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Effectiveness of virtual reality cycling exercise towards the motoric and cardiorespiratory functions of post-stroke patients

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Abstract

Introduction. Virtual reality (VR) cycling exercise was developed as a physical rehabilitation therapy to impair the deficit on motoric function and cardiorespiratory fitness on post-stroke patients with lower extremity disorder. This study aims to determine the effectiveness of VR cycling exercise towards the impairment of lower extremity motoric function and cardiorespiratory fitness on post-stroke patients.

Methods. This study engaged 15 people chosen through a purposive sampling method, who were divided into 8 intervention groups of post-stroke patients without comorbidities (post stroke ≥ 2 years) and 7 healthy people in a control group. The Fugl-Meyer assessment was used to decide the participation of the patients. To assess the lower extremity motoric functions, the timed up-and-go test (TUGT) was carried out, the 6-minute walking test (6-MWT) was conducted to assess the gait function and VO_2max was tested to assess the cardiorespiratory fitness. VR cycling exercise was conducted for 3 months, twice a week.

Results. Both groups performed significantly differently ($p < 0.05$) in terms of balance, gait ability, and cardiorespiratory fitness. The decrease in the TUGT score and increase in the 6-MWT and VO_2max test scores of the intervention group obtained after undergoing VR cycling exercise was significantly bigger than it was before performing the exercise. The group of post-stroke patients was able to take the exercise in 40–60 min of each exercise period.

Conclusions. VR cycling exercise is a highly effective intervention to increase motoric function and cardiorespiratory fitness in chronic post-stroke patients. Therefore, taking VR cycling exercise is recommended for stroke rehabilitation and clinical practice purposes.

Key words: motoric function, cardiorespiratory fitness, rehabilitation, stroke, virtual reality cycling

Introduction

Stroke has become a remaining major health problem among the community with high mortality and morbidity rates. To date, stroke has taken second place as the factor causing deaths and third place as the factor causing disability worldwide. Globally, from 1990 to 2019, stroke incidents have increased by 70%, prevalence by 85%, death due to stroke by 43%, and post-stroke disability by 32% [1]. WHO (2016) data shows that there are 13.7 million new cases on stroke per year and approximately 5.5 million deaths due to stroke [2]. For stroke sufferers, death is not the only thing to worry about. However, most can survive despite the disability that lingers on [2]. It is closely related with a condition in some developing countries, including Indonesia. This is in line with research by Basic Health Research (Riskesdas) in 2017, 2013, and 2018, which revealed a significant increase in the prevalence of strokes in Indonesia from year to year. Almost 56.5% of these stroke patients also suffer from a stroke-induced disability [3].

Stroke is a clinical syndrome that is marked with symptoms or clinical signs that rapidly develop in the form of focal (or global) brain function injury that lasts for more than 24 hours without an obvious cause beyond the blood vessel itself [4]. Stroke can have long-term consequences, such as sensory, motor, communication, emotion, memory, and mobility function disorders that cause restrictions in daily activities and participation in social activities. Post-stroke motoric function disorder happens due to insufficient coordination in movement, selective movement loss, and inadequate motoric control, which are a few symptoms that frequently emerge. The existence of disability in the form of paralysis or one-sided extremity muscle weakness (hemiparesis) is a particular characteristic of stroke. Approx. 50% of the stroke survivors suffer from hemiparesis for 6 months after the stroke attack [5].

Neuromotor deficit is the main cause of long-term disability that results in paralysis among post-stroke patients. Disability as the impact of a stroke causes significant problems in physical, psychological, and social living aspects and disturbs the quality of life of stroke sufferers [6]. Post-stroke rehabilitation helps tackle the disabilities that are one impact of stroke [7]. Stroke sufferers need to progress through a rehabilitation process to return their motoric function to ameliorate any skill deficit in performing their daily activities. Instead, their self-independence will likely improve and their dependence on their family will be decreased [8].

Physical therapy and medium- or high-intensity exercise are recommended for the sufferers as part of a comprehensive rehabilitation programme in the post-stroke chronic phase [9]. There are two modalities of physical therapy for post-stroke patients in neurological rehabilitation with a motoric movement disorder on the lower extremity, which include

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assessment and virtual reality-oriented therapies [10]. Virtual reality (VR) is a simulation of a real environment which is produced through computer software and run by the users using a human interface machine (avatar). Technology-based rehabilitation therapy is a promising tool for more-interactive, effective, and independent therapeutic exercises than conventional ones.

The development of the recent VR-based technology which is applied in physical fitness rehabilitation and post-stroke motoric movement creates improvement in functional capacities and rehabilitation success by minimising the functional limitation caused by the disability [11]. The use of VR for physical therapy on the lower extremities can improve motoric movement compared to conventional therapy, although the gait ability of the patients does not significantly improve [12]. The success of the physical therapy for the lower extremities does not only relate to the exercise of motoric movement but also to the cardiorespiratory fitness. The additional cardiorespiratory exercise in VR-based physical therapy for the lower extremities would increase the mobility transfer skill from the virtual environment (VE) to the actual mobility in the real world. Post-stroke sufferers generally have low mobility due to the decline in physical activities. Physical skills are strongly connected to the cardiorespiratory fitness (VO_2) within the body. Although the top average of VO_2 among post-stroke sufferers increases during their rehabilitation which lasts for 1–6 months, the VO_2 capacity only reaches 73% compared to normal cardiorespiratory fitness [13]. The decrease in physical activities in the post-stroke period is related to the weakened gait ability [14]. Therefore, a VR-based innovation for physical therapy, particularly for the lower extremities, is needed.

VR-based cycling exercise for post-stroke sufferers is a technology that uses a cycling simulator applying augmented reality (virtual reality augmented cycling/VRAC) that was developed to improve the balance and gait ability, widen the motoric motions (Range of Motion/ROM) on the lower extremities and increase the capacity of the cardiorespiratory system (maximum VO_2). Some previous research produced prototypes of the VRAC simulator device that was then tested and its mechatronic components validated with a view to manipulating the VE to reform the motoric movement behaviour and effectiveness in a laboratory environment [15–17]. The objective of this research is to determine the effectiveness of VR-based physical cycling exercise towards the motoric system of the lower extremities and cardiorespiratory fitness among chronic post-stroke patients.

Subjects and methods

Research design

This research implemented a pre- and post-experimental with control group design. It was conducted in the Regional Public Hospital of Kalisat, Jember, Indonesia from April to July 2022.

Research subjects

The subject of this research consisted of 15 people who were collected using the purposive sampling method. They were organised into two groups: Post-stroke, which was made up of 8 post-stroke patients (aged 40–60 years old, ≥ 2 years post-stroke), and Control, consisting of 7 healthy controls (aged 40–60 years old). The post-stroke patients were out-patients in the polyclinic of neurology in the Regional Public Hospital of Kalisat who were diagnosed with light ischemic stroke by a doctor. Other inclusion criteria of the post-stroke patients were a remaining lower extremity motoric disorder that was assessed by the Fugl-Meyer Assessment Low Extremity test (FMA-LE score, ranging from 28/34), possessing community ambulation that reached the limit (gait speed ranges from 0.56 to 1.10 m/s) and reporting the remaining symptoms of a GAITRite test, such as limited gait ability. Unconscious patients with bilateral hemiplegia, sensory aphasia, or a communication problem that can cause barriers in completing the exercise, have a historical cardiac disease, arrhythmia, or chronic-obstructive pulmonary disease (COPD), and those experiencing dementia or a mental disorder were excluded from this research. The healthy control subjects were needed as the reference to compare the improvement on post-stroke patients' motoric and cardiorespiratory functions after undergoing the exercise [18].

Outcome measures

The characterisation of the post-stroke patients' sensory-motor function status was conducted by the Fugl-Meyer assessment low extremity (FMA-LE). FMA-LE is an instrument that has good validity and reliability to measure the sensorimotor function [19, 20] and is related to the gait speed [21, 22].

The safety variable was measured based on the observation of the lack/existence of advert events (AE) (such as fainting, exhaustion, dizziness, nausea, eye strain (asthenopia) due to VE exposure. The score of the rate of perceived exertion (RPE) was ≤ 14, heart rate (HR) was between 80 and 100 times/minute, and blood pressure was not more than 200/100 mmHg during the exercise.

The feasibility variable was measured using the participant's total presence during the exercise. The increased time duration of the exercise over the previous exercise was at least 20 min per session. The total duration of the exercise and the activity assessment using virtual reality (presence) and the experience of using VR were measured by using Witmer and Singer's Presence Questionnaire (PQ) > 39 [23].

The effectiveness variable was assessed by comparing the level of improvement on balance, gait ability, and cardiorespiratory fitness before (pre-) and after (post-) the training, which included the TUGT (timed up-and-go test) to measure the balance, 6-MWT (6-minute walking test) to measure the gait ability, and VO_2max to assess the cardiorespiratory fitness.

VRAC simulator

VRAC was developed to address motor control and fitness deficits post-stroke. The mechatronic components of VRAC are modular, with the pedal sensor, handlebar, and HR monitor, which control the behaviour of the user's avatar in the VE, as shown in Figure 1. The mechatronic components were designed to transform the recumbent bike into a virtual reality-based bicycle (augmented bicycle). In summary, the VE input encompassed the gaits generated by each lower extremity on the pedals, which were instrumented with the HR from the HR monitor. The pedals has a force transducer which separately measures each lower extremity. If an imbalanced force is detected, the VE user will obliquely move to the weaker side. The HR data are transmitted to the VE and this input is used to determine the avatar's speed. When the user's HR increases, the avatar peddles faster. In this experiment, the data from the pedals and HR monitor were collected by the system and used as the performance measurement [24].

Figure 1. VR system-based cycling components for post-stroke training: (A) pedal module, (B) cadence module, (C) calibration tool and sensors monitoring, (D) heart-rate monitor module, (E) data acquisition box, (F) central processing unit, (G) virtual environment

The VE from the VRAC simulator device in this research has two avatars: the rider, representing the user, and a pacer, who is a non-player character and fulfils the role of the virtual trainer (see Figure 2). The speed of the bicycle pacer was decided by using fuzzy logic with three parameters: the HR target decided by physiotherapy, the distance between the rider and pacer, and the rider's HR. The users were instructed to follow the cycling route set by the pacer by maintaining a safe distance and keeping HR under the HR target. The users' HR is presented in the VE. If their HR exceeded the HR target, the hearts in the VE beat faster and increased in size, which was a strong visual indicator that the user needed to restrain themselves a bit to maintain a secure range of the exercise since the VRAC is integrated with the bicycle's functionalities and the user's, and therefore the HR's, workload, which can be adjusted by changing a setting on the bicycle, such as the work speed (in watts) and resistant mode (constant or isokinetic). Besides using the HR input in the VE to push a certain aerobic effort, VE features such as increasing the cycling speed (strengthening or decreasing the user's RPMs), the route's width, and the inclination of the route, can be used to modify the user's HR and maintain their participation [24].

Figure 2. Virtual environment of the simulator where the rider (behind) follows the cycling track of the virtual trainer (ahead) at a safe distance and monitors the heart rate safely during training

Intervention

The cycling exercise using the VR simulator was performed for 12 weeks, twice weekly, based on the recommendation for physical exercise for the stroke sufferers by the American Heart Association [25]. The intensity of the exercise was arranged in the initial session, which was between 20 and 30 pulses per minute above HR break point. The research subject could exceed the intensity during the exercise if the RPE was ≤ 14 and the cycling pattern did not show incoordination due to exhaustion. The duration could increase during the following exercise session until it reached 60 min. The VR-based cycling exercise involved several components, such as stretching, exercise, and cooling down activities, which were supervised and under the control of a doctor/physiotherapist within a HR target that is 20–30 bpm above the HR break point. The stretching session was conducted by adhering to YMCA cycle ergometry submaximal VO_2 test protocols [26]. The initial peddling speed was 50 revolutions per minute for 30 min. In the session of initial exercise, the subject peddled the bicycle for 20–30 min, which increased along with the exercise duration, which reached 60 min. The cooling down session was conducted as in the stretching session, in which the peddling speed was 50 revolutions per minute for 3 min. The exercise was ended if the HR reached more than the targeted HR or the blood pressure was more than 200/100 mm Hg during the exercise.

Data analysis

Safety was assessed by reviewing the intervention log. The feasibility was assessed by using the presence, exercise period, and engagement factors of the PQ. The data of the exercise period were concluded and grouped based on weeks and used as the total exercise. The engagement was measured by summing up items 5, 6, 10, 18, 23 and 32 from the PQ score each week. The totals were averaged for the fifteen research subjects and were analysed descriptively for the 12-week exercise programme to determine the engagement of the subjects in the exercise. The effectiveness was assessed by inferential analysis from VO_2 and the results of the TUGT and 6-MWT. The statistical analysis was conducted using IBM SPSS Version 22.0 for Windows. The normal distribution was confirmed by the Sapiro–Wilk test. All descriptive statistics are presented as mean ± standard deviation for normally distributed data. The comparisons of the variables were analysed using the independent *t*-test and paired *t*-test based on types, distribution, and number of groups involved in the comparison. The statistical significance was set at $p < 0.05$.

Results

Characteristics of the research subject

The characteristics of the research subjects are presented in Table 1. There were significant differences in terms of statistics concerning the basic sensory-motor score (FM score).

The sex, age, and weight of the subjects in both groups were not significantly different in terms of statistics, as shown in Table 1. A significant difference can be seen in the Fugl-Meyer score. This is due to the remaining motoric function disorder in the lower extremity in the test group, with an average score of 25.2 out of 34 as the normal score. The existence of disability implies the existence of long-term effects of stroke that were experienced for more than 2 years.

Table 1. General characteristics of the participants

Characteristics	Post-stroke patient (n = 8) mean ± *SD*	Healthy control (n = 7) mean ± *SD*	p
Sex (male/female)	4/4	4/3	
Age (years)	51.7 ± 4.4	47.1 ± 4.6	0.074
Weight (kg)	63.4 ± 4.8	70.1 ± 9.8	0.052
Fugl-Meyer (score)	25.2 ± 0.9	34 ± 0.0	0.002*

significant difference, independent sample t-test: * $p < 0.05$

Cycling exercise is appropriate for post-stroke chronic rehabilitation for 6 months with chronic spasticity > 12 months post-stroke. Patients ≥ 2 years post-stroke were included considering previous functional abilities, impairment of psychological function (cognitive, emotional and communication), impairment of body function (including pain) and activity limitation and participation restriction so they can complete the exercise regimen [27–29]. In addition, treatment in post-stroke with evolution time 27.8 ± 14.7 months contributes to a reduction in post-stroke spasticity [30].

Safety of VRAC simulator

The safety of the VRAC was determined based on the lack/existence of advert events, where the control was measured from the HR score, blood pressure, and SpO_2. The assessment result towards the safety of the VRAC simulator is presented in Table 2.

The post-stroke patients' blood pressure and HR were higher than the control group, as shown in Table 2. The blood pressure and HR of the post-stroke patients and the control group increased after they performed the exercise. The O_2 saturation of both the post-stroke patients and the control group were in the normal range. After statistical analysis, the result revealed a significant difference ($p < 0.05$) between blood pressure, HR, and oxygen saturation before and after performing the exercise among both the post-stroke patients and the healthy control group.

Feasibility of VRAC simulator

The VRAC feasibility was assessed by the total presence, the total of the achieved duration of the exercise, and how much the users gain experience in using the virtual reality (presence). The assessment result towards the feasibility of the VRAC simulator is presented in Table 3.

Table 3. Feasibility of VRAC simulator

Parameters	Post-stroke patients (n = 8) mean ± *SD*	Healthy controls (n = 7) mean ± *SD*	p
Exercise duration (min)	37.23 ± 1.07	38.33 ± 0.00	0.068
Cycling comfort (PQ score)	49.59 ± 3.21	49.83 ± 2.98	0.056

significant difference, independent sample t-test: * $p < 0.05$

As can be seen in Table 3, the duration of the exercise and cycling comfort (PQ score) in the post-stroke patients were not significantly different from the healthy control group. When experiencing comfort, motivation is maintained to continue to come and do the exercise. This evidences the feasibility of the VRAC simulator, as it was well-received by both groups.

Effectiveness of VRAC simulator

The assessment of the effectiveness of the VRAC simulator towards the changes in balance, gait ability, and fitness is presented in Table 4.

Based on Table 4, in both the post-stroke patients and the health control group, it was demonstrated that there are significant changes in TUGT (walking speed and balance), 6-MWT (gait ability), and VO_2 after being undertaking the VR-based cycling exercise programme for 12 weeks ($p < 0.05$).

Table 2. Safety of VRAC simulator

Parameters	Post-stroke patients (n = 8) mean ± *SD*		p	Healthy controls (n = 7) mean ± *SD*		p
	pre-test	post-test		pre-test	post-test	
Systolic blood pressure (mmHg)	154.45 ± 1.25	168.79 ± 1.97	0.001*	125.83 ± 1.32	133.62 ± 1.52	0.001*
Diastolic blood pressure (mmHg)	70.71 ± 1.17	88.70 ± 1.44	0.001*	72.39 ± 1.36	82.53 ± 0.96	0.001*
Heart rate (bpm)	79.05 ± 0.79	96.71 ± 0.62	0.001*	75.40 ± 0.61	87.17 ± 0.39	0.001*
Oxygen saturation (%)	96.99 ± 0.32	95.78 ± 0.34	0.001*	97.10 ± 0.15	96.10 ± 0.37	0.001*

significant difference, paired t-test: * $p < 0.05$

Table 4. Changes in balance, gait ability and fitness

Parameters	Post-stroke patients (n = 8) mean ± *SD*		p	Healthy controls (n =7) mean ± *SD*		p
	pre-test	post-test		pre-test	post-test	
TUGT (s)	11.92 ± 3.27	11.62 ± 3.11	0.002*	5.87 ± 0.31	5.83 ± 0.30	0.047*
6-MWT (m)	312.79 ± 48.06	325.41 ± 49.24	0.001*	658.84 ± 5.72	662.68 ± 5.55	0.001*
VO_2	19.58 ± 2.76	20.34 ± 2.82	0.001*	41.17 ± 0.74	41.40 ± 0.72	0.001*

TUGT – timed up-and-go test, 6-MWT – 6-minute walking test, VO_2 – oxygen consumption
significant difference, paired t-test: * $p < 0.05$

Discussion

Characteristics of the research subject

The post-stroke patients engaged in this research were mostly male. They were considered three times more vulnerable than female patients. Female patients are vulnerable to stroke at older ages. This is related to the role of the oestrogen hormone, which can keep the vascular structure of the brain healthy by increasing the efficiency of mitochondria. Oestrogen binds to the vascular smooth muscle and endothelial receptors, thereby facilitating vascular vasodilation [31]. The average age of the post-stroke patients is higher than the healthy control group. Stroke incidents increase with age, and double after 55 years of age [32]. However, there is a worrying trend where the incidence of stroke in people aged 20–54 years old increased from 12.9% to 18.6% of global stroke cases between 1990 and 2016 [29]. Approx. 10–15% of all stroke cases occurred to adults aged 25–49 years old [32]. The increased age leads to a vulnerability towards atherosclerosis as the main cause of vascular disorder in the brain [33].

Safety of VRAC simulator

The blood pressure of the post-stroke patients before and after the exercise was higher than the healthy control group. This is related to the fact that most of the post-stroke patients had a history of hypertension due to the pathophysiology of the disease and were still in the medication period. The significant increase in blood pressure before and after the exercise of both groups revealed a normal body adaptation after receiving load during exercise. When the physical exercise occurred, a control would happen and was integrated to the blood pressure. The blood pressure is controlled by the autonomic nervous system, particularly special sensors in the carotid artery and aortic arch, or the so-called baroreceptor reflux. Baroreceptors are very sensitive towards changes in arterial pressure. Baroreceptor reflux is used as the controller of blood pressure changes. The increase of the epinephrine hormone during physical exercise causes the increase in the strength of the contractions of the heart muscle. Nevertheless, the blood pressure did not directly increase significantly due to the effects of epinephrine in the blood vessels, which can cause dilatation. When doing the cycling exercise, the heart works harder to fulfil the blood supply to the whole body. This depends on the blood pressure. This process starts when the blood leaves the heart and circulates throughout the body and returns to the heart. In the post-exercise phase, the work of the sympathetic nervous system increases while the work of the parasympathetic nervous system reduces so the blood pressure tends to rise after exercise [34]. The scores of the blood vessels before and after performing the VR-based cycling exercise on both the post-stroke patients and healthy control group were not more than 200/100 mm Hg.

The heart rate (HR) of the post-stroke patients before and after the exercise was higher than the healthy control group. The significant change of HR before and after the exercise both in the post-stroke patients and in healthy control group is a physiological response. The physical exercise caused an increase in the HR. This increase was caused by the increase of blood demand, which drives O_2 to active body tissue. The higher the intensity of the exercise, the higher the heart rate climbs. This change is managed by the neurohormonal system [35]. The HR scores before and after the exercise, both in the post-stroke patients and the healthy control group, were in the normal range (80–100 beats/minute).

The O_2 saturation of the post-stroke patients before and after performing the exercise was higher than in the healthy control group. There was a significant change in oxygen saturation between the conditions before and after the exercise among the post-stroke patients and the healthy control group. The increase in O_2 saturation probably occurred as the intake of the oxygen by the lungs after physical exercise increases 15 times over the normal level and decreases gradually for 40 min after physical exercise. The bigger the ventilation and blood flow, the more O_2 is diffused into pulmonary capillaries and binds to haemoglobin. The body maintains the level of oxygen in the blood, so it will decrease during the exercise and the oxygen saturation score will increase after the physical exercise [36].

The significant increase in blood pressure, HR, and O_2 saturation before and after the exercise is statistically considered as a physiological response of the body towards the increase in oxygen demand due to the exercise. While doing the cycling exercise, the heart beats faster and stronger. After the break period, the blood pressure and HR frequency will return to normal. The changes in blood pressure and heart rate during and immediately after exercise are termed acute effects of exercise.

The Borg scale for RPE assessment is recommended to measure the intensity of physical exercise during stroke rehabilitation. The average RPE in stroke patients (10.9) both before and after the training was higher than the in healthy control group (9.5). Both are within the normal range, which for RPE is ≤ 14. There were no adverts events (AE) in this research during the cycling exercise across the 12 weeks of the programme. However, exhaustion at the beginning of the exercise was seen. Therefore, it can be concluded that the VR simulator has an appropriate safety level.

Feasibility of VRAC simulator

The VR cycling exercise simulator fulfilled the feasibility testing. In this research, the duration of the exercise for the post-stroke patients could be increased up to 60 min in each exercise session with comfort. This fulfilled the guidelines where stroke patients are suggested to exercise for 45 min based on the therapy needed, at least 5 times per week, at a level that allow the patients to achieve their rehabilitation goals as long as they benefit from the therapy and can tolerate it [37].

Effectiveness towards balance

The timed up-and-go test is a kind of measurement used to evaluate walking balance related to the risks of falling among the post-stroke patients, with sensitivity and specification level as high as 87%. The duration of < 13.5 s for the TUGT is related to an increased risk of falling [38]. The average time (seconds) needed by the stroke patients to complete the TUGT was longer than the healthy control group (see Table 4). There was a significant decrease in the average time in the post-stroke patients after completing the exercise programme. This revealed that there was an increase in walking balance and speed, which was measured using the TUGT. In the first month of the TUGT evaluation, the average time obtained was 15.43 s, which means that there is a light risk of falling, and in the third month, the average time was reduced to 7.29 s, which means that the patients had already achieved independence in maintaining the walking balance.

Effectiveness towards gait ability

The 6-MWT is an observational clinical measurement that is designed to assess functional capacity and evaluate the walking speed of stroke patients. The 6-MWT is a time-based test that measures travel time as the output. This test is conducted on a long track [39]. The American Thoracic Society (ATS) recommended that the length of the track used for the 6-MWT is 30 m. Thus, the protocol of the 6-MWT applied in this research was walking for 6 minutes along a 30-metre-long track and turning around in three steps.

The average mileage (in metres) that could be achieved by the post-stroke patients in completing the 6-MWT test was shorter than the healthy control group. Nevertheless, there was a significant increase of mileage (in metres) of the post-stroke patients after taking the VR-based cycling for within 3 months, twice per week (see Table 4). This shows that there was improvement in the motoric movement skill and gait speed, which were measured by the 6-MWT test, from the first to the third month. In the first month of the evaluation, the average mileage was 237.42 m, which increased to 434.08 m in the third month. Standard reference equations for optimal values of 6-MWT for healthy population-based samples are not yet available. In one study, the mean 6MWD in healthy people aged 21–78 years was 581.4 ± 66.5 m (range 383–800) for females and 608.7 ± 80.1 m (range 410–875) for males [40]. Another study also reported that the average 6-MWT of a healthy person aged 40–80 years old is 571 ± 90 m (around 380–782 m) [41]height, weight, spirometry, heart rate (HR. The difference in the population sample, types, and support frequency as well as the total practical test can explain the average difference in the 6-MWT among the healthy controls reported in the study. In this research, the achieved mileage of the post-stroke patients after undertaking the VR-based cycling exercise programme within a range of achieved mileage healthy person's distance referred to the two previous research.

Effectiveness of cardiorespiratory fitness

VO_2max is the maximum ability of someone in consuming O_2 during physical activities in order to create energy until it reaches the maximum score and cannot be increased any further, even with the increasing intensity of the exercise. The lung functional capacity has a direct connection with VO_2max through the ventilation mechanism [42]. The 6-MWT test is one of the reliable, valid, and responsive tests to measure the lung functional capacity, based on the recommendation of the American Thoracic Society. Hence, the score in VO_2max in this research was obtained from the calculation of the 6-MWT conversion.

The average VO_2max among the post-stroke patients was lower than the healthy control group. However, there was a significant improvement in the average VO_2max score among the post-stroke patients after undertaking the VR-based cycling exercise programme for 3 months, twice per week (see Table 4). In the first month of the initial exercise, the average VO_2max score was 15.06, which was then increased to 26.86 in the third month. This revealed that there was an increase in the respiratory fitness among the post-stroke patients.

VO_2max can be affected by the intensity of physical exercise. Intense physical exercise can increase VO_2max as much as 20%. Physical exercise such as cycling can generate a re-synthesis of adenosine triphosphate (ATP) with the aerobic mechanism, adjusted intensity (from low to high intensity), duration (usual length of time), and the availability of oxygen. The intensity depends on cardiorespiratory attempts, which is related to the maximum heart rate (HRmax) and maximum oxygen consumption (VO_2max), which determines the increase in oxygen consumption that connects to the break condition [42].

According to previous research, aerobic exercise in a certain scope such as several months with high or low intensity (%VO_2max 40 up to ≥ 60), medium duration (16–45 min) can cause an increase in the neuroplasticity phenomenon, an increase of cognitive function (especially the memory function), mitigate neuro-degeneration, minimise anxiety and depression, and dispose of metabolic wastes, which further lead to faster recovery, so the physical fitness improved [43].

Limitations

This research has several limitations. First, the sample of this research was relatively small and limited to the research subject in a regional public hospital in Kalisat, Jember, which may be inaccurate, as it does not necessarily represent the whole population. Second, the research subject of this research is not a random sample from a similar population. However, confounding factors such as age, sex, and body weight were controlled. It is suggested for future research to investigate a bigger sample and include only post-stroke patients as a one-arm study to verify the advancement and to reflect the general population.

Conclusions

VRAC exercise conducted twice per week for 12 weeks can increase the gait speed, gait ability, and VO_2max among post-stroke patients. It is evident that it can improve the lower extremity motoric function and increase the cardiorespiratory fitness, although the successful exercise did not totally recover the motoric functions to their level before the stroke or to be as stable as those in the healthy control group. However, this kind of exercise can be recommended for rehabilitation therapy for the chronic phase of post-stroke patients. This exercise regimen has no inherent time limitations that accurately decide when to begin the recovery process after the rehabilitation, yet it has been stated that improvement can be seen at least in the first 6 months.

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Committee of Medical Ethics of Jember State Polytechnic (approval No.: 143/ PL17/PG/2022).

Informed consent

Informed consent has been obtained from all individuals included in this study.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

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