)	
Dominant leg	**Right**	11 (78.6)	12 (87.7)	1.00
	Left	3 (21.4)	2 (14.3)	
Meniscus condition	**Intact**	5 (35.7)	5 (35.7)	1.00
	Repaired	9 (64.3)	9 (64.3)	

Intervention

Balance exercises were the main part of the intervention. Participants did single-task balance exercises or cognitive dual-task balance exercises according to their allocation in groups. The exercise programs were performed three times a week, for four weeks, each session lasting 20 min. The sessions were conducted for each participant individually under the supervision of a trained physiotherapist with three years of experience in physiotherapy, especially in knee post-surgical physiotherapy.

The following balance exercises were performed according to the ability of the participants in the mentioned order for the single-task group: standing on the operated leg on the ground and a foam with a thickness of 10.5 cm; standing on the two-way balance board without and with a 10.5 cm thick foam in the medial-lateral, anterior-posterior direction and multidirectional balance board on both legs and then on the operated leg. During the exercise sessions, participants were asked to focus and try to keep their balance.

In the dual-task group, the participants were asked to perform the exercises of the single-task group while simultaneously performing cognitive exercises. These cognitive tasks included saying numbers in reverse order with a certain interval, saying the days of the week in reverse and alternative ways, saying names that start with a specific letter, saying names with a certain number of dots, saying names with a certain number of letters, saying the names of cities with a special letter, and spelling some words reversely.

To prevent fatigue, the participants were given a three-minute break in the middle of the exercises. The exercises progressed in the order mentioned, and entering the next exercise mode in the following session was dependent on the patient's condition and abilities.

Data Analysis

The study outcomes included the static balance variables and subscale scores of the KOOS questionnaire, with their responsiveness being already proven and reported.[22,23] A computerized algorithm was developed using MATLAB software to calculate the static balance variables by COP coordinates including mean displacement of COP in anterior-posterior and medial-lateral direction (mm), the total path length of COP (mm), mean velocity of COP (mm/s), root mean square (RMS) of displacement and velocity, and the elliptical area of COP (mm^2) computed from raw data obtained from the FDM platform. Scores of KOOS subscales were calculated separately.

Statistical Analysis

SPSS software version 25 was used for statistical analysis. A significance level of 0.05 was considered significant. Kolmogorov-Smirnov (K-S) test was used to check the normality of data distribution. An independent t-test and a paired t-test were conducted to compare the COP variables and KOOS scores between and within groups, respectively. ANCOVA test was employed to control the basic effect of variables. Pearson's correlation coefficient was used to examine the relationship between the balance indices and the scores of the KOOS questionnaire.

Results

Subject Characteristics

Among all the patients who referred to the clinic, 12 did not meet the inclusion criteria and 8 were unwilling to participate in the study due to personal problems. Moreover, two subjects were excluded from the study due to COVID-19 disease, and finally, 28 individuals participated in the study [Figure 1]. The results of the K-S test showed that all characteristic variables had a normal distribution. There was no statistically significant difference in the demographic information of the participants between the two groups. The results of the independent t-test for age, height, weight, body mass index, and distance between injury and surgery [Table 1] and the Chi-square test for gender, involved leg, dominant leg, and meniscus status [Table 2] exhibited no significant difference between the two groups before the balance exercises intervention (P>0.05). The ranges of pre-injury physical activity level (Tegner Activity Scale) were 3-8 and 3-9 for the dual-task and the single-task groups, respectively. However, the median for both groups was 5.

Balance Assessment

Few COP variables in groups did not have a normal distribution. Outlier data in these variables were identified and corrected using the mean ± 3 standard deviation method. Then, it was determined if the variables had a normal distribution. Within-group analysis showed that both types of interventions had a significant effect in reducing the value of all variables related to static balance. The results of the paired t-test for all variables of static balance were significant in both groups (P<0.05) [Table 3]. For between-group analysis, after the interventions, the results of the ANCOVA test showed no significant difference in COP parameters between the two groups (P>0.05) [Table 3].

Table 3. Comparison between the cognitive dual-task and single-task balance exercises within and between groups

Variable (Unite)	Single-task			Cognitive dual-task			ANCOVA (between groups)
	Before intervention Mean (SD)	After intervention Mean (SD)	*P* value	Before intervention Mean (SD)	After intervention Mean (SD)	*P* value	
Mean displacement of COP (mm)	0.36 (0.05)	0.30 (0.05)	0.00	0.28 (0.03)	0.26 (0.04)	0.00	0.35
Mean displacement of COP in AP (mm)	0.23 (0.04)	0.19 (0.03)	0.00	0.18 (0.02)	0.17 (0.03)	0.01	0.37
Mean displacement of COP in ML (mm)	0.23 (0.02)	0.19 (0.03)	0.00	0.18 (0.01)	0.15 (0.03)	0.00	0.80
Total path length of COP (mm)	716.96 (101.13)	593.68 (107.47)	0.00	554.33 (66.25)	503.59 (87.50)	0.00	0.35
COP velocity (mm/s)	35.84 (5.05)	29.65 (5.31)	0.00	27.71 (3.31)	25.17 (4.37)	0.00	0.35
RMS of COP displacement	0.47 (0.06)	0.38 (0.07)	0.00	0.36 (0.04)	0.32 (0.05)	0.00	0.34
RMS of COP velocity	46.29 (6.61)	37.90 (7.00)	0.00	35.33 (4.13)	31.94 (5.52)	0.00	0.33
Elliptical area of COP (mm^2)	227.77 (59.79)	149.32 (39.69)	0.00	164.55 (34.85)	137.42 (40.20)	0.00	0.66

SD: Standard deviation, COP: Center of pressure, AP: Anterior-posterior direction, ML: Medial-lateral direction, RMS: Root mean square

Functional Disability

In both groups, the scores of the KOOS increased significantly (P<0.05) in all subscales of the questionnaire [Table 4]. However, there was no statistically significant difference in any of the questionnaire subscale scores between the two groups (P>0.05) [Table 4].

The results of correlation analysis showed that there was only a statistically significant relationship between the symptoms and the sports activity subscale of the KOOS in the dual-task and the single-task group respectively with the mean displacement of the COP in the anterior-posterior direction (r=0.59, P=0.02).

Discussion

The main purpose of this study was to compare the effect of cognitive dual-task and single-task exercises on static balance among individuals with ACL reconstruction surgery. The results of this study showed that both interventions could significantly improve balance in these people. However, after the interventions, there was no significant difference between the two groups in the effects of the two types of exercises on static balance.

Performing balance exercises on the balance board may improve pre-programmed movement patterns.[24] Standing on a balance board in different directions leads to reinforced and taught movement patterns that are activated in that direction.[24] In addition, exercises on a balance board have led to the strengthening of balance feedback control by increasing proprioceptive inputs.[24]

Table 4. Comparison KOOS subscales within and between groups

Variable	Single-task			Cognitive dual-task			*P* value Between groups after intervention
	Before intervention Mean (SD)	After intervention Mean (SD)	*P* value	Before intervention Mean (SD)	After intervention Mean (SD)	*P* value	
Symptoms	57.29 (17.26)	69.07 (17.09)	0.01	70.57 (13.56)	79.79 (11.30)	0.04	0.06
Pain	60.36 (16.73)	71.43 (18.71)	0.04	63.71 (14.66)	80.36 (13.21)	0.00	0.15
Performance in ADLs	66.14 (16.38)	80.86 (12.46)	0.00	68.50 (15.46)	86.29 (11.05)	0.00	0.23
Performance in sports	14.64 (13.22)	43.57 (19.05)	0.00	12.14 (14.23)	30.36 (24.61)	0.03	0.12
Quality of life	64.28 (19.24)	37.07 (17.26)	0.00	28.21 (16.15)	45.21 (20.72)	0.00	0.26

KOOS: Knee Injury and Osteoarthritis Outcome Score, SD: Standard Deviation, ADLs: Activities of daily living

In our study, the decreased displacement and speed of COP indicate an increase in the ability of the body to stand upright with less sway, meaning that the COP reaches a stable position with less circulation and lower postural oscillation speed. In other words, the ability of the postural control system to maintain balance has increased. The RMS of COP displacement and speed are sensitive to changes in proprioception.[25] A decrease in the elliptical area of COP also shows that balance training has improved neuromuscular and sensorimotor performance and the body has been able to limit postural sway to a smaller area. It is generally accepted that smaller areas lead to better postural control, whereas larger areas result in greater deviations in the COP and poorer postural balance.[26] In a study conducted by Thompson et al.[27], a decrease in displacement and speed of COP was considered an improvement in balance, and a reduction in COP speed was indicated as the ability of athletes to predict body position changes compared to non-athletes.

Based on our study results, there was no difference between single and cognitive dual-task exercises in the improvement of static balance. One of the reasons for this finding may be related to the method of performing evaluations. In this study, only static balance and single-task situations were investigated. It is possible that in more challenging conditions, the differences would be significant. In a study by Grueva-Pancheva and Stambolieva[28], differences between the two groups were observed in standing on an unstable surface with eyes closed. Our results might have been different if we had tested the participants in dual-task conditions because they had been trained in dual-task conditions. In a study carried out by Onegh et al.[29], no difference was observed between single and dual-task exercises for improving the balance of people with ankle instability. They stated that the exercises were performed dynamically and with a cognitive task, while the evaluations were done statically without a cognitive task. Konak et al.[30], in a study on people with osteoporosis, did not observe a difference in static balance measurements between the two groups; however, they found that the participants in the dual-task group experienced greater improvements in both the Berg Balance Scale scores and walking speed compared to those in the single-task group. They concluded that the differences between the groups were related to dynamic balance evaluations.

According to cognitive task difficulty theory, more challenging cognitive tasks would result in greater improvement in motor performance in dual-task conditions.[31] In our study, the cognitive tasks in the dual-task group might have not been challenging enough for the neural pathways and did not affect the balance of our young participants. In some studies conducted on elderly groups and neurological patients, cognitive dual-task exercises have been more effective than single-task exercises for improving balance and walking.[32] Our study population had high cognitive and functional levels of performance and they could switch their attention from balance task to cognitive task and vice versa effortlessly.

Based on the findings of this study, both cognitive dual-task and single-task balance exercises caused an increase in the scores of the KOOS. Higher scores in the questionnaire indicate a better functional status and less disability.[33] Therefore, both types of exercises led to the improvement of the functional level of ACL reconstructed individuals. However, there was no statistically significant difference between the two groups after the interventions, which showed cognitive dual-task balance exercises at the functional level measured with the KOOS questionnaire are not preferable to single-task balance exercises in ACL reconstructed individuals.

Based on the findings of this study, the observed relationships had a significant moderate correlation only between the symptoms and the sports activity subscale of the KOOS in the dual-task and the single-task groups, respectively, with the mean displacement of the COP in the anterior-posterior direction. It can be said that in general, there was no significant relationship between the variables of static balance and the subscales of the questionnaire. Similar to our findings, there was no correlation between the postural stability variables and the KOOS subscale in a study by Wang et al.[34] It may be concluded that the KOOS subscales and static balance variables evaluate different aspects of a person's performance and ability level.

The main limitations of this study were the withdrawal of participants and the low sample size due to the COVID-19 pandemic, the lack of more treatment sessions and follow-up, and the absence of assessment in dual-task conditions, more dynamic and challenging balance, or cognitive tasks. Since our participants reached a functional level as healthy people during 12 sessions, they were unwilling to continue further. Moreover, according to the pilot phase, participants were not able to maintain their balance in a more dynamic and challenging way and they could not even stand with their eyes closed.

Conclusion

Both cognitive dual-task and single-task balance exercises improve static balance indicators and the level of knee functional disability. However, there were no significant differences between the two types of balance exercises in improving static balance and knee functional disability levels in ACL reconstructed individuals. It seems that there is no superiority of cognitive dual-task conditions over single-task conditions in terms of balance exercise in the rehabilitation of ACL-reconstructed individuals. Evaluation of other aspects and states of static balance or dynamic balance requires further research studies.

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