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The 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 figure out the effectiveness of VR cycling exercise towards the impairment of lower extremity motoric function and cardiorespiratory fitness on the post-stroke patients.
Methods. This study engaged 15 people chosen through a purposive sampling method which were divided into 8 intervention groups of post-stroke patients without comorbid (post stroke ≥ 2 years) and 7 healthy people in a control group. Fugl Meyer assessment was used to decide the participation of the patients. To assess the lower extremity motoric functions, timed up-and-go test (TUGT) was carried out. 6-minute walking test (6-MWT) was conducted to assess the function of gaits. VO_2max was carried out to assess the cardiorespiratory fitness. VR cycling exercise had been conducted for 3 months, twice a week.
Results. Both groups performed significant difference ($p < 0.05$) in terms of balance, gait ability, and cardiorespiratory fitness. The decrease of TUGT score and increase of 6-MWT and VO_2max tests' scores of the intervention group obtained after having VR cycling exercise was significantly bigger than it was before taking the exercise. The group of post-stroke patients were able to take the exercise in 40–60 minutes/time of exercise.
Conclusions. VR cycling exercise is such an effective intervention to increase motoric function and cardiorespiratory fitness on chronic post-stroke patients. Therefore, taking VR cycling exercise is recommended for a 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 the second place as the factor causing deaths and third place as the factor causing disability worldwide. Globally, stroke incidents increased to 70%, prevalence 85%, death due to stroke 43%, and post-stroke disability 32% [1]. WHO (2016) data showed that there are 13.7 million new cases on stroke per year and approximately 5.5 million deaths happened due to stroke [2]. For stroke sufferers, death is not the only thing to worry about. However, most of them can survive in spite of a disability that lingers on [2]. It is closely related with a condition in some developing countries, including Indonesia. This is in line with a research result of Basic Health Research (Riskesdas) in 2017, 2013, and 2018 which revealed the significant increase of stroke prevalence in Indonesia from year to year. There are almost 56.5% of stroke patients who also suffered from disability [3].

Stroke is a clinical syndrome which is marked with a symptom or clinical signs which are rapidly developing in the form of focal (or global) brain function injury that last for more than 24 hours without an obvious cause unless the blood vessel [4]. Stroke can cause long-term effects such as sensory, motor, communication, emotion, memories, and mobility function disorders that cause restrictions in daily activities and participation in social activities. Post-stroke motoric function disorder happened due to insufficient coordination on the movement, selective movement loss, and inadequate motoric control which are parts of 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. Around 50% of the stroke survivors suffered 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 the post-stroke patients. Disability as the impact of stroke caused significant problems in physical, psychological, and social living aspects as well as disturbing the living quality of the stroke sufferers [6]. A post-stroke rehabilitation helps tackle disabilities as the impact of stroke [7]. Stroke sufferers need to pass through a rehabilitation process to return their motoric function so that they will not experience a skill deficit in doing daily activities. Instead, their self-independent would likely improve and family dependency will be decreased [8].

Physical therapy and medium or high intensity exercise are recommended for the sufferers as part of a comprehensive rehabilitation on the post-stroke chronic phase [9]. There are two modalities of physical therapy for post-stroke patients in neurological rehabilitation with motoric movement disorder on lower extremity that include assessment and virtual reality oriented therapies [10]. Virtual reality (VR) is a simulation of the real environment which is produced through a computer software and ran by the users using human interface machine (avatar). Technology-based rehabilitation therapy is a promising tool for a more-interactive, effective, and independent therapeutic exercises than conventional ones.

The development of the recent VR-based technology which are applied on the physical fitness rehabilitation and post-stroke motoric movement create an improvement on the functional capacities and rehabilitation success by minimizing the functional limitation caused by disability [11]. The use of VR for a physical therapy on the lower extremity can increase better motoric moves compared to the conventional therapy although the gait ability of the patients has not significantly improved [12]. The success of the physical therapy for the lower extremity does not only relate to the exercise of motoric movement but also the cardiorespiratory fitness. The additional cardiorespiratory exercise on VR-based physical therapy for lower extremity 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 of physical activities. Physical skills are strongly connected to the cardiorespiratory fitness (VO_2) within a body. Although the top average of VO_2 among the post-stroke sufferers increased during the rehabilitation which lasted for 1–6 months, the capacity of VO_2 only reached 73% compared to the normal cardiorespiratory fitness [13]. The decrease of physical activities in the post-stroke period is related to the weakened gait ability [14]. Therefore, an innovation for a physical therapy particularly for lower extremity that is VR-based is needed.

VR-based cycling exercise for post-stroke sufferers is a technology on cycling simulator which applied augmented reality (virtual reality augmented cycling/VRAC) which was developed to improve the balance and gait ability, widen the motoric motions (Range of Motion/ROM) on the lower extremity and increase the cardiorespiratory system (maximum VO_2). Some research which had been conducted produced prototypes of VRAC simulator device which had been tried out and its mechatronic components had been validated, the manipulation of VE to reform the motoric movement behaviour, and effectiveness in the laboratory environment [15–17]. The objectives of this research is to figure out the effectiveness of VR-based physical cycling exercise towards the motoric system of lower extremity and cardiorespiratory fitness among the chronic post-stroke patients.

Subjects and methods

Research design

This research implemented pre- and post-experimental with control group design. It was conducted in 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 by using purposive sampling method. They were grouped into two in which 8 people were the post-stroke patients (aged 40–60 years old, ≥ 2 year post-stroke) and 7 people were the healthy control (aged 40-60 years old). The post-stroke patients were the out-patients in the polyclinic of neurology in the Regional Public Hospital of Kalisat who were diagnosed by the doctor for light ischemic stroke. The inclusive criteria of the other post-stroke patients were the remaining lower extremity motoric disorder which was assessed by Fugl-Meyer low extremity (FM score, ranging from 24–26/34), possessed a household community ambulation that reached the limit (the gait speed ranges from 0.56 to 1.10 m/s) and report the remaining symptoms such as limited gait ability. The unconscious patients with bilateral hemiplegia, sensory aphasia, or communication problem that can cause barriers in completing the exercise have historical diseases of cardiac, arrhythmia, and chronic-obstructive pulmonary disease (COPD), as well as experiencing dementia or mental disorder which 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 being interfered with the exercise [18].

Outcome measures

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

The safety variable was measured by referring to the observation result towards the in/availability of advert events (AE) (such as faint, being exhausted, dizzy, nausea, shocked eyes) due to VE exposure, the score of rated of perceive exertion (RPE) was ≤ 14, heart rate (HR) was between 80 and 100 times/minute, and blood pressure was not more than 200/100 mm Hg during the exercise.

The feasibility variable was measured by using the total presence during the exercise. The increased time duration of the exercise was at least 20 minutes 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-Singer Presence Questionnaire (PQ) > 39 [23].

The effectiveness variable was assessed from how big is the improvement on balance, gait ability, and cardiorespiratory fitness before (pre-) and after (post-) the training which includes 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 was modular with the pedal sensor, handlebar, and HR monitor that control the behaviour of users' avatar in the VE as shown in Figure 1. The mechatronic components were designed to transform the recumbent cycle become a virtual reality-based cycle (augmented cycle). In summary, the VE input encompassed the gaits generated by each lower extremity on the pedals which had been instrumented with HR from the HR monitor. The pedals had a force transducer which separately measures each lower extremity. If the imbalanced force happened, the VE users will obliquely move to the weak side. The HR data were transmitted to VE and the input will push avatar's speed. When users' HR in reality increased, the avatar will paddle faster. The data from the pedals and HR monitor were collected by the system and used as performance's 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 VRAC simulator device in this research have two avatars: first, the rider representing the users in reality and pacer as the non-player character which is actually the virtual trainer (see Figure 2). The speed of the bicycle pacemaker was decided by using Fuzzy logic with three parameters namely HR target decided by physiotherapy, the distance between rider and pacer as well as the HR rider. The users were instructed to follow the cycling route from the pacer by keeping the safe distance and keeping the HR to remain under the HR target. Users' HR will be presented in VE. If HR of the users exceeded the HR target, the hearts in VE will beat faster and become bigger. It implies that the users need to control themselves a little bit to be still in a secure range of the exercise since VRAC is integrated with bicycle's functionalities, users' and HR's workload which can be adjusted by changing the setting on the bicycle such as the work speed (in Watt) and resistant mode (constant or isokinetic). Besides using the R input in the VE to push a certain aerobic effort, VE feature such as increasing the cycling (strengthening or decreasing users' circular per minute), route's width, and the level of the route can be used to modify users' HR and maintain their participation [24].

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

Intervention

Cycling exercise by using VR simulator was lasted for 12 weeks with 2 times of exercise in a week based on the recommendation for physical exercise for the stroke sufferers by American Heart Association [25]. The intensity of the exercise was arranged on the initial session which was between 20 and 30 pulses per minute above break HR. 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. Duration can increase during the following exercise session until it reached 60 minutes. VR-based cycling exercise involved several sessions such as stretching, exercise, and cooling down activities which were supervised and under the control of the doctor/physiotherapy within HR time zone target that is 20–30 bpm above HR break. The stretching session was conducted by adhering to YMCA cycle ergometry submaximal VO_2 test protocols [26]. The initial paddling speed was 50 revolutions per minute for 30 minutes. On the session of initial exercise, the subject paddled the bicycle for 20–30 minutes and it increases along with the increase of the exercise duration which reached 60 minutes. The cooling down session was conducted as it is in the stretching session in which the paddling speed was 50 revolutions per minute during 3 minutes. The exercise was ended if the HR had reached more than the targeted HR and 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 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 item 5, 6, 10, 18, 23 and 32 from the PQ score each week. The total average for fifteen research subjects and were analysed descriptively for 12 week exercise to decide the engagement of the subjects in the exercise. The effectiveness was assessed by inferential analysis from VO_2 and the results of TUGT and 6-MWT. The statistical analysis was conducted by using SPSS 22.0 for windows. The normal distribution was assessed by Saphiro–Wilk test. A descriptive statistic was presented as mean ± standard deviation for normally distributed data. The comparison of variables was analysed by using independent t-test and paired t-test based on types, distribution, and number of groups involved in the comparison. The statistical significance was decided on $p < 0.05$.

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

The informed consents had been obtained from all individuals who were involved in this research.

Results

Characteristics of the research subject

In general, the characteristics of the research subjects were briefly presented in Table 1. There are significant differences in terms of statistics concerning the basic score of sensory-motor (FM score) which was observed through both groups.

Table 1. General characteristics of the participants

Characteristics	Post-stroke patient (n = 8) mean ± SD	Healthy Person (n = 7) mean ± SD	p
Gender (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

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

Cycling exercise is appropriate for post-stroke chronic rehabilitation for 6 months with chronic spasticity > 12 months post-stroke. Post-stroke patient ≥ 2 years 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 [27–29]. In addition, treatment in post-stroke with evolution time 27.8 ± 14.7 month contributes to a reduction of post stroke spasticity [30].

The safety of VRAC simulator

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

Table 2. Safety of VRAC simulator

Parameters	Post-stroke patient (n = 8) mean ± SD		p	Healthy Person (n = 7) mean ± SD		p
	Pre-test	Post-test		Pre-test	Post-test	
Systolic blood pressure (mm Hg)	154.45±1.25	168.79±1.97	0.001*	125.83±1.32	133.62±1.52	0.001*
Diastolic blood pressure (mm Hg)	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

Post-stroke patient's blood pressure and HR were higher than control group, as shown in Table 2. The blood pressure and HR of post-stroke patients and control group increased after they did the exercise. The saturation of O_2 both on post-stroke patients and control group were in normal range score. After being statistically analysed, the result revealed a significant difference (p < 0.05) between blood pressure, HR, and oxygen saturation before and after taking exercise among either the post stroke patients or health control group.

The feasibility of VRAC simulator

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

Table 3. Feasibility of VRAC simulator

Parameters	Post-stroke patient (*n* = 8) mean ± *SD*	Healthy Person (*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: * $p < 0.05$

Table 3, the duration length of the exercise and cycling comfort (PQ score) on the post-stroke patients were not significantly different with the health control group. When experiencing the comfort, there is a motivation to always come to do the exercise. This means that the feasibility of VR was evident as it can be well received by both groups.

The effectiveness of VRAC simulator

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

Table 4. Changes in balance, gait ability and fitness

Parameters	Post-stroke patient (*n* = 8) mean ± *SD*		*p*	Healthy Person (*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: * $p < 0.05$

Based on Table 4, on the post-stroke patients and 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 interfered through VR-based cycling exercise for 12 weeks ($p < 0.05$).

Discussion

The characteristics of 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 towards stroke attack at older age. This is related to the role of oestrogen hormone which can keep the vascular in brain healthy by increasing the efficiency of mitochondria. Oestrogen binds to vascular smooth muscle and endothelial receptors thereby facilitating vascular vasodilation [31]. The average age of the post-stroke patients is bigger than the health control group. Stroke incidents increased as long as the increase of age, twice bigger after 55 years old [32]. However, there is a worrying trend where stroke that attack people aged 20–54 years old increased from 12.9% to 18.6% from all global stroke cases between 1990 to 2016 [29]. Around 10–15% of all stroke cases happened 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 brain [33].

The safety of VRAC simulator

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

The heart rate (HR) of the stroke patients before and after the exercise is higher than the health control group. The significant change of HR before and after the exercise both on the stroke patients and health control group is such a physiologic responses. Physical exercise causes the increase of HR frequency. This increase was caused by the increase of blood demand which drives O_2 to active body tissue. The more the intensity of the exercise, the more the rate of the heart. This change is managed by neurohormonal system [35]. The HR score before and after the exercise both on the stroke patients and health control group were in the normal range score (80–100 times/minute).

O_2 saturation of stroke patients before and after taking the exercise was higher than the health control group. There is a significant change on oxygen saturation between the condition before and after the exercise among the stroke patient and health control group. The increase of O_2 saturation happened probably due to the take of the oxygen by lungs after the physical exercise increase 15 times bigger than normal and it will decrease gradually until 40 minutes after the physical exercise. The bigger the ventilation and blood flow, the more the O_2 diffused to pulmonary capillaries and binds to haemoglobin. The body will maintain the level of oxygen in blood so that it will drop during the exercise and the saturation score of the oxygen will increase after the physical exercise [36].

The significant increase of blood pressure, HR, and O_2 saturation before and after the exercise is statistically considered as a physiologic response of the body towards the increase of oxygen demand due to the exercise. While doing the cycling exercise, the heart beats faster and stronger. After break period, the blood pressure and HR frequency will return as it normally is. The changes on blood pressure and heart rate during and right after the exercise is called as the acute effects of the exercise.

Borg scale for RPE assessment is recommended to measure the intensity of physical exercise during the stroke rehabilitation. The average RPE on stroke patients (score 10.9) both before and after the training is higher than the health control group (score 9.5). The RPE (Rated of Perceive Exertion) was ≤ 14. There is no adverts events (AE) in this research during the cycling exercise within 12 weeks. However, exhaustion in the beginning of the exercise happened. Therefore, it can be concluded that VR simulator has an appropriate safety level.

The feasibility of VRAC simulator

The additional VR simulator on the cycling exercise had fulfilled the feasibility. In this research, the duration of the exercise of post-stroke patients could be completed up to 60 minutes in each exercise with comfort. This fit the guidelines where stroke patients are suggested to take 45 minutes each based on the therapy needed, at least 5 times a week, on a possible level that allow the patients to achieve their rehabilitation foals as long as they can get advantage from the therapy and can tolerate it [37].

The effectiveness towards balance

Time 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 big as 87%.

The duration that was < 13.5 seconds for TUGT is related to the increase risk of falling [38]. The average time (seconds) needed by the stroke patients in completing the TUGT is longer that the health control group (see Table 4). There was a significant decrease on time average on stroke patients after doing the exercise. This revealed that there is an increase on walking balance and speed which was measured by using TUGT. The first month of the TUGT evaluation, the average time obtained 15.43 seconds which means that there is a light risk of falling and in the third month, the average time changed to 7.29 seconds which means that the patients already had a thorough independent in maintaining the walking balance.

The effectiveness towards gait ability

6-MWT is an observational clinic measurement which is designed to assess functional capacity and evaluate the walking speed of stroke patients. 6-MWT is a time-based test that engages travel time as the output. This test is conducted in a long track [39]. American Thoracic Society (ATS) recommended that the length of the track used for 6-MWT is 30 meters. Thus, the protocol of 6-MWT applied in this research is walking for 6 minutes in a 30-meter long track and go around in three steps.

The average mileage (in meter) which can be achieved by the post-stroke patients in completing the 6-MWT test is shorter than the health control group. Nevertheless, there was a significant increase of mileage (in meter) of stroke patients after taking the VR-based cycling exercise within 3 months, twice a week (see Table 4). This shows that there is an improvement on the motoric movement skill and gait speed which were measured by 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 became 434.08 in the third month. The optimal reference equation of the health population-based sample did not a standardized method of 6-MWT as it is not available in a research, the average of 6-MWT on a healthy person aged 21–78 years old is 581.4 ± 66.5 m (approximately 383–800) for females and 608.7 ± 80.1m (approximately 410–875) for males [40]. Another research also reported that the average 6-MWT of healthy person aged 40–80 years old is 571 ± 90m (around 380–782 m) [41]. The difference on the population sample, types, and support frequency as well as the total practical test can explain the average difference of 6-MWT among the healthy people reported in the study. In this research, the achieved mileage of post-stroke patients after taking VR-based cycling exercise within a healthy person's distance referred to the two previous research.

The effectiveness of cardiorespiratory fitness

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

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

VO_2max can be affected by the intensity of physical exercise. The intense physical exercise can increase VO_2max as big as 20%. The physical exercise such as cycling can generate a re-synthesis of adenosine triphosphate (ATP) with aerobic mechanism, adjustment intensity (from low to high intensity), duration (usual length of time), and the availability of the oxygen. The intensity depends on cardiorespiratory attempts which is related to the maximum heart rate (HRmax) or maximum oxygen consumption (VO_2max) which determines the increase of 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 $\geq$ 60), medium duration (16–45 minutes) can cause an increase of neuroplasticity phenomenon, the increase of cognitive function (especially memory function), avoid neuro-degeneration, minimize anxiety, depression, dispose the metabolic wastes, which further lead to a fast recovery so that the physical fitness improved [43].

Limitation

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 of Kalisat, Jember, which may be inaccurate as it resembles the whole population. Second, the research subject of this research is not a random sample from similar population. However, a confounding factors such as age, gender, and body weight had been controlled. It is suggested for future research to investigate a bigger sample and included only post-stroke patient as a one-arm study to make sure the advancement and to reflect general population.

Conclusions

VRAC Exercise within 12 weeks which was conducted twice a week can increase the gait speed, gait ability, and VO_2max among the post-stroke patients. This is evident that it can impair the lower extremity motoric function and increase the cardiorespiratory fitness although the success of the exercise had not totally recovered the motoric functions as it was before the stroke attack or as stable as those in the health control group. However, this kind of exercise can be recommended for a rehabilitation therapy for a chronic phase of post-stroke patients. There is no time boundaries that is accurately decided to begin the recovery process after the rehabilitation yet it has been stated that the improvement can be seen at least in the first 6 months.

Disclosure statement
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Conflict of interest
The authors state no conflict of interest.

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