Custom game paced video games played by persons post-stroke have comparable aerobic intensity but higher accuracy, greater enjoyment and less effort than off-the-shelf game

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Abstract— *Use of active video games in stroke rehabilitation is supported with efficacy studies of balance and mobility for persons in acute, sub-acute and chronic phases post-stroke. They have been characterized as well for their potential promotion of physical activity (PA). Games may be designed specifically for rehabilitation, or adapted from their intended recreational use for serious application such as rehabilitation or promotion of PA. A major limitation of the commercially available games is their lack of customization of movement parameters and inability to record performance metrics that are useful for practice. They are however, considered engaging and may promote high intensity of therapy (repetitions and physiologic correlates). This study compared the performance of persons in the chronic phase post-stroke playing a custom rehabilitation game to a comparable recreational active video game. The goal of the study was to determine, which game promoted greater exercise intensity and which was more enjoyable and less effortful. Fifteen participants in the chronic phase post-stroke were studied. The recreational game was played at a significantly higher intensity, both for repetitions, and energy expenditure while the experience of playing the custom game was reported as more enjoyable and less effortful. Further, movement accuracy was greater during custom game play. While intensity for metabolic equivalents (METs) and % of maximum heart rate were significantly greater when the recreational game was played, both games were played in the same intensity band to promote moderate activity. The custom game was comparable in intensity but superior in performance, enjoyment and perception of effort. The findings support efforts to develop custom games to promote physical activity for persons post-stroke.*

Keywords— *post-stroke, CVA, active video games, energy expenditure, intensity of training, enjoyment, custom video games*

I. Introduction

Active video games, also called serious games, have been shown to improve motor performance of persons post-stroke. These games may be customized for rehabilitation or adapted from their original purpose of recreation and applied therapeutically. It has been shown that recreational games that are bundled with commercially available game consoles such as the Nintendo Wii and Microsoft Kinect may address body function and structure, and activities as well as provide elements of motor learning such as knowledge of performance and knowledge of results. [1, 2] Further, it has been demonstrated that using active video games has comparable efficacy to standard of care in improving balance and walking [3-5] and have the potential to promote physical activity (PA.) [6, 7]

There are multiple considerations in selecting a game for rehabilitation. The game should meet the therapeutic goals of the patient, provide performance metrics and promote desirable movement patterns. [8] In fact, customization to the person's abilities is an integral recommendation for user centered design of games for persons with different disabilities. [9] One of the main disadvantages of using recreational games adapted for rehabilitation is that they cannot be adjusted to each person's needs/performance. Alternatively, customized video games allow for the control of the games' pacing. Specifically for persons post-stroke a game-based rehab-preference survey revealed that game pacing, how fast a player must respond in the game, was an integral factor that must be considered when implementing games-based rehabilitation strategies. [10] In a game where pace is not adjustable the person may experience

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frustration and decreased enjoyment or motivation possible interfering with adherence.

One of the purported benefits of active video games is that they make therapy enjoyable and therefore more motivating. Enjoyment is a positive emotion linked to intrinsic motivation [11] and is both a predictor and an outcome of PA participation. [12, 13] It is an individual's perception related to competence and personal preference, which can be associated with the type of PA, intensity level, environmental conditions, competition, and whether the activity takes place in an individual or group format. [11] Due to importance of PA for adults, enjoyment is an important construct for understanding PA participation, so the anticipated physical and psychological benefits can be realized.

While enjoyment and motivation have been touted as a benefit of active video games they have not been systematically studied in the application of these games for persons post-stroke. Some preliminary work [14] has suggested an inverse relationship between enjoyment and perceived effort. As enjoyment increases perception of effort decreases.

The purpose of this study was to compare the exercise intensity (movement repetitions and physiologic correlates), movement accuracy, enjoyment and perceived effort when persons post-stroke played a customized video game developed for rehabilitation and a comparable recreational game. We hypothesized that exercise intensity would be greater for the recreational game and that enjoyment would be greater, perceived effort would be lower and accuracy would be greater for the customized game.

II. METHODS

A. Participants

Participants were individuals in the chronic phase post-stroke who were 1. able to walk 100 feet without assistance 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). [15] A positive response resulted in consultation with their physician to be cleared for the protocol.

B. Equipment

The VSTEP is an interactive video game originally developed and validated by the authors. [16] The current version was developed using UNITY 3-d and C#. It uses the Kinect 1 sensor for skeletal tracking of the lower extremities. For the experiment the visual display (Fig. 1) 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 and Bluetooth Polar Heart HC-10 Monitor.

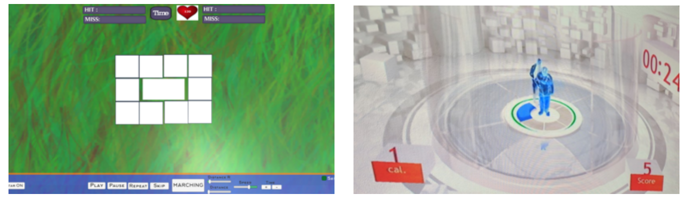

Fig 1. VSTEP (left) with customization of stepping volume and speed of presentation and the Microsoft Kinect™ game (right) with similar stepping activities to VSTEP but without customization.

C. Procedure

a) Familiarization: Participants first had their height and weight measured and gave a short history of their activity. During the familiarization phase of the study a member of the study team explained each activity the participants would perform. The participants were then given time to practice each activity and ask questions for clarifications. If subjects had assistive devices they were allowed to use the devices during the activities and practiced with the devices in the familiarization round.

Participants were also familiarized with and practiced the Borg Rate of perceived exertion (RPE) scale used to measure how hard participants felt they were exerting themselves during physical activity. A member of the study team asked participants to rate how hard they felt that they were working on a scale of 6 (rest) -20 (maximum exertion). A study team member held up a clipboard that had the numbers 6-20 and their respective written in bold print. Participants could point or verbally indicate their RPE when asked. [17]

The two activities that were practiced during familiarization and game are described as follows:

- VSTEP: Participants played the VSTEP game. During familiarization phase the game was calibrated to the individual participant's movement and therefore the distance from the center square to the tiles could differ on the affected vs unaffected side based on the participants' abilities. There was a center square and 6 tiles 1) right side, 2) right diagonal, 3) right front, 4) left front, 5) left diagonal, 6) left side (see Fig. 1 left). There was no stepping in the backward direction. For this game participants used their body movements to control avatar shoes on the screen. The participants started standing in the center square and then used the avatar shoes to step on tiles when they lit up. The participants were directed to step on blue tiles with their left feet and red tiles with their right feet. The speed and location of the lit-up tiles was directed by the game. The participant played 6 rounds of VSTEP lasting 1.5 minutes each. In between each round the participants were directed to lift their feet in a march-like step to contact a ball on the screen with the avatar shoe for 30 second bouts (five times total).

- Kinect: Participants played the Microsoft X-Box Kinect™ game Light Race at "easy" difficulty. For this game there was a circle of four tiles 1) right side, 2) right front, 3) left

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front, and 4) left side (see Fig. 1 right). The game was played at the easiest level where there was no stepping backward. The size of the circle and the position of the tiles was the same for all participants. An onscreen avatar was controlled with body movements to step on the tiles when they turn blue. If the participants stepped on a correct tile it turned green and if they stepped on an incorrect tile it turned orange. The speed was driven by the game. Participants were instructed to keep moving throughout the game. The participants played six rounds of Kinect lasting 1.5 minutes each. Between each round of Kinect (five times total) participants were instructed to march at their own pace for 30 seconds.

Once familiarized with the protocol participants were instrumented with a Polar Monitor and the mask for the portable metabolic cart unit. 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 marker was used for frequency counts.

b) Game Play: The two conditions (VSTEP and Kinect) were performed as described above for 8.5 minutes each with a ten-minute rest interval in between each condition. 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 each the exercise bout. 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.

b) Accuracy of the stepping was also extracted from the videos for both conditions. Accuracy was operationally defined and a protocol for acceptable counts was developed and validated. Inter-rater reliability was established. The VSTEP stepping accuracy was also recorded by the system.

c) Heart rate and metabolic equivalents: 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 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, % maxHR, METs) and maximum values (% maxHR, METs), and accuracy of side stepping for each subject were calculated in Microsoft Excel 2010 (Microsoft Corp., Redmond, WA, USA, 2010). These data, together with RPE and PACES, were then exported to SPSS Statistics 24 (IBM Corp., Armonk, USA, 2016). 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 1-tailed. For the remaining comparisons the hypotheses were two-tailed. Level of significance was set on value alpha ≤ 0.05.

III. RESULTS

A. Participants

Fifteen participants completed the study. They ranged in age from (38-72 years). 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. 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
Hemiparetic side (n = right / left)		9 / 6
Walking aid (n = yes / no)	In the community	11 / 4
	During training conditions	8 / 5
Orthotic (n = yes / no)		9 / 6
FMA (score)		21.4 ± 4.67

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

B. Frequency and accuracy of stepping and marching

a) Frequency of side steps: Frequency was signfiicantly higher for the Kinect for both the affected (t = 5.931; p = 0.000) and unaffected (t = 5.998; p = 0.000) limb. There was no difference in frequency between limbs (Fig. 2).

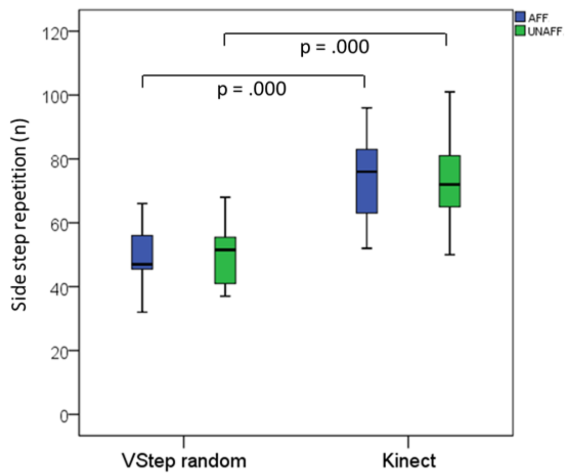

Fig. 2. Comparison of side step repetition with the affected (AFF) and the unaffected (UNAFF) limbs between training with VSTEP and Kinect (n = 12).

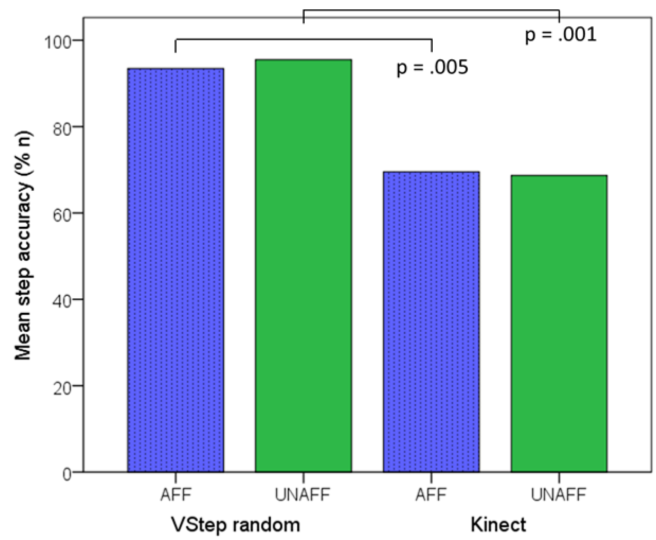

Fig. 3. Comparison of step accuracy with the affected (AFF) and the unaffected (UNAFF) limbs between training with VSTEP random and Kinect (n = 10).

b) Accuracy of side steps: Accuracy was significantly better for the VSTEP than Kinect for both the affected (t = -3.665; p = 0.005) and unaffected (t = -5.143; p = 0.001) limbs. There was no difference between the affected and the unaffected limb for mean step accuracy (n = 11) for either condition (Fig. 3).

c) Frequency of total stepping, total marching and total lower limb movements: The frequency of total steps weas significantly greater for the Kinect (t = 6.643; p = 0.000). The was no significant different between the frequency of the total marches. (Figure 4a) The frequency of the total movements (steps + marches) was significantly greater for the Kinect (t = 2.606; p = 0.024) (Figure 4b).

C. Exercise intensity

a) Heart rate: The maximum % maxHR (t = -3.640; p = 0.004) and the mean % maxHR (t = -4.510; p = 0.001) were significantly greater for the Kinect. During both the conditions exercise was in the band recommended for aerobic exercise for persons post stroke (Fig 5) . [21]

b) Metabolic equivalent: The maximum METs (t = -3.286; p = 0.007) and the mean METs (t = -4.489; p = 0.001) were significantly greater for the Kinect. During both conditions (VSTEP: 3.07 METs; Kinect: 3.72 METs) exercise was in the band considered moderate exerice (Fig. 6).

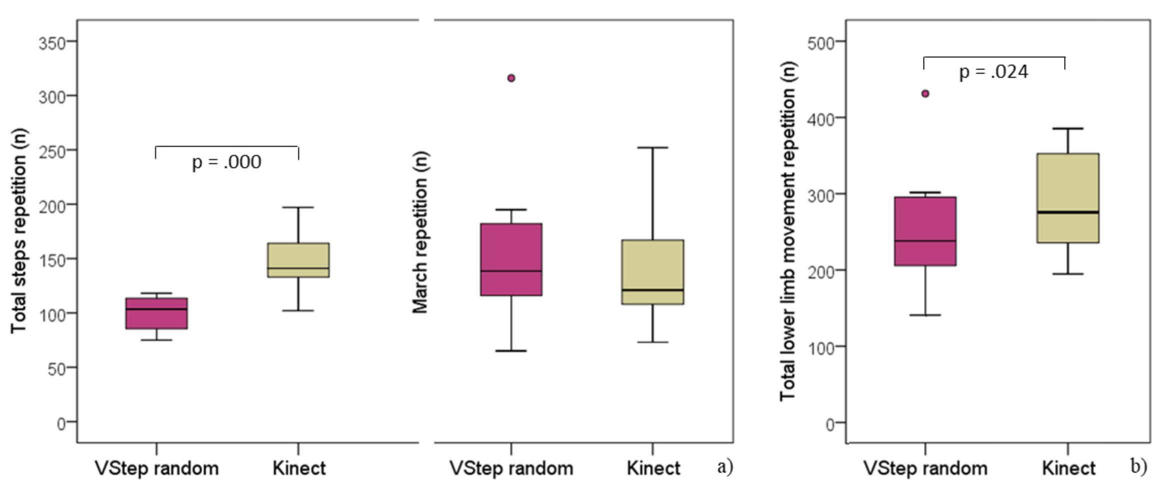

Fig. 4. Comparison of total steps and march repetition (a) and total lower limb movement repetition (b) between training with VSTEP and Kinect (n = 12).

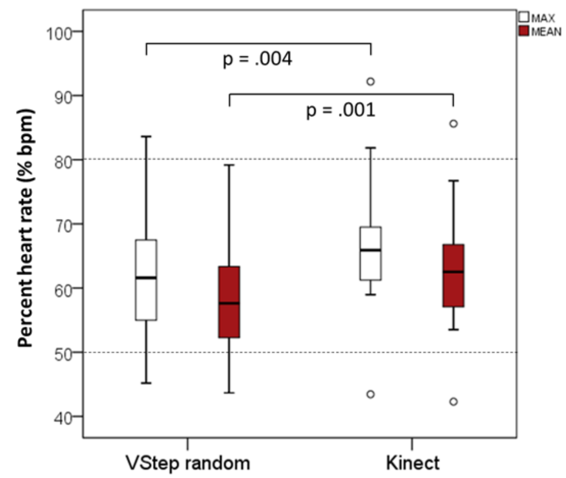

Fig. 5. Comparison of maximum and mean % of max heart rate between training with VStep random and Kinect (n = 12). Area of recommended target heart rate for aerobic training for persons post-stroke indicated by the doted lines. [21]

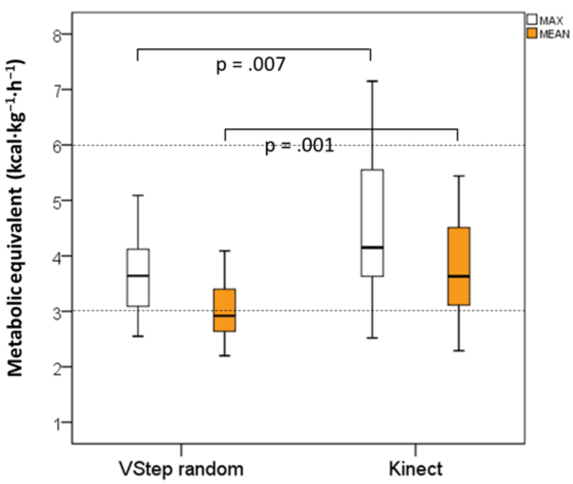

Fig. 6. Comparison of median maximum and mean metabolic equivalent (METs) between training with VStep and Kinect (n = 13). Area of moderate exercise intensity is marked between the doted lines.

D. Perceived exertion and enjoyment

a) Rate of perceived exertion: RPE at the end of exercise was significantly greater for the Kinect ($t = 2.197$; $p = 0.047$) (Table II). For both conditions, VSTEP ($t = -2.797$; $p = 0.007$) and Kinect ($t = -3.122$; $p = 0.004$), RPE at the end was significantly higher to RPE at the middle of training.

b) Enjoyment: Enjoyment was significantly gerater for the VSTEP than the Kinect ($t = -2.454$; $p = 0.015$) (Table II).

TABLE II. SUBJECTIVE MEASURES OF EXERTION AND ENJOYMENT OF THE ACTIVITIES

n = 14		**VSTEP**	**Kinect**	p value
RPE	Middle	12.00 ± 2.48	12.36 ± 2.73	0.315
	End	12.79 ± 3.12	13.64 ± 3.13	0.047
PACES		90.57 ± 16.64	81.07 ± 19.22	0.015

RPE – Borg rating scale of perceived exertion, PACES – physical activity enjoyment scale

IV. DISCUSSION

As hypothesized we found that the exercise intensity was greater (both for repetitions, METs and % of maximum heart rate) for the recreational game. As anticipated the reports of enjoyment was greater and the perception of effort was lower when participants played the custom game. Finally, accuracy of performance was significantly better when participants played the custom game.

Intensity of exercise was measured both by repetitions of the movements and metabolic equivalents. While the repetitions of movement were significantly greater for the Kinect, this came at the cost of decreased movement accuracy. The volume of the VSTEP was manually adjusted in this experiment which supported movement accuracy for persons post-stroke. This manipulation may in part explain reports of greater enjoyment (there was a substantial 10-point difference). The ability to "keep up with the game's pace" by adjusting the volume of stepping may also explain the perception of effort being lower. This is consistent with what others have reported and interpreted with the context of an exercise flow experience. [14] Enjoyment using the PACES has been reported to be greater with a Wii-based intervention compared to standard of care. [22] To our knowledge this study is the first to compare enjoyment between custom and off-the-shelf games

Importantly, while the Kinect condition was significantly greater for METs and % of maximum HR both groups exercised within the recommended moderate intensity for persons in the chronic phase post-stroke. [21] Suggesting that there can be a balance between movement control and intensity of physical activity.

The translation of these findings into practice and the interpretation of the clinical meaning are yet to be fully tested. However, these positive results support further study.

V. CONCLUSION

Playing a custom game paced video game consisting of stepping and marching movements met the recommended guidelines for moderate activity exercise that were comparable to those executed when playing an off-the-shelf game. While the stepping frequency was greater for the off-the-shelf game, this came at the cost of lower accuracy. Further the custom game was reported to be more enjoyable and less effortful These findings support the use of custom video games over off-the-shelf games for promotion of physical activity while maintaining desirable movement control.

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