Research Article

Effects of Exergame Training on Functional Activities Among Newly-Fitted Patients with Unilateral Transtibial Amputation: A Preliminary Study

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Abstract

Objective: This preliminary study investigated the effects of adding exergame training to conventional exercises on the functional activities of newly fitted patients with unilateral transtibial amputation.

Patients & Methods: A total of 22 newly fitted patients with unilateral transtibial amputation were equally and randomly divided into two groups: Exergame (EG), those performing exercises and exergame training; and Control (C), those performing exercise only. The 2-Min Walk test (2MWT), Timed Up and Go (TUG) test, Amputee Mobility Predictor with Prosthesis Test (AMPPRO), and Physiological Cost Index were assessed at baseline and after 2 and 4 weeks of the intervention.

Results: Both interventions effectively improved the 2MWT distance, TUG test time, and AMPPRO score in patients with newly fitted transtibial amputation ($P < 0.001$). Additionally, a significant improvement in the TUG test time in the EG versus C group after the 4-week intervention ($P = 0.04$, effect size: 0.53).

Conclusion: The findings of this preliminary study further support that adding exergames to exercises significantly increases movement speed among amputee patients.

Keywords: Transtibial amputation; Exergame training; Virtual reality; Lower limb amputees

Introduction

The prevalence of amputation in Europe is 17–30 cases per 100,000 populations; however, data are lacking for monitoring and comparison at the international level [1]. The number of Americans with amputation is expected to increase from 1.6 million to 3.6 million by 2050 [2]. Furthermore, an estimated 57.7 million individuals worldwide live with amputation due to traumatic causes, with a particularly high prevalence of amputation in children in the Middle East, South Asia, East Asia, and North Africa [3]. The Iraqi Ministry of Environment reported that the number of victims affected by landmines and war remnants in the south of Iraq totaled 34,077 injured individuals (30,201 male, 3,876 female), many of whom required amputation [4]. In 2020, the World Health Organization stated that more than 5 million Iraqis suffered greatly as a result of the conflict in the country for the past 5 years, with up to 500,000 citizens having suffered injuries of some kind and thousands losing limbs [5]. Many problems may occur after amputation, including psychological difficulties, depression, anxiety, and an increased risk of falling, especially in the acute phase following amputation [6]. A reported 54.4% of patients recorded falling in the past year, while 49.2% had a fear of falling, which is common among amputee patients [7].

In other words, people with lower-limb amputation face difficulty maintaining their balance when walking on uneven ground, which may affect their mobility and participation in daily activities [8]. Maintaining postural stability and balance is a fundamental requirement for functional mobility [9, 10]. During dynamic tasks such as walking, sufficient joint torque must be generated by the leg muscles, movement must be maintained within the center of mass, and the body weight must be actively shifted between the limbs [11]. Therefore, reducing the reliance on ambulatory aids and improving gait characteristics and functional activity in patients with amputation is now the main goal of rehabilitation interventions, including muscle strengthening, functional exercises, gait training, endurance training, and balance exercises [12-15].

Recently, virtual reality–based rehabilitation treatment programs have been introduced as advanced training tools to improve postural control, coordination, balance, and energy expenditure for a variety of patients, including those with spinal cord injury [16], Parkinson’s disease [17], and Down syndrome [18]. Exergames, active video games, and virtual reality training have all been extensively tested for their ability to enhance physical activity [19]. Exergames are defined as "computer games that are driven by gross physical movements of the player, combining real-time motion detection with engaging video games that can help motivate people to exercise" [17]. The XBOX Kinect (released in late 2010) was the first commercial gaming system that involved free movement without the need for a balance board and handheld controller [20].

Ditchburn and Ciobanu (2021) systematically reviewed the effects of exergames in patients with lower-limb amputation. That study concluded that exergames improve physical activity, balance, cognition, emotional state, quality of life, and pain in patients with lower-limb amputation. However, the authors recommended further studies to determine the effects of exergames on people with amputation [21].

In a recent randomized controlled trial, Abbas et al. (2021) investigated the effects of the addition of virtual reality training to traditional exercise programs on balance and gait in patients with traumatic, previously fit, and unilateral transtibial amputation. In this study, the virtual reality training group showed significantly superior effects on balance, Timed Up and Go (TUG) test time, and Dynamic Gait Index. The authors thus concluded that exergames are a safe and effective intervention for improving balance and gait in unilateral previously fit traumatic lower-limb amputees [22]. However, it should be noted that this study included experienced prosthetic users who may be accustomed to their

disability and would experience different issues from those of newly fitted amputees. Volume changes, stump sweating, weight shifting, phantom pain, fear of falling, skin breakdown, patient compliance, and muscle weakness are all main issues that predominantly affect walking capacity in newly fitted patients [14, 23-25].
In addition, Exergame has recently developed and demonstrated its efficacy in improving several functional parameters in a variety of therapeutic contexts, including neurological and musculoskeletal illnesses, as well as over age ranges. However, its usefulness in improving functional parameters in lower limb amputees, particularly in newly fitted patients with transtibial amputation, has received little attention.
To the best of our knowledge, research regarding the use of virtual reality or exergames to improve the balance and postural control of patients with lower-limb amputation, especially newly fitted patients, is limited [21]. Therefore, the present study was designed to investigate the effects of adding exergames to conventional exercises on balance, postural stability, movement speed, and functional activity among newly fitted patients with unilateral transtibial amputation.

Methods

Study design

This was a single-blinded randomized clinical trial in which the assessor was blinded to the treatment. The XBOX Kinect™ system (Microsoft, Redmond, WA, USA) was used to apply the exergames. The Exergame (EG) group performed exergame plus conventional exercises, whereas the Control (C) group performed only conventional exercises for 4 weeks. Both groups performed the same amount of exercise. For example, in the C group, more time was spent on weight shifting and static balance exercises to ensure that both groups performed the same amount of intensity exercise, and this was applied for the rest of the gait training exercises of weeks 2, 3, and 4. Participants performed the 2-Min Walk Test (2MWT), TUG test, Amputee Mobility Predictor with Prosthesis (AMPPRO) test, and Physiological Cost Index (PCI) at baseline and after 2 and 4 weeks of the rehabilitation intervention in both groups. The study design is summarized in the flowchart in Figure 1.

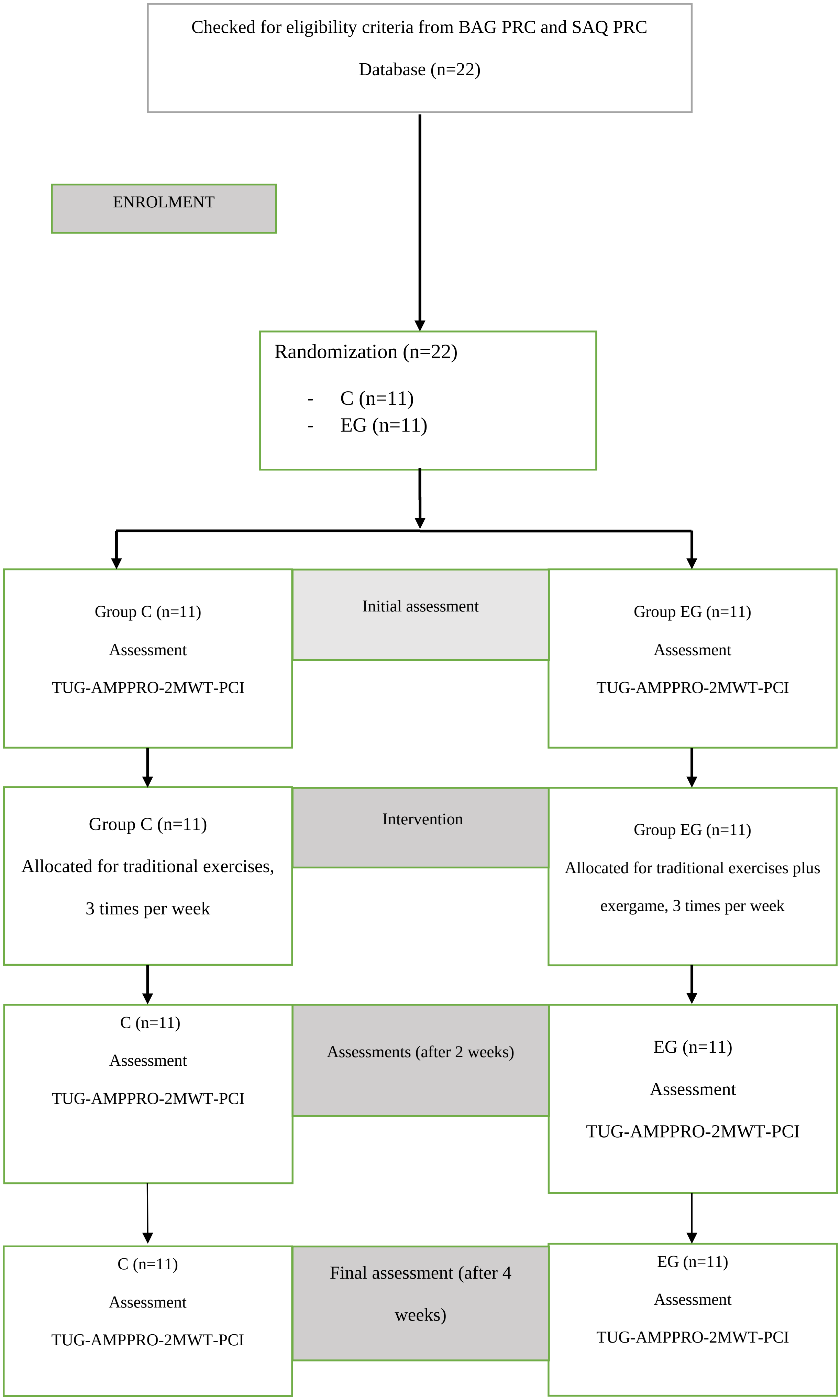
Checked for eligibility criteria from BAG PRC and SAQ PRC Database (n=22)
ENROLMENT
Randomization (n=22)
- C (n=11)
- EG (n=11)
Group C (n=11)
Assessment
TUG-AMPPRO-2MWT-PCI
Initial assessment
Group EG (n=11)
Assessment
TUG-AMPPRO-2MWT-PCI
Group C (n=11)
Allocated for traditional exercises, 3 times per week
Intervention
Group EG (n=11)
Allocated for traditional exercises plus exergame, 3 times per week
C (n=11)
Assessment
TUG-AMPPRO-2MWT-PCI
Assessments (after 2 weeks)
EG (n=11)
Assessment
TUG-AMPPRO-2MWT-PCI
C (n=11)
Assessment
TUG-AMPPRO-2MWT-PCI
Final assessment (after 4 weeks)
EG (n=11)
Assessment
TUG-AMPPRO-2MWT-PCI

Figure 1. Study flow diagram

Participants

The patients were recruited from Baghdad Physical Rehabilitation Center and Sader Al Qanat Physical Rehabilitation Center. The author analyzed the records of the two centers and selected newly fitted patients with transtibial amputation for enrollment. A total of 100 patients were contacted, of whom only 22 met all study requirements and agreed to participate. The study was started in July 2020 and completed in April 2021. Approval was obtained from the ethical committee of the Tehran University of Medical Sciences (no. IR.TUMS.FNM.RCE.1400.120). Written informed consent was obtained from all participants.

The study included newly fitted patients with unilateral transtibial amputation, aged 30–65 years, and who were cognitively able to engage in the program (score >23 on the Arabic version of Modified Mini-Mental Status Exam) [26]. Exclusion criteria comprised any additional medical conditions (e.g., congestive heart failure, neurological disorder) that might limit exercise participation, prosthetic fit issues (e.g., pain and discomfort) indicated by a score < 6 on the Prosthetic Socket Fit Comfort Scale [27], or an inability to adhere to the 4-week intervention as explained before participation.

Grouping

Before randomization, a trained and experienced research assistant, blinded to the intervention type, assessed all participants, who were then randomly assigned to either the Exergame (EG) or Control (C) groups. Randomization involved the participants selecting a card at random from a container containing 22 cards, with "1" indicating placement in the EG group and "2" in the C group. The exercise program, aligned with the manual reference by the International Committee of the Red Cross [28], consisted of three sessions per week for 4 weeks. Both groups performed the same exercises, and the EG group additionally engaged in a 30-minute exergame protocol featuring six games from Kinect™ Adventures™ (Reflex Ridge and River Rush) and Kinect Sports™ (Boxing), as per a previous study [20] (Figure 2). To equalize intervention time, extra sets and repetitions of gait training exercises were added to the C group. Both groups were instructed to perform home strengthening exercises three times per week following the manual developed by Gailey and Ann [29].

Figure 2. A patient playing a Boxing game

Each exercise was administered in 3 sets of 10 repetitions, three times per week (3×10), during the first week. Each repetition lasted for 10 seconds with a 5-second rest between repetitions. Subsequently, the number of repetitions gradually increased starting from the second week. In the second week, the exercises were performed in 3 sets of 12 repetitions (3×12), and for the third week, they consisted of 3 sets of 15 repetitions. In the fourth week, the exercises were completed with 3 sets of 18 repetitions.

Outcome measures

The 2-Minute Walk Test (2MWT) was utilized to measure the distance participants could walk in 2 minutes, assessing physical function in patients with transtibial amputation and considered sensitive to changes after rehabilitation [30]. The test was conducted on a 50-foot-long obstacle-free walking path. A measuring wheel, held by the physiotherapist walking behind the patient, accurately measured the distance covered during the test. The patient walked for 2 minutes, and the distance was automatically calculated by the wheel. The test–retest reliability of the assistive device has been documented [31, 32].

The speed of mobility was evaluated using the Timed Up and Go (TUG) test, a valid and reliable assessment for patients with transtibial amputation [33]. The test utilized a measuring tape, a chair with armrest, tape for marking the ground, and a stopwatch. A 3-meter (or 9 feet, 10 inches) walkway was measured with the chair placed at one end as the starting point, and a piece of tape (or a cone) at the other end served as the marker. The patient, seated with their back against the backrest, received instructions to stand up and walk to the marker upon hearing "go," turn around at the marker, return to the chair, and sit. The time taken to complete the test was recorded, with the stopwatch initiated at

the word "Go" and stopped when the patient was seated. The use of an assistive device was permitted and consistently documented at each assessment. One practice trial was allowed before the timed performance [34, 35].
The Amputee Mobility Predictor with Prosthesis (AMPPRO) test was employed to gauge the functional activities of the patients. This test, known for its high test–retest reliability and internal consistency in patients with unilateral lower-limb amputation [36], is endorsed as one of the recommended outcome measure tools by the British Association of Chartered Physiotherapists for use in the rehabilitation of amputees [37].
The Physiological Cost Index (PCI) was utilized to measure heart rate and reliably assess changes in energy expenditure during walking among individuals with disabilities [38, 39]. The PCI was calculated using the formula: PCI (beats/m) = [mean heart rate at work (beats/min) – mean heart rate at rest (beats/min]) / speed (m/min) [40]. As the distance for this test is not standardized, we opted for the distance walked in 2 minutes [38, 41, 42]. During the PCI test, a Polar™ Heart Rate Monitor™ with a chest strap (POLAR, China) was employed as a valid and accurate measurement tool to monitor heart rate [43].
All assessments were conducted at baseline and after 2 and 4 weeks of the intervention. To minimize the impact of fatigue, measurements were taken before the treatment sessions.

Treatment intervention

Control © group

Participants in the Control (C) group were instructed to engage in home strengthening exercises targeting global muscles, trunk, and lower limbs, as outlined in the manual developed by Gailey and Ann [29]. A skilled physiotherapist, with clinical experience working with amputee patients, provided practical demonstrations of all exercises. Following the demonstrations, participants were given the exercise manual, which included videos illustrating the correct execution of each exercise. Additionally, under the supervision of an experienced physiotherapist, participants performed gait training exercises (refer to Table 1). To maintain consistency in intervention duration between groups, the exercises were practiced for 1 hour [28].

Table 1. Gait training exercises

First week	**Second week**	**Third and fourth week**
1. Weight shifting exercises	1. Walking over obstacles	1. Walking on a line with speed and closed eyes
2. Moving the ball under the sound leg	2. Walking in a line	2. Balance Exercises while doing exercise for sound leg
3. Stool stepping exercises	3. Walking Backwards	3. Balance on an Unstable surface with both legs.
4. Gait training	4. Balance Exercise while doing exercises for sound leg (using a TheraBand)	4. Walking up and down stairs

5. walking laterally 6. balance exercise on one foot		

Exergame (EG) group

Participants in the Exergame (EG) group followed the same exercise protocol as the Control (C) group, with the exception that gait training exercises were performed for a duration of 30 minutes. Additionally, participants engaged in exergames using XBOX Kinect (Microsoft). The system included a Kinect sensor (Kinect head: rectangular part, 110 mm W × 25 mm D × 15 mm H) and a base (30 mm W × 30 mm D × 15 mm H), eliminating the need for a handheld controller. The Kinect 360 relied on infrared sensors to detect body movements in the gaming environment. Games were displayed on a wide plasma screen (37" wall-mounted 720-p resolution LED; LG, South Korea). Participants played six games from Kinect™ Adventures (Reflex Ridge and River Rush) and Kinect Sports™ (boxing) for a duration of 30 minutes [20]. Both exergame and gait training exercises were completed on the same day for each participant in the EG group.

Statistical analysis

All statistical analyses were conducted using SPSS version 26.0 (SPSS Inc., Chicago, IL, USA). A prior power analysis was performed to calculate the sample size. Normal data distribution was ensured through Shapiro-Wilk and Kolmogorov–Smirnov tests. An independent t-test was employed to compare the improvement in outcome measures between the Exergame and Control groups. Additionally, the one-way repeated measures analysis of variance was utilized to compare the mean 2-Minute Walk Test (2MWT), Timed Up and Go (TUG) test, Amputee Mobility Predictor with Prosthesis (AMPPRO) test, and Physiological Cost Index (PCI) between groups at the three defined time points (i.e., before and after 2 and 4 weeks of the intervention). In the event of statistically significant results, the Bonferroni post hoc test was applied to identify variables that were significantly different across various time frames. The level of significance was set at $p < 0.05$.

Results

Twenty-two participants (n=11 per group) were enrolled from Baghdad Physical Rehabilitation Center and Sader Al Qanat Physical Rehabilitation Center and participated in the study. Only male participants who completed the intervention protocol were included in this study. No adverse events occurred during the study. Table 2 presents the baseline characteristics of the study participants. At baseline, no significant differences were observed between the Control and Exergame groups, except in the Timed Up and Go (TUG) test time (P = 0.04) (Table 2).

Table 2. Basic demographic and clinical characteristic of participants

Variable	**Control group (n=11)**	**Exergame group (n=11)**	**P value**
Age (years)	48.73±14.24	48.91±11.02	.974
2MWT (meter)	76.48±35.30	106.27±50.06	.123

TUG (seconds)	32.15±17.04	16.02±8.21	.010
AMPPRO (Range 0-47 points)	35±7.43	30.36±7.24	.154
PCI (beats/minute)	1.15±1.23	.79±.49	.384

Abbreviations: 2MWT, Two Minutes Walking test; TUG, Time Up and Go test; AMPPRO, Amputee Mobility Predictor with Prosthesis; PCI, Physiological Cost Index.

Regarding the cause of amputations, traumatic causes were the most common, constituting 45.5% in the Control group and 63.6% in the Exergame group. The second most common cause was Diabetic Mellitus (DM), representing 45.5% in the Control group and 9.1% in the Exergame group. Vascular and infectious causes of amputation were 27.3% and 9.1%, respectively.

Within each group, the 2-Minute Walk Test (2MWT) measured in meters, Timed Up and Go (TUG) test time in seconds, and Amputee Mobility Predictor with Prosthesis (AMPPRO) scores significantly improved after the intervention in both the Control (C) and Exergame (EG) groups (refer to Table 3). However, the Physiological Cost Index (PCI) in beats per meter did not show significant improvement in either group (P = 0.37) (Table 3).

Pairwise comparisons of the first (baseline), second (after 2 weeks), and third (after 4 weeks) assessments of the 2MWT, TUG, and AMPPRO were conducted using Bonferroni post hoc analysis (refer to Table 4). The results indicated significant differences between each two assessment stages after the intervention in both groups ($p<0.05$).

Table 3. Comparison of the Variables Before, after 2, and 4 Weeks of Intervention in Exergame (n=11) and Control (n=11) Groups Using One-way Repeated Measures ANOVA.

Exergame group (n=11)					Control group (n=11)			
	baseline	After 2 weeks	After 4 weeks	P-value	baseline	After 2 weeks	After 4 weeks	P-value
2MWT (meter)	106.27 (50.06)	138.58 (35.83)	158.59 (33.11)	<0.001	76.48 (35.3)	92.78 (51.08)	116.41 (43.82)	<0.001
TUG (seconds)	16.44 (8.53)	9.54 (2.66)	8.06 (1.91)	<0.001	32.15 (17.04)	19.87 (14.76)	15.61 (11.82)	<0.001
AMPPRO (Range 0-47 points)	35 (7.43)	41.55 (3.67)	43.45 (2.25)	<0.001	30.36 (7.24)	37.09 (5.16)	40.18 (4.89)	<0.001
PCI (beats/minute)	.79 (.49)	1.18 (.84)	.86 (0.69)	.15	1.15 (1.23)	1.63 (1.09)	1.62 (1.22)	.25

Abbreviations: 2MWT, 2-minute walk test; TUG, Timed Up and Go test; AMPPRO, Amputee Mobility Predictor with Prosthesis test; PCI, Physiological Cost Index test. Values are Mean (SD)

Table 4. *Pairwise Comparison of Mean Variables at Baseline, After Two Weeks, and After Four Weeks Using Bonferroni Test*

	Exergame group (n=11)					Control group (n=11)		
Variables	Time*		Mean difference	95% CI for difference	P-value	Mean difference	95% CI for difference	P-value
2MWT (meter)	1	3	52.32	(27.66-76.97)	<0.001	39.92	(23.22-56.63)	<0.001
	1	2	28.31	(7.24-49.38)	0.01	16.29	(6.39-38.98)	0.019
	2	3	24	(15.64-32.37)	<0.001	23.63	(1.92-45.33)	0.032
TUG (seconds)	1	3	7.95	(1.83-14.08)	0.01	16.54	(6.84-26.23)	0.002
	1	2	6.48	(0.29-12.67)	0.04	12.28	(4.34-20.21)	0.004
	2	3	1.47	(0.26-2.68)	0.01	4.26	(0.55-7.96)	0.024
AMPPRO (Range 0-47 points)	1	3	8.45	(3.55-13.35)	0.002	9.81	(6.67-12.95)	<0.001
	1	2	6.54	(2.92-10.16)	0.001	6.72	(4.43-9.02)	<0.001
	2	3	1.9	(0.15-3.65)	0.032	3.09	(1.72-4.45)	<0.001

*Time 1, 2, and 3 are the baseline, after 2 and 4 weeks of the intervention.
Abbreviations: 2MWT, 2-minute walk test; TUG, Timed Up and Go test; AMPPRO, Amputee Mobility Predictor with Prosthesis test; PCI, Physiological Cost Index test.

The outcomes of this preliminary study affirm that the Timed Up and Go (TUG) test time exhibited significant improvement in the Exergame (EG) group compared to the Control (C) group (P = 0.04; power = 0.53) (refer to Table 5). Specifically, the utilization of exergames alongside conventional exercises resulted in a notable enhancement in TUG test performance after the 4-week intervention. However, there were no significant improvements observed in the 2-Minute Walk Test (2MWT), Amputee Mobility Predictor with Prosthesis (AMPPRO), or Physiological Cost Index (PCI) results.

Table 5. *Comparison of Improvement of Variables After Four Weeks of Intervention Compared to Baseline Between Exergame (n=11) and Control (n=11) Groups Using Independent t-test.*

Improvement after 4 weeks	t	df	P value	Mean difference	Confidence %95 Interval of the Difference		Power
					Lower	Upper	
2MWT (meter)	1.19	20	.24	12.39	9.24	34.03	0.20
TUG (seconds)	2.14	20	.04*	8.58	16.91	249	0.53
AMPPRO (Range 0-47 points)	.67	20	.50	1.36	5.59	2.86	0.09
PCI (beats/minute)	.90	15.95	.37	.40	.53	1.33	0.13

Abbreviations: EG, Exergame group; C, Control group; 2MWT, 2-minute walk test; TUG, Timed Up and Go test; AMPPRO, Amputee Mobility Predictor with Prosthesis test; PCI, Physiological Cost Index test.

Discussion

This study aimed to clarify the effects of adding exergames to the conventional exercise program for newly fitted patients with transtibial amputation on gait, balance, speed of movement, and functional activity using the 2MWT, TUG, AMPPRO, and PCI outcome measures. Of the 100 patients identified, only 22 fulfilled the requirements of the study and agreed to participate.

Overall, 59% of participants had right-side amputations, while 41% had left-side amputations. This study exclusively included first-time users who had not undergone any post-fitting rehabilitation. Additionally, 55% of participants experienced amputation due to traumatic incidents, particularly explosions related to conflict, while the remaining cases were attributed to car accidents. These findings align with Esquenazi's study in 2004, which noted that in countries with recent histories of war or civil conflict, traumatic incidents may constitute up to 80% of all amputations [39]. Notably, diabetes mellitus was identified as a risk factor for amputation in 27% of participants [40].

The findings of the current study demonstrate that the conventional exercise protocol led to improvements in the 2MWT, TUG test, and AMPPRO outcome measures. Notably, the supplementation of exergames to the conventional exercise protocol resulted in a significant enhancement in the speed of movement, as evidenced by the reduction in TUG test time. The TUG test serves as an assessment tool for changes in walking speed, encompassing various gait components such as speed, balance, risk of falling, and functional mobility across diverse patient populations, including amputees. Through intergroup comparison, it was determined that exergames induced a noteworthy improvement in TUG test time compared to the Control group. Consequently, the speed and balance of newly fitted patients with transtibial amputation exhibited significant improvement in the Exergame group.

The results of the present study agree with those of Abbas et al., who added virtual reality training to conventional physiotherapy (three sessions per week for 6 weeks) for previously fit (at least 6 months prior) patients after traumatic transtibial amputation [22]. Abbas et al. reported that the TUG test time was significantly improved in the virtual reality training versus control group of patients with transtibial amputation.

However, it should be noted that the present study included only newly fitted patients with transtibial amputation who did not have a long-duration post-fitting rehabilitation program. Although the recruited patients in the study by Abbas et al. completed the program at least 12 months before study enrollment, the authors claimed that gait and balance deficiencies were long-lasting problems and still present among their participants.

While previous investigations have struggled to pinpoint the precise timeframe required for an amputee to acclimate to a new prosthesis, particularly in the context of biomechanical testing, Zhang et al. (2019) underscored the unreliability of assessing prosthetic interventions for less than 1 hour among transtibial amputee patients [44]. Hence, in the current study, the initial assessments of newly fitted amputees were conducted 1 day after receiving the new prosthesis.

Furthermore, it is noteworthy that our participants utilized ambulatory aids, such as crutches and walkers, particularly in the initial sessions of both the exergame and exercise protocols, as maintaining balance without assistance was challenging during these interventions. Although participants in both groups initiated the interventions with the aid of walkers or crutches, a majority progressed to performing the activities independently after the initial sessions. The outcomes of the present study align with a prior investigation, which highlighted that physiotherapy interventions encompassing muscle strengthening, endurance training, and balance exercises contribute to the reduction of reliance on ambulatory aids while enhancing gait characteristics and functional activity in individuals with amputation [45].

The results of the present study indicate that both interventions effectively enhanced balance and mobility among individuals with transtibial amputation. Previous research has demonstrated the positive impact of short intensive training programs on walking speed and distance in amputees with traumatic lower-limb amputation [42]. The ability to maintain balance is significantly compromised following lower-limb amputation, as the stump cannot fully replicate the foot's role as a proprioceptive organ. Consequently, the postural control system undergoes reprogramming, and compensatory mechanisms develop to address challenges such as weight-bearing asymmetry, diminished somatosensation, reduced support, and increased joint stiffness [46]. Geurts and Mulder highlighted that the balance issues in individuals with lower-limb amputation stem significantly from peripheral motor and sensory deficits, including: (1) a lack of active ankle torque generation to restore balance in the sagittal plane; (2) an absence of weight-shifting ability to control posture in the coronal plane; and (3) impaired somatosensory input from the amputated side [47]. Prior evidence underscores the importance of enhancing input on lower-limb prostheses to restore and enhance postural control and functional balance [22].

The Amputee Mobility Predictor (AMP) is a established and valid performance-based outcome measure extensively utilized in individuals with lower-limb amputation, assessing functional mobility both with a prosthesis (AMPPRO) and without (AMPnoPRO) [36]. Existing evidence affirms that individuals with lower-limb amputation often experience compromised functional mobility. Consequently, physiotherapy exercises have been employed to enhance mobility and prosthetic control, as measured by AMPPRO and AMPnoPRO [14]. The AMP demonstrates discriminatory capacity across K-levels, with the K-level system categorizing patients based on their activity into five levels (K0–K4). Notably, K0 represents patients unable to ambulate, while K4 encompasses individuals with the highest activity levels, surpassing basic ambulation skills, including young active people and athletes [48]. In Group C, two participants progressed from K1 to K2, five from K2 to K3, three from K2 to K4, and one from K3 to K4. In the EG group, one participant advanced from K1 to K3, four from K3 to K4, one from K2 to K4, four from K3 to K4, and one remained at K4 post-intervention. The findings of the present study demonstrate significant improvements in AMPPRO among newly fitted patients who underwent transtibial amputation following both interventions.

The outcomes of the 2MWT consistently improved throughout the intervention protocol, achieving statistically significant enhancement after 4 weeks in both groups ($P \leq 0.001$). This finding aligns with prior studies employing diverse exercise modalities in individuals with lower-limb amputation [14, 15, 22, 42]. Although no significant intergroup difference was observed in the 2MWT, this may be attributed to the test primarily reflecting aerobic capacity and overall fitness level rather than serving as a direct indicator of gait and balance parameters [22]. Nevertheless, it is noteworthy that the mean improvement after 4 weeks was more pronounced in the Exergame group.

The measurement of energy expenditure during walking in patients with lower-limb amputation is a well-established method typically conducted by assessing oxygen consumption, particularly in clinical settings. Previous investigations have affirmed that the utilization of walking aids is associated with a significant increase in energy expenditure and a simultaneous decrease in walking speed [49]. In this study, the Physiological Cost Index (PCI) test was implemented concurrently with the 2MWT, and given that participants were newly introduced to their prostheses, walking aids were employed for safety during the test. This may elucidate the absence of a significant difference in PCI both within and between groups. Additionally, the limited duration of the 4-week program and the initially minimal exercise intensity might contribute to the lack of a significant effect on PCI. Extending the program for a longer duration could potentially unveil significant changes. Another plausible explanation for the non-significant effect on PCI could be that alterations in walking speed alone may be insufficient to impact cardiac rate; hence, exercise intensity may emerge as a crucial factor in eliciting a notable difference in PCI, as suggested by a prior study demonstrating significant changes in the PCI test after 3 days of intensive training in patients with lower-limb amputation [42].

Based on the findings of this study, both interventions, involving exercise alone and the incorporation of exergames with conventional exercises, demonstrated efficacy in enhancing walking distance, speed of movement, and functional activities among newly fitted patients with transtibial amputation. It appears that both interventions have the potential to positively impact the activities of daily living for individuals with transtibial amputation. However, the addition of exergames to conventional physiotherapy exercises notably improved the speed of movement in this patient population.

In conclusion, the existing literature on the effects of virtual reality (VR) in amputee rehabilitation is limited, necessitating more randomized controlled trials (RCTs) with larger participant cohorts and extended rehabilitation sessions. Moreover, it is essential to recognize that exergames may not be suitable for certain patients in the early stages of rehabilitation, as they require dynamic balance in weight-bearing activities to engage in the video games. Additionally, not all video games may be suitable for amputee patients, emphasizing the importance of conducting a pilot study to assess the feasibility of the selected games before embarking on any RCTs

Limitations

The present study has several identified limitations. A notable number of participants relied on support from family members or friends to attend physiotherapy sessions, given their functional limitations and inability to go outside alone. Consequently, some patients were excluded as they could not complete all 12 sessions. The coronavirus disease 2019 crisis further impacted patient attendance due to lockdown measures. Additionally, the study solely included male participants, limiting the generalizability of the findings to female patients. Furthermore, this study is preliminary, characterized by a small sample size. Subsequent investigations with larger participant cohorts, encompassing both genders, are warranted to yield more conclusive results.

Conclusion

Both interventions, involving exercise alone and the integration of exergames with conventional exercises, demonstrated effectiveness in enhancing walking distance, speed of movement, and functional activities, as evaluated through the 2MWT, TUG test, and AMPPRO, among newly fitted patients with transtibial amputation. Notably, a significant improvement in the TUG test results was observed in the group utilizing exergames compared to the exercise-only group after the 4-week intervention. In summary, the addition of exergames to conventional physiotherapy exercises significantly enhanced the movement speed of individuals newly fitted with transtibial amputation.

Ethical Considerations

Compliance with ethical guidelines

The research method was approved by the ethical committee of the Tehran University of medical sciences [NO: IR.TUMS.FNM.RCE.1400.120]. Written consents were obtained from all the patients before joining the study. In addition, the intervention protocol was explained to each patient before signing the consent. The patients were informed that they had allowed to withdraw from the study without any further emotional, physical, and financial harm.

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