Playing self-paced video games requires the same energy expenditure but is more enjoyable and less effortful than standard of care activities

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Abstract**—***The purpose of this study was to determine if a custom self-paced video game promoted intense training without compromising movement symmetry, while being perceived as less effortful and more enjoyable than a comparable standard of care activity. Fifteen participants, (38-72 years old) in the chronic phase post-stroke participated in this study. They played a custom self-paced stepping video game (VSTEP) and a comparable standard of care stepping activity (SOC). Data collected for each activity included, stepping frequency and accuracy, kinematics, exercise intensity, perceived effort, and enjoyment. There were no significant differences in repetitions or exercise intensity between conditions. The difference of the maximum side step length between the unaffected and affected lower extremity (LE) was significant in SOC, but not in the VSTEP condition. Maximum march height of the affected limb and symmetry of marching was significantly greater for VSTEP compared to SOC. Perceived effort was statistically significantly lower and enjoyment was statistically significantly higher for VSTEP compared to SOC. In conclusion, playing custom self-paced video games required the same energy expenditure but was more enjoyable, promoted movement symmetry and was less effortful than SOC*.

Keywords—*active video games, self-paced games, exercise intensity, kinematics, stroke*

I. Introduction

Visual feedback is a rehabilitation strategy that uses an external visual cue to drive an individual's motor performance. Visual cues may provide knowledge of results about a movement goal and knowledge of performance about the movement. Knowledge of results (KR) provides information about the outcome of the movement task, for example, it may indicate that the desired movement goal relative to movement time or repetitions was achieved. Knowledge of performance (KP) provides information about the quality or kinematics of movement. For example, KP may indicate the trajectory of the limb involved in the desired movement. In a clinical setting visual feedback in its simplest form uses real physical targets to provide KP and KR. For example, a therapist may place tape marks on the floor and patients will see how many times (KR) they can touch the tape, or how many times they undershoot or overshoot the tape (KP). The use of technology in rehabilitation provides additional means to implement these two types of feedback. Motion capture and movement tracking can automate the tasks performed by the clinician and create onscreen displays with visual targets that are augmented with visual and auditory feedback for both KR and KP. These strategies have taken different forms and shown to be successful for persons post-stroke.[1]–[3] For example, KP visual feedback delivered via an onscreen display of force-plate derived kinematics was shown to improve walking and activities of daily living of persons post-stroke by reducing LE asymmetry. [1] Secondly, a study using KR and KP via screens providing postural information and onscreen visual targets showed improvements in balance for individuals with subacute stroke.[2] Lastly, a double blind randomized control trial consisting of standard care physical therapy paired with an additional 30-minutes of virtual reality training using augment KP and KR showed balance improvements for persons in the chronic phase post-stroke. [3]

There are several proposed advantages of using video-games to provide augmented feedback for individuals post-stroke. One benefit, unique to custom games is the ability to control pacing. A game-based rehab-preference survey for individual post-stroke revealed that game pacing, how fast a player must respond in the game, is an integral factor that must be considered when implementing games-based rehabilitation strategies. [4] Therefore self-pacing of a custom game is an additional advantage over off the shelf-games, allowing the users to play at their own achievable levels comparable to standard of care, which is also self-paced.

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Another proposed benefit of using video games for the rehabilitation of individuals post-stroke is that they promote exercise intensity required to achieve the recommended levels for deconditioned individuals. Studies examining off-the-shelf active video games have shown that healthy individuals are able to achieve greater energy expenditure during game play compared to sitting or standing, while clinical populations such as individuals with cerebral palsy and individuals post-stroke are able to achieve the recommended exercise intensities of greater than 3 METs. [5], [6] The existing studies primarily have examined off the shelf games with game-determined pacing. To our knowledge, no studies have examined energy expenditure during self-paced custom video game play for individuals post-stroke compared to a standard of care activity.

Additionally, another favorable claim regarding video games is that they make therapy more enjoyable. Enjoyment is a person's perception of an activity or event related to competence and personal preference and is a positive emotion linked to intrinsic motivation.[7] Enjoyment can be an outcome of physical activity participation but is also a predictor of participation.[8], [9] Enjoyment, however, has not be systematically studied in the application of video games for individuals post-stroke. Specifically, a study examining the enjoyment of a custom self-paced game compared to an equivalent standard of care activity has not been conducted. Also, some preliminary research has a suggested an inverse relationship between enjoyment and perceived effort such that as enjoyment increases, perception of effort decreases.[10] Therefore, both enjoyment and perceived effort should be assessed to better understand the benefits of the application of video games for individuals post-stroke.

While the proposed benefits of video games for individuals post-stroke have been shown in preliminary studies[6], [11]–[13] few studies have focused on the effect of visual feedback, provided in this way on kinematics. Fewer studies still, have compared video game conditions to a direct comparison standard of care activity. Therefore, the primary purpose of this study was to determine if a custom self-paced video game would promote intense training (repetitions and energy expenditure) while being less effortful and more enjoyable than a comparable standard of care activity. The secondary purpose was to quantify how knowledge of performance, influenced stepping kinematics. We hypothesized that repetitions and energy expenditure would be comparable, but kinematics would be more asymmetrical during standard of care compared to the custom video game. Further, perceived effort would be lower, and enjoyment would be greater for the custom self-paced video game compared to standard of care.

II. METHODS

A. Participants

Participants were individuals in the chronic phase post-stroke who were 1). able to walk 100 feet without assistance and 2). stand for three minutes continually. They were excluded if they had a history of a). severe heart disease, b). heart attack, c). valve replacement or coronary artery bypass surgery, d). severe lung disease, e). uncontrolled diabetes, f). traumatic brain injury or neurological disorder other than stroke, g). had a history of unstable medical condition or musculoskeletal disorder such as arthritis or hip and knee surgery or h). any other condition that would interfere with repeated stepping. Participants were screened for participation using the Physical Activity Readiness Questionnaire (PAR-Q).[14] A positive response resulted in consultation with their physician to be cleared for the protocol.

Fifteen participants completed the study. They ranged in age from 38-72 years-old. The mean time post-stroke was 8 years. They presented with mild to moderate severity on the Fugl-Meyer. Details of the participants and demographics are presented in Table I.

TABLE I. PARTICIPANTS' CHARACTERISTICS (N = 15)

Descriptor		Value
Gender (n = male / female)		10 / 5
Age (years)		55.4 ± 14.3
Time post-stroke (years)		8.3 ± 7.6
Orthotic (n = yes / no)		9 / 6
FMA (score)		21.4 ± 4.67
Hemiparetic side (n = right / left)		9 / 6
Walking aid (n = yes / no)	In the community	11 / 4
	During training conditions	8 / 5

Values are reported as mean ± standard deviation unless otherwise indicated;
FMA – the LE section of the Fugl-Meyer Assessment Scale.

B. Equipment

The VSTEP is an interactive video game originally developed and validated by the authors.[15] The current version was developed using UNITY 3d game engine (*Unity Technologies, Denmark*) and C# programing language. It uses the Kinect 1 sensor (*Microsoft Corp, United States*) for skeletal tracking of the lower extremities. For the experiment the visual display was rendered with a short throw projector with a size of 5 ft high by 4 ft wide. Metabolic data were collected with a Cosmed KB4 portable metabolic cart (*Cosmed, The Metabolic Company, Italy*) and Bluetooth Polar Heart HC-10 Monitor (*Polar Electro, Finland*).

C. Procedure

First, participants had their height and weight measured and gave a short history of their activity. Then a member of the study team explained and demonstrated the two activities. Participants were given time to ask questions and to practice each activity, including rating their perceived exertion on the Borg Rate of perceived exertion (RPE) scale. Participants were allowed to use their assistive devices, during familiarization and data collection. Calibration of the VSTEP volume occurred during familiarization phase. While participants practiced the VSTEP, the game was calibrated independently for the affected and unaffected lower extremities. The two conditions were as follows (Figure 1).

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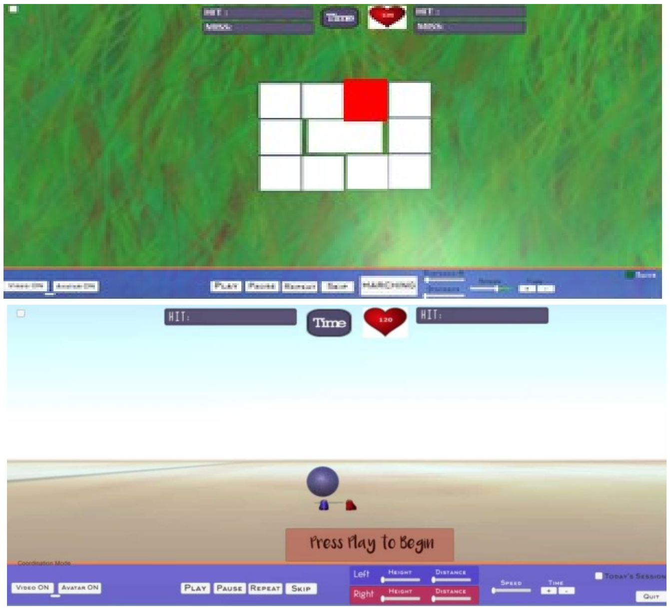

Fig. 1. VSTEP consisted of self-paced movements using visual feedback for stepping (top) and marching (bottom).

1). *VSTEP*: For this game participants used their body movements to interact with onscreen elements. Participants were instructed to step with the right or left LE in a specific direction (forward, side, or diagonal) and back to the center rectangle for 30 seconds at a time. After initiating the first step in one direction the target and center tiles alternated changing color at the pace set by the participant's stepping. After 1.5 minutes of three different directions, participants were instructed to contact an onscreen red ball with the dorsum of their right foot. Once contacted, the ball turned blue and was to be contacted with the left foot. The red and blue balls alternated, at the participant's pace for 30 seconds, to simulate marching. Overall, 1.5 minutes of stepping alternated with 30 seconds of contacting the ball for a total of 8.5 minutes. The tiles and the ball provided KR, changing color when successfully stepped on or contacted. Avatar shoes provided KP by showing the participants the trajectory of their feet and how far away from the targets they were.

2). *Standard of Care (SOC)*: The same set of movements in the same sequence was performed for the Standard of Care (SOC) condition for the same duration, without any visual targets. For example, participants were directed to step forward with their right foot for 30 seconds returning back to standing between each step. After thirty seconds, a new direction was indicated. After 1.5 minutes of stepping, participants were instructed to march in place. Similarly to the VSTEP condition, 1.5 minutes of stepping alternated with 30 seconds of marching for a total of 8.5 minutes. The two activities were equivalent in sequencing, timing, and pacing, with the addition of the visual feedback in the VSTEP condition being the only difference between the conditions.

Once participants were familiarized with the protocol and understanding of the activities was confirmed, participants were instrumented with a heart rate monitor (*Polar HC-10, Finland*) and a mask for the portable metabolic cart unit (*Cosmed KB4*). They then rested for 10 minutes to obtain their baseline physiological data. A reflective marker was placed on the heel of each shoe at the ankle height just prior to game play.

The two conditions (VSTEP and SOC) were performed for 8.5 minutes each with a ten-minute rest interval in between each condition. The duration of the activity bouts was selected for participants to reach an exercise plateau, in order to extract and analyze metabolic data and derive METS.[6] The order of the conditions was counterbalanced.

Event markers were recorded on the metabolic unit at the start and end of each exercise bout. RPE was recorded at beginning, middle and end of the exercise bout. A study team member held up a clipboard that had the numbers 6-20 and their respective perceived exertion levels (rest – maximum exertion) written in bold print. [16], [17] Participants could point or verbally indicate their RPE when asked.

Additionally, at the end of each bout participants completed the Physical Activity Enjoyment Scales (PACES). The PACES is an 18-item scale that assesses enjoyment for physical activity by asking patients to rate how they feel at the time of physical activity on a 7-point Likert scale, from 1 (I enjoy it) to 7 (I hate it). [18] Eleven items are negatively worded, and seven items are positively worded. After reversing the scores for the negatively worded items, an overall enjoyment score is determined by summing the numbers. Scores range between 18-126, with higher scores indicating higher enjoyment. [19] At the conclusion of both conditions, participants were tested for their motor control using the Fugl Meyer. [20]

D. Data Extraction and Reduction

a) Frequency of stepping and marching was extracted from the videos for both conditions. Two assessors (one had acquired the videos, the other verified the counts) manually counted the steps. A protocol for acceptable counts was developed and validated. Inter-rater reliability was established. Frequency of stepping was determined by the number of steps completed for each 30 second period defined by limb and direction of step. For example if the participant was instructed to step with their right foot forward for 30 seconds the number of steps with that limb in that direction for 30 seconds was the frequency. Additioanlly, the total number of steps over each 8.5 minute bout was also considered when extracting and analyzing frequency.

b) Accuracy of the VSTEP stepping was also extracted from the videos. Two assessors (one had acquired the videos, the other verified the counts) manually counted the accuarte steps. A step was considered accurate if the participant's foot landed partially or fully within the target tile. Similarly, when recorded by the system a step was considered accurate if the participant stepped into the correct tile as required by the game. The foot was considered "on target" when half of the foot had entered the target tile. Within the game, this is ensured using object colliders both on the foot (placed around the arch of the foot) and the tile (around the boundaries). Only counts from the video data were included in the analysis. The SOC did not have an accuracy requirement.

c) Kinematic analyses were performed for both conditions. A blinded assessor was chosen to view and extract data from the participant videos. Each video was manually digitized using the video player application, Kinovea 0.8.15 (*Kinovea.org, France*), to appropriately count and analyze all side-steps and marches completed by each participant. For the side-stepping procedure, at least 10 consecutive side-steps were extracted, measuring the distance from start to end point of the participants heel marker movement. Side steps were analyzed from the second block of the condition to ensure proficiency with the task while avoiding participant fatigue. The third block of stepping was only utilized if not enough stepping data could be extracted from the second block. For the marching, an average of the total march heights was taken. The distance was measured from the heel marker when standing on the ground to its highest point during the march. Inter-limb symmetry ratios of side step length and march height were calculated with mean values of the unaffected (U) and affected (A) lower extremities using the equation (1): A value of 1 indicated perfect symmetry.

$$\text{Symmetry} = 2U / (U + A) \qquad \square\square\square$$

d) Heart rate and metabolic equivalent: Raw data from the Cosmed system were exported as a Microsoft Excel file. In Excel, the data were visually inspected to verify the markers for the start and end time of each bout. Any erroneous markers were removed, and the bouts were labeled. In Matlab (*MathWorks, United States*) a three-minute plateau was selected and filtered using a band pass filter. The plateau was defined as stable data extracted 240 seconds from the end of the exercise bout. The volume of oxygen consumption (VO2), percent of maximum heart rate (% maxHR) and metabolic equivalent (METs) were calculated using standard formulas.

E. Data Analysis

The mean (frequency of stepping and marching, kinematics, % maxHR, METs) and maximum values (kinematics, % maxHR, METs), accuracy of stepping and marching, and symmetry ratios for each subject were calculated in Microsoft Excel 2010 *(Microsoft Corp., United States*). These data, together with RPE and PACES, were then exported to SPSS Statistics 24 (*IBM Corp., United States*). Mean values and standard deviations were calculated. Box plots were drawn to display variation in samples. Paired t-tests were used to test for differences. For comparisons between the affected and the unaffected limbs' parameters, and between RPE at the middle and at the end of each training and the PACES, the hypotheses were one-tailed. For the remaining comparisons the hypotheses were two-tailed. Level of significance was set on value alpha ≤ 0.05.

III. RESULTS

A. Frequency and accuracy of stepping and marching

a) Frequency: There were no significant differences in frequency of stepping and marching between VSTEP and the SOC for the affected LE. Frequency of stepping was significantly greater for the VSTEP compared to SOC when the unaffected limb was used in the forward direction (t = -2.233; p = 0.045). All other comparins for the affected limb were not significant. Only the SOC condition had greater frequency of the unaffected limb with side stepping (t = -2.232; p = 0.021) for within group comparisons of the affected and unaffected lower estremities. The remaining within group comparisons between the frequency of the unaffected and affected limbs was not signficant (Table II).

b) Accuracy: There were no significant difference between the affected and unaffected limb for stepping accuracy in all directs with the VSTEP (Table III).

TABLE II. FREQUENCY AND ACCURACY OF STEPPING AND MARCHING

n = 12-13	Limb	**SOC**	**VSTEP**	
		Frequency (n)		***Accuracy (%)***
Side Step	A	33.31 ± 8.49	31.38 ± 8.22	91.51 ± 13.05
	U	35.08 ± 7.99*	32.31 ± 8.07	95.70 ± 9.70
Forward step	A	20.92 ± 5.48	20.85 ± 6.15*	100 ± 0.00
	U	19.69 ± 5.65	22.38 ± 4.35+	98.74 ± 2.53
Diagonal step	A	15.69 ± 8.17	15.69 ± 7.34	98.29 ± 4.35
	U	16.00 ± 5.98	15.92 ± 6.71	97.83 ± 6.41
March	Both	111.00 ± 48.11	112.77 ± 57.95	

SOC – standard of care, A/U – affected/unaffected limb,
* comparison within condition between the affected and unaffected limb p < 0.05
\+ comparison between the SOC and VSTEP conditions p <.05

B. Kinematics and symmetry of stepping and marching

a)Kinematics and symmetry of stepping: Between conditions, both the affected and unaffected lower extremities demonstrated greater mean and maximum side step displacements during SOC compared to VSTEP. Within the two conditions the unaffected limb showed significantly greater displacement than the affected limb for mean side step in both the conditions (SOC mean side step: t = -1,977, p = 0.037; VESTEP mean side step t = -2.494; p =0.015). However, in the VSTEP condition, the difference of the maximum side step length between the unaffected and affected limb was not significantly different. The symmetry of step length was not significantly different between SOC and VSTEP (Table III).

b) Kinematics and symmetry of marching: As expected, the unaffected lower limb, compared to the affected, had significantly greater displacement for mean march height, comparably, in both SOC and VSTEP (SOC mean march height: t = -6.689, p = 0.000; VSTEP mean march height: t = -3.149, p = 0.004). Maximum march height of the affected limb, however, was significantly higher for VSTEP compared to SOC *(t = -2.258, p = 0.045)*. Futhermore, symmetry of marching was significantly greater for the VSTEP *(t = 2.452, p = 0.032)* (Table IV).

TABLE III. KINEMATICS AND SYMMETRY OF STEPPING

n = 12	Limb	**SOC**	**VSTEP**	p value
Mean side step length (cm)	A	40.87 ± 13.00	30.64 ± 11.69	0.001+
	U	51.62 ± 9.73*	39.55 ± 9.00*	0.000+
Max side step length (cm)	A	48.11 ± 14.36	40.67 ± 12.33	0.004+
	U	59.21 ± 12.28*	47.07 ± 9.92	0.001+
Side step length symmetry ratio		1.13 ± 0.21	1.15 ± 0.20	0.537

SOC – standard of care, A/U – affected/unaffected limb,
*comparison within condition between the affected and unaffected limb p < 0.05
+ comparison between the SOC and VSTEP conditions p <.05

TABLE IV. KINEMATICS AND SYMMETRY OF MARCHING

n = 12	Limb	**SOC**	**VSTEP**	p value
Mean march height (cm)	A	30.93 ± 19.36	40.70 ± 21.64	0.059
	U	59.36 ± 16.77*	58.19 ± 28.25*	0.879
Max march height (cm)	A	38.41 ± 20.84	50.27 ± 22.31	0.045
	U	72.49 ± 15.93*	71.02 ± 26.30*	0.855
March height symmetry ratio		1.36 ± 0.20	1.19 ± 0.23	0.032+

SOC – standard of care, A/U – affected/unaffected limb,
*comparison between the affected and unaffected limb p < 0.05.
+ comparison between the SOC and VSTEP conditions p <.05

C. Exercise intensity

a) Heart rate: There were no significant differences in % of max HR between the VSTEP and SOC. Both groups exercised in the target heart rate zone recommended for the accrual of health benefits for post-stroke Fig. 2).

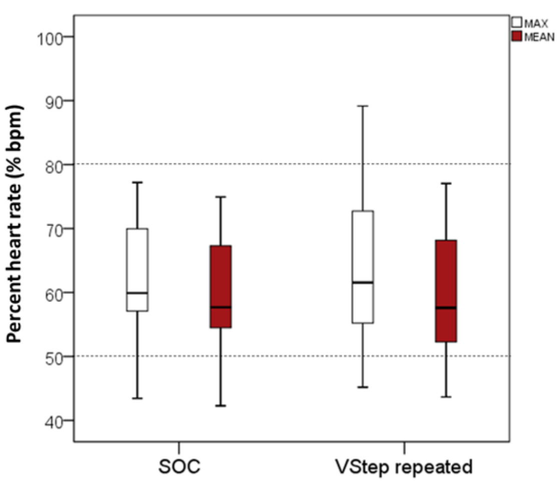

Fig. 2. Comparison of maximum and mean % of max heart rate between standard of care and training with VStep (n = 12). Area of recommended target heart rate for aerobic training for persons post-stroke indicated by the doted lines.

b) Metabolic equivalent: There were no significant differences in METs between the VSTEP and SOC. Both groups achieved moderate intensity of training (Fig. 3).

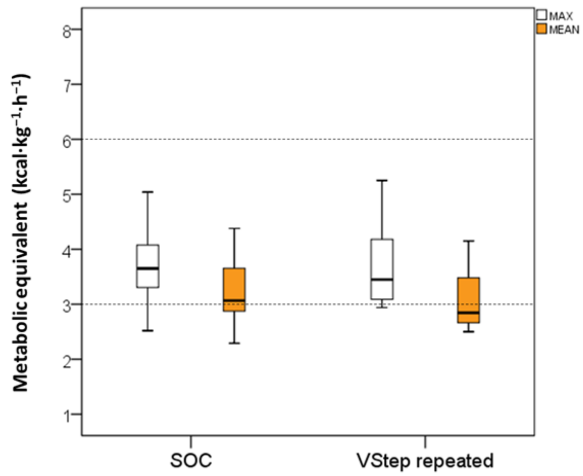

Fig. 3. Comparison of maximum and mean metabolic equivalent (METs) between standard of care and training with VStep (n = 12). Area of moderate exercise intensity is marked between the doted lines.

D. Perceived exertion and enjoyment

a) *Rate of perceived exertion* was significantly greater for the SOC at both the middle and end of the exercise bout. The difference was 1 on the RPE scale.

b) *Enjoyment:* Enjoyment was significantly greater for the VSTEP compared to the SOC. There was a difference of 5 points on the PACES (Table V).

TABLE V. MEASURES OF EXERTION AND ENJOYMENT

n = 15		**SOC**	**VSTEP**	p value
RPE	Middle	13.53 ± 1.81	12.47 ± 2.17	0.028+
	End	14.93 ± 1.91	14.00 ± 2.36	0.034+
PACES		78.27 ± 23.51	83.67 ± 20.54	0.037+

RPE – Borg rating scale of perceived exertion, PACES – physical activity enjoyment scale,
SOC – standard of care, + comparison between the SOC and VSTEP conditions p<.05

IV. DISCUSSION

As hypothesized repetitions and energy expenditure were comparable across both conditions, while asymmetry of stepping and marching was greater for the SOC. Additionally, as predicted, perceived effort was lower, and enjoyment was higher for the custom video game compared to the SOC.

Overall, repetitions were comparable between the VSTEP and SOC conditions. There were, however, differences in the amplitude and symmetry of movements. During the VSTEP the amplitude of the affected LE was lower for side stepping but higher for marching than during SOC, resulting in better movement symmetry. These differences may be attributed to the KR and KP provided by the visual feedback in the video game. The KR provided by the color changing tiles may have created confines for the side-stepping task, reducing side step displacements, within the VSTEP. The tiles may also have driven the affected limb so as to decrease the difference between the affected and unaffected limb for the maximum side step. The ball provided a goal-oriented target to aim for while the avatar shoes provided information about the trajectory and distance required to reach the target. This KP may have driven the affected limb to march higher in the VSTEP, influencing both the maximum march height of the affected limb and the symmetry ratio. The other differences in kinematics between the affected and unaffected limbs were expected based on the presence of temporal and spatial asymmetries along with other abnormal gait patterns in community ambulating adults post-stroke. [21], [22] Importantly the visual KP and KR feedback from the VSTEP promoted a more symmetrical stepping pattern and greater use of the affected LE. Previous studies involving KP and KR delivered via video games show benefits in LE outcomes for patients post-stroke, [1]–[3] but few studies specifically focused on kinematics.

Levels of physical activity required for health benefits for deconditioned individuals, recommend that individuals achieve moderate intensity, defined as a MET level of 3.0-5.9 or a percentage maximal heart rate greater than 50%. [23], [24] This study indicated that both interventions, allowed individuals to achieve this recommended intensity. This study along with previously published studies support the claim that video games can be used to achieve moderate intensity levels of physical activity [6], [12] for individual post-stroke. Importantly, while there was no difference in intensity between the two interventions, there was decreased perceived exertion for the VSTEP with a change in category from “hard” during SOC to “somewhat hard” during VSTEP.

As hypothesized, enjoyment was significantly greater for individuals when playing the VSTEP compared to the SOC. Similarly, previous literature has shown a positive relationship between video game play and enjoyment for individuals post-stroke. In a previous study participants post-stroke demonstrated an average of 4/5 points of enjoyment while playing the Wii Run game. [6] In a second study individuals post stroke reported a 6-point higher score on the PACES when playing Wii Fit balance games compared to SOC. [25] Therefore, findings of this study are comparable to findings comparing off-the-shelf rehab games to SOC, indicating good levels of enjoyment for the video game conditions.

CONCLUSION

The self-paced custom game, VSTEP, used in this study achieved comparable exercise intensity to the SOC, both of which were consistent with the recommended physical activity intensity for individuals in the chronic phase poststroke. Unlike the SOC however, this game was perceived as more enjoyable and less effortful. Additionally, the VSTEP positively impacted patterns of LE movement in a beneficial way for adults with chronic stroke. Therefore, it may be a preferred intervention in the management of care for individuals post-stroke.

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