ORIGINAL ARTICLE

The Use of Virtual Reality in Stable Sitting Trunk Rehabilitation for Stroke Patients: A Pilot Study

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ABSTRACT

INTRODUCTION: Virtual reality (VR) holds promise for stroke rehabilitation. However, many existing VR systems requires users to stand while playing, posing a potential falling risk for stroke patients. This study investigated the effects of a custom-developed VR system that focus on trunk rehabilitation in stable sitting position on muscle activities, postural control, and physiological cost compared to conventional trunk exercises in stroke patients. **MATERIALS AND METHODS**: A cross-sectional observational pilot study was conducted involving 12 paretic stroke subjects performing four exercises: two Conventional Trunk Exercises (CTE) and two VR-based Trunk Exercises (VRTE) using customized Tilt-The-Maze (self-paced) or Catch-The-Mole (game-paced) games. Muscle activity was measured using electromyography (EMG). Postural control data in the Anterior-Posterior (AP) and Medio-Lateral (ML) axes was recorded using a force plate, while the physiological cost was measured via a heart rate sensor during the exercises. **RESULTS**: The results indicated low muscle activity and light -intensity cardiovascular responses in all CTE and VRTE exercises. Game-paced VRTE recorded slightly higher Center of Pressure (CoP) velocity in the AP and ML axes versus CTE (AP:4.40±1.80 vs. 4.02±1.20 cm/s; ML:6.40±2.54 vs. 5.42±2.21 cm/s). In contrast, the self-paced VRTE showed an insignificant impact on postural control than both CTE and game-paced VRTE. **CONCLUSION**: The game-paced VRTE induced comparable effects on muscular activation, postural control, and physiological cost to that of CTE in stroke patients. The findings suggest the stable-sitting VR system as a supplementary approach to the existing trunk rehabilitation protocols for stroke patients.

Keywords
Virtual reality, sitting position, postural control, muscle activity, stroke rehabilitation.

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INTRODUCTION

Balance impairment is a common clinical consequence of stroke, with estimates indicating that up to 80% of stroke survivors experience certain degree of balance dysfunction.[1] The deterioration of balance ability will significantly compromise the activities of daily living (ADL), induces greater fatigue, and increases the risk of falling for these individuals.[2,3] Balance issues in stroke survivors also substantially contribute to healthcare costs. In 2015, injurious falls associated cases incurred a national burden of $2.9 billion USD in informal caregiving expenses in the United States of America.[4]

The trunk of the human body plays a pivotal role in maintaining balance and gait.[5,6] Extensive evidence has demonstrated the effectiveness of trunk training in improving trunk control, balance, and overall mobility.[7] Past studies have also identified that trunk function as a useful predictor of balance,[8] walking ability,[9] and ADL outcomes.[10,11] However, trunk rehabilitation of stroke patients is strenuous as the monotonous nature of conventional therapy could inadvertently lead to patient attrition.[12]

Addressing this challenge, Virtual Reality (VR) emerges as a promising alternative to enhance patient engagement and training intensity.[13] Commercialized VR gaming systems, like Nintendo Wii™ Balance Board, positively impacted balance function, range of motion, and ADLs in stroke rehabilitation.[14,15] Recent observational studies have also revealed that VR can effectively challenge stability limits[16] but results in low activation of balance-related muscles.[17] The therapeutic applicability of VR solutions for balance rehabilitation is hindered by the absence of reliable calibration for different impairment levels, especially for patients with difficulty standing or maintaining balance.[18,19] This concern is especially pertinent for stroke survivors, as studies have identified distinctive challenges in standing positions, including exaggerated postural sway[20] and an increased risk of falling.[21]

In addition, findings from a recent review suggests that VR -based trunk exercises can improve trunk functions in both subacute and chronic stroke patients.[22] However, these VR -based exercises often overlook the crucial dynamic and coordination aspects of trunk movement. The studies apply a range of trunk training strategies, such as simulated driving[23] or canoeing[24], which fail to promote meaningful trunk movement, thereby limiting the potential of trunk rehabilitation.

Therefore, there is a demand for a VR solution tailored to trunk rehabilitation in a seated posture, specifically designed for stroke survivors with standing disabilities. To the best of knowledge, there are no studies focusing on the effects of VR in stable-sitting trunk rehabilitation currently. Consequently, this study aimed to bridge this research gap by investigating the impact of a custom-developed stable sitting VR system on muscular activation, postural control, and physiological cost in stroke survivors compared to conventional therapy. We hypothesized that the VR-based trunk exercises (VRTE) would demonstrate comparable outcomes to the conventional trunk exercises (CTE).

METHODS

Participants

This within-participant, repeated measures cross-sectional pilot study involved 12 stroke patients (9 males and 3 females) undergoing standard rehabilitation. The pilot sample size was determined based on the recommendation by Julious.[25] The participants were recruited voluntarily from the rehabilitation unit of Advanced Medical & Dental Institute (AMDI), Universiti Sains Malaysia (USM), based on the following inclusion criteria: (1) age 18 and above; (2) experiencing paretic status from a single stroke; and (3) capable of maintaining a stable sitting position. In addition, those who have the following criteria were excluded from the study: (1) suffering from comorbidities that could potentially interfere with the experiment; (2) epilepsy within recent years; or (3) having an implanted pacemaker.

The study was approved by the Human Research Ethics Committee of USM (JEPeM) (*JEPeM Code: USM/JEPeM/22120824*). The Medical Device Authority (MDA), Ministry of Health Malaysia, had also granted an exemption from registration of medical devices for the custom-developed stable sitting VR system in this study under protocol number *FS-GMD-20230308-4*. All participants provided informed consent.

Experimental Setup

Figure 1 displays the experimental setup, featuring a custom-developed NEAR3 Force Plate (USM, Penang, Malaysia), a game-operating desktop (PC #1), and another desktop (PC #2) for continuous data recording. The force plate was positioned approximately 1 m from a monitor displaying the game interface. The force plate functions both as a controller input for participants to engage with the game via trunk movements and as a tool for measuring ground reaction forces and the Center of Pressure (CoP) during various activities.

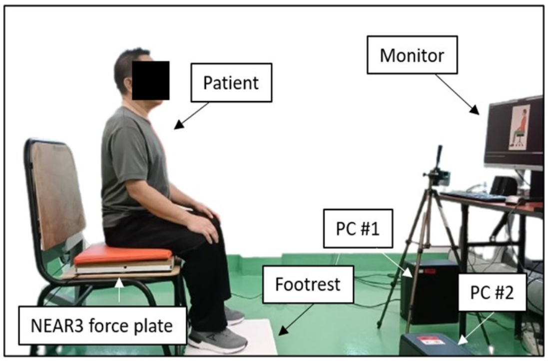


Figure 1: The experimental setup shows a stroke participant sitting on the NEAR3 force plate facing the monitor display.

Figure 2 showcases the connection between real-world trunk movements and their virtual representation within the VR game environment. In Figure 2A, the lateral trunk flexion performed by the participant is illustrated, while Figure 2B displays the corresponding CoP changes recorded by the force plate. The CoP is represented as a green dot: rightward flexion moves the CoP positively in the Medio-Lateral (ML) axis, leftward flexion moves it negatively; forward flexion shifts the CoP positively in the Anterior-Posterior (AP) axis, while arching backward moves it negatively. Subsequently, the acquired CoP data are utilized to map the movement of the mallet in the game interface, as depicted in Figure 2C.

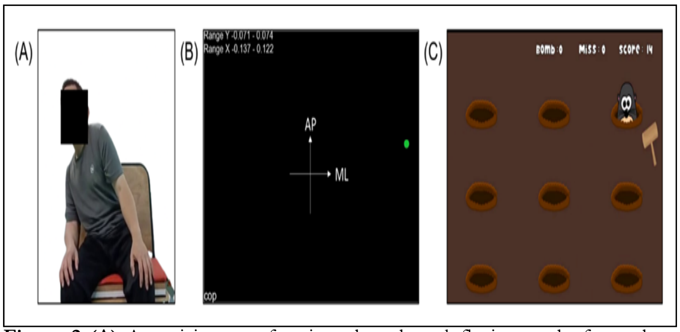


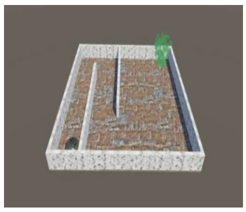
Figure 2 (A) A participant performing a lateral trunk flexion on the force plate. (B) The green dot represents the CoP on the force plate, shifting directionally with trunk movement. (C) Mapping of acquired CoP data to control the movement of the mallet in the VR game interface.

Intervention

Prior to the experiment, the participants' demographic and clinical data were collected to ensure the inclusion criteria were met. Electromyography (EMG) data were collected using a Shimmer3 EMG Unit (Shimmer, Dublin, Ireland). Following the SENIAM guidelines, the electrode patches were positioned bilaterally over the lumbar erector spinae, and a reference electrode was placed on spinous processes C7.[26] Participants were then instructed to perform the Reference Voluntary Contraction (RVC) procedure to establish baseline values.[27] To ensure maximal trunk movement and minimize compensation of other body parts during the exercise, participants were seated securely on the force plate, with their palms placed on their laps and their feet were gently supported onto the ground or a footrest. Additionally, participants were instructed to avoid touching the seat's backrest during the exercise. The sequence of exercises was randomized. For CTE, participants performed two stable-sitting core exercises, trunk flexion-extension, and trunk sagittal inclination, with three repetitions each.[28] Trunk flexion-extension exercise involves alternately curling and arching the trunk in frontal direction, while sagittal trunk inclination exercise involves lateral flexion and extension. For VRTE, participants engaged in two custom-developed non-immersive VR games, Catch-The-Mole and Tilt-The-Maze. As described in Table I, Tilt-The-Maze presented a self-paced VR game where players navigate a rolling ball through a maze by tilting the platform through trunk movements. In contrast, Catch-The-Mole adopted a game-paced approach, requiring players to react quickly to the appearance of moles at nine different positions and tapping them with a virtual mallet controlled via trunk movements.

Prior to VRTE, participants were subjected to calibration tasks in which they were asked to sit still for 10 seconds to map their static CoP to the game's centre position. Subsequently, participants performed maximal frontal, backward, and lateral trunk excursions to establish the game boundaries. A practice session and a detailed explanation of the exercises were provided to reduce the learning effect during the actual assessment sessions.[29] Both games amounted to roughly 5 minutes of gameplay time, with sufficient rest intervals between each exercise to prevent fatigue. Concurrently, the participant's Heart Rate (HR) was measured continuously using a wrist-worn Polar Verity Sense heart rate monitor (Polar Electro, Kempele, Finland) throughout the exercise.

Table I: Description of the two types of Serious Games used for the VRTE.

Game	Tilt-The-Maze	Catch-The-Mole
Figure		
Game description	Players navigate a rolling ball through a set of mazes to reach a target by tilting the maze using trunk movements	Players react to the appearance of moles in nine different positions by moving the hammer using trunk movements to hit the moles
Pace of the game	Self-paced. Players dictate their own pace of movement	Game-paced. The player must react to a target. Speed increases with player success
Type of movement required	Trunk movement in the AP and ML axes	Trunk movement in the AP and ML axes

Outcome Measures

Muscle Activation

The mean EMG amplitude of the erector spinae muscles was recorded at a sampling rate of 1024 Hz using a Shimmer3 EMG unit. The erector spinae muscle is selected as the targeted muscle group for investigation due to its importance to trunk control and movement.[30] Subsequently, a 20 Hz fourth-order high-pass Butterworth filter was applied to process the raw EMG signal, followed by a low-pass cut-off of 511 Hz. Line noises were then removed using a multi-taper estimate of sinusoidal components. Then, the signal was rectified by taking the absolute value of the filtered signal. Finally, a fourth-order, zero-phase-lag low-pass Butterworth filter with a cut-off frequency of 10 Hz was applied to obtain a smoothed linear envelope. The maximum value from the three RVC trials was selected as the 100% RVC value for EMG normalization.

Postural Control

CoP data in the AP and ML axes were recorded using the custom-developed force plate at sampling rate of 80Hz. Given that this study exclusively focused on trunk movements executed in a stable sitting position, CoP movements were assessed as a surrogate measure to evaluate postural control changes, including the speed and range of trunk movement during the stable sitting trunk exercises.[16,31] The range of CoP excursion in the AP and ML axes (CoP $Range_{AP}$, CoP $Range_{ML}$) indicates the maximum range of trunk motion during the exercise,[31] and the velocity of CoP displacement (CoP $Velocity_{AP}$, CoP $Velocity_{ML}$) reflects the velocity of trunk movement.[16] The CoP range and velocity were derived based on the equations outlined in a previous study.[32]

Physiological Cost

A wrist-worn Polar heart rate monitor was used to record participants' HR. The raw data is collected using the Polar software development kit (SDK). The data was then computed as a percentage of the predicted maximum HR (%HRmax=220 - age), corresponding to the physiological expenditure during the exercises.

Statistical Analysis

Statistical Package for the Social Sciences (SPSS) v27.0 for Windows (SPSS, Chicago, IL) was applied to conduct statistical analyses. Boxplots were first used to identify any outliers in the data. Next, the normality of the data was assessed using the Shapiro-Wilk test. A one-way repeated measures Analysis of Variance (ANOVA) was performed for normally distributed data. Besides, the sphericity assumption was evaluated using Mauchly's test of sphericity, and violations of this assumption were adjusted using the Greenhouse-Geisser correction. Partial eta-squared (η^2) was calculated to measure the effect size for each main effect and interaction. Additionally, post-hoc pairwise comparisons were conducted using Bonferroni corrections to examine specific differences between different exercises. The statistical significance level was set at $\alpha=0.05$.

RESULTS

Demographic and Clinical Characteristics of Participants

All stroke patients successfully completed both CTE and VRTE sessions without any adverse effects. Table II presents the demographic and clinical characteristics of the participants. This study included 12 stroke patients with a mean age of 46 years old. Table III demonstrates the descriptive statistics and ANOVA results for EMG, postural control, and physiological cost. For conventional exercises, trunk flexion-extension exercise does not involve motion in ML axis; while trunk sagittal inclination exercise does not involve motion AP axis. Therefore, data points for these cases are represented with a dash ("-") to denote the absence of values. ANOVA results in Table III revealed significant differences in CoP $Range_{ML}$, CoP $Velocity_{ML}$ and CoP $Velocity_{AP}$ between exercises. To interpret these observed differences, post-hoc tests with Bonferroni corrections were conducted. The results are visually presented in Figure 3, with asterisk (*) brackets highlighting statistically significant differences.

Table II: Demographic and clinical characteristics of the participants.

Characteristics	Participants (n = 12)
Age (year), mean (SD)	46.33 (9.74)
Gender, n females (%)	3 (25%)
Time since stroke (months), mean (SD)	8.70 (5.85)
Left hemisphere stroke, n (%)	6 (50%)
BMI (kg/m^2), mean (SD)	25.68 (3.71)
Height (cm), mean (SD)	166.08 (9.78)
Weight (kg), mean (SD)	71.00 (12.92)

Muscle Activation

Referring to Table III, the mean EMG amplitude for the erector spinae muscle ranged from 23.08±15.32 to 33.67 ±27.68%RVC. The muscle activation levels for all CTE and VRTE exercises were relatively low, and the high standard deviations observed indicates substantial variability. Due to the sphericity assumption violation for both the EMG of left and right erector spinae, the Greenhouse-Geisser correction was applied to compensate for the accuracy. Accordingly, the difference in mean EMG amplitude in both the left ($F[2.09, 20.92] = 1.144$, $p=0.340$, partial $\eta^2=0.103$) and right erector spinae muscle ($F[1.60, 16.00]=1.090$, $p=0.346$, partial $\eta^2=0.098$) were statistically insignificant. This finding suggests that the CTE and VRTE engage the erector spinae at a similar level, potentially influenced by factors such as gameplay strategies adopted and compensatory movements during the exercises.

Postural Control

CoP Parameters in the ML Axis

Table III displays ANOVA results revealing significant differences in CoP Range$_{ML}$ ($F[2, 22]=14.050$, $p<0.001$, partial $\eta^2=0.561$) and CoP Velocity$_{ML}$ ($F[2, 22]=42.351$, $p<0.001$, partial $\eta^2=0.794$). Post-hoc comparisons illustrated in Figure 3A indicated a lower range of CoP during the self-paced Tilt-The-Maze game (11.50±4.18 cm) than in the CTE (17.10±5.50 cm; $p=0.003$) and game-paced Catch-The-Mole (17.51±4.87 cm; $p=0.002$). Figure 3B highlights that the Catch-The-Mole game achieved a higher CoP Velocity$_{ML}$ (6.40±2.54 cm/s) than the Tilt-The-Maze game (2.32±0.99 cm/s; $p<0.001$) and CTE (5.42±2.21 cm/s), although the result was insignificant. Regardless, the Tilt-The-Maze game showed significantly lower CoP Velocity$_{ML}$ than all other exercises (all pairwise comparisons $p<0.05$). Notably, the effect sizes for the CoP velocity and range in the ML axis were particularly compelling, with η^2 values of 0.794 and 0.561, respectively.

CoP Parameters in the AP axis

Additionally, Table III also shows that the changes in CoP Range$_{AP}$ were statistically insignificant ($F[2, 22]=0.473$, $p=0.630$, partial $\eta^2=0.041$), but the CoP Velocity$_{AP}$ was significantly different ($F[2, 22]=17.950$, $p<0.05$, partial $\eta^2 =0.620$). Figure 3C shows that the Tilt-The-Maze game promoted significantly lower CoP Velocity$_{AP}$ (2.04±0.71 cm/s) than both CTE (4.02±1.20; $p<0.001$) and Catch-The-Mole game (4.40±1.80; $p<0.001$).

Physiological Cost

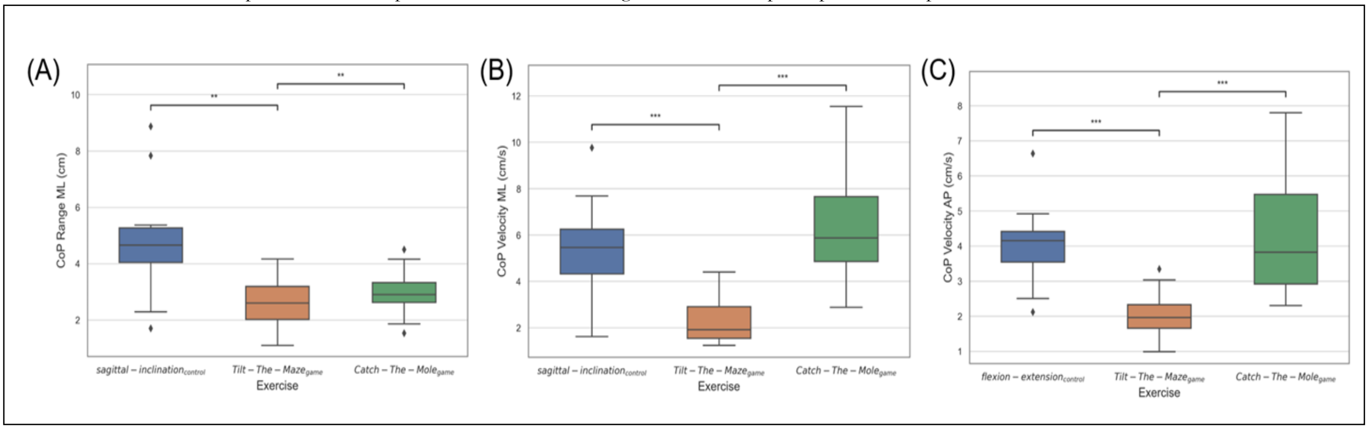
Table III also shows that there is insignificant changes in the HR between different exercises ($F[3, 30]=1.451$, $p=0.248$, partial $\eta^2=0.127$), indicating consistent exercise intensity across all exercises. The participants recorded an

Table III: Descriptive outcome measures and ANOVA results.

	Conventional trunk exercise		Virtual reality trunk exercise		ANOVA		
	Trunk flexion-extension	Sagittal trunk inclination	Tilt-The-Maze	Catch-The-Mole	F-Stat	p-value	Effect size (η^2)
EMG							
ES left (%RVC)	23.08 (15.32)	23.26 (15.91)	23.14 (16.77)	26.51 (14.21)	1.144 (df = [2.09, 20.91])	p = 0.340	0.103
ES right (%RVC)	33.67 (27.68)	30.05 (21.57)	27.38 (18.60)	28.27 (14.02)	1.090 (df = [1.60, 16.00])	p = 0.346	0.098
Postural control							
CoP velocity ML (cm/s)	-	5.42 (2.21)	2.32 (0.99)	6.40 (2.54)	42.351 (df = [2,22])	p < 0.001	0.794
CoP range ML (cm)	-	17.10 (5.50)	11.50 (4.18)	17.51 (4.87)	14.050 (df = [2,22])	p < 0.001	0.561
CoP velocity AP (cm/s)	4.02 (1.20)	-	2.04 (0.71)	4.40 (1.80)	17.950 (df = [2,22])	p < 0.05	0.62
CoP range AP (cm/s)	14.09 (3.88)	-	13.01 (3.09)	13.52 (4.38)	0.473 (df = [2,22])	p = 0.630	0.041
Physiological cost							
Heart rate (%HRmax)	45.71 (8.47)	47.22 (9.15)	47.39 (10.14)	47.82 (9.47)	1.451 (df = [3, 30])	p = 0.248	0.127

Note: Values are presented as means, with standard deviations (SD) in brackets; For conventional exercises that do not involve motion in the specific axis (AP or ML), the data points are represented with a dash ("-") to indicate the absence of values in those cases.
ES: Erector Spinae; RVC: Reference Voluntary Contraction; CoP: Center of Pressure; AP: Anterior-Posterior; ML: Medio-Lateral; HRmax: Predicted maximum heart rate

Figure 3: Values for the (A) CoP range in the ML axis, (B) CoP velocity in the ML axis, and (C) CoP velocity in the AP axis for different exercises in stroke patients. The box plots were constructed using data trials of all participants. Note: p-value at *<.05, **<.01, and ***<.001.



HRmax range of 45.71–47.82%, suggesting a uniform low-intensity cardiovascular response during CTE and VRTE exercises. From a clinical perspective, this finding implies that introducing VR-based exercises does not increase cardiovascular demand, therefore it could be a safe adjunct to conventional rehabilitation practices.

DISCUSSION

Muscle Activation

The EMG values in this study were measured in the form of %RVC due to the inability of stroke patients to perform Maximal Voluntary Isometric Contraction (MVIC) tasks.[33] Muscle activity levels greater than 50% of MVIC were categorized as challenging for healthy individuals.[34] The findings indicate that CTE and VRTE resulted in relatively low muscle activity (23.08±15.32 to 33.67±27.6), with insignificant differences in mean EMG amplitude among exercises. This suggests that the level of muscle activation in the erector spinae muscles was comparable between the CTE and VRTE.

The mean EMG amplitude was hypothesized to be higher in VRTE since previous studies also observed that muscle activities tend to be more intense when the participants were engaged.[35] However, the mean EMG amplitude between CTE and VRTE was insignificantly different, possibly due to participants adopting strategies to gain higher scores, such as maintaining a central position in the game to react faster to the targets. This strategic adaptation could compromise trunk muscle excursions and reduce overall muscle activation[36] Additionally, participants may engage in undesirable compensatory movements during VR-based exercises, causing the intended muscles to be less active.[37,38]

The notably high standard deviations in the EMG amplitude for both erector spinae muscles (14.02–27.68% RVC) may be ascribed to the heterogeneity of the recruited participants, as the severity and extent of impairments vary widely among stroke patients. These findings are aligned with earlier research suggesting fewer synergies in neuropathological conditions linked to stroke severity.[39] Moreover, Transcranial Magnetic Stimulation (TMS) findings suggest that cortical stroke lesions lead to impaired contralesional trunk muscle activation.[40] These factors could account for the high variability observed in this study.

Postural Control

As shown in Figure 2, the Tilt-The-Maze game exhibited a significantly lower CoP Range$_{ML}$ and CoP Velocity in both AP and ML axes than other exercises (all pairwise<0.05). In addition, the effect sizes for the CoP velocity and range in the ML axis were high, with η^2 values of 0.794 and 0.561, respectively. These effect sizes highlight the strong influence of the type of exercise on postural control metrics in the ML axis, suggesting that Tilt-The-Maze leads to a reduced range and speed of trunk movement compared to other exercises.

The observed findings can be attributed to the game's self-paced design and goal.[16,19] This game entails tilting the maze using CoP adjustments to guide a rolling ball towards the target. Participants only need to perform slight trunk movements to tilt the maze, and the ball will roll according to the gravity mechanism of the game. The self-paced nature of the game also allows participants to control their movement and avoid making large trunk movements or quick responses to achieve the goal. Conversely, the Catch-The-Mole game yielded significantly higher CoP Velocity in both AP and ML axes than Tilt-The-Maze, as well as higher than CTE, albeit insignificantly. This indicates that the Catch-The-Mole game involves faster trunk movements, mainly when reacting to the game targets.

This game-paced approach offers potential benefits in training trunk movement speed and responsiveness in stroke patients. For example, the elevated velocity during the game may lead to increased repetition, aligning with previous studies showcasing VR's immersive capability to enhance patients' motivation, resulting in higher repetition than conventional exercises.[13] Higher repetition enhances the intensity of rehabilitation, contributing to sensorimotor pathway recovery and improving clinical outcomes in stroke patients.[41,42]

The observed changes in postural responses among participants engaged in VRTE could be attributed to the immersive nature of VR environments. The VR system in this study utilized multisensory feedback mechanisms, such as the representation of the patient's trunk movements through a game avatar, the display of scores achieved, and auditory and visual cues signalling goal accomplishment. The feedback mechanisms might boost patient engagement and participation in trunk exercises.[43] This encouragement to exert greater effort is a likely key factor for the accelerated and more extensive trunk movements recorded during the Catch-The-Mole game.

Physiological Cost

HR is an objective and reliable measure of physical activity energy expenditure.[44] In this study, the mean HR between CTE and VRTE exercises was insignificantly different. Participants' HR remained around 45%, indicating a relatively low-intensity cardiovascular response compared to the recommended range (55–64%).[45] The observed results indicate a slightly lower intensity compared to previous studies, which demonstrated moderate activity levels through custom-made VR games in chronic stroke patients.[46,47] It is important to note that the present research solely focused on games in stable sitting positions, which may result in lower HR responses than standing positions.[46]

Despite anticipating higher HR due to the rapid trunk movements in the fast-paced Catch-The-Mole game, the brief exercise duration could have depreciated the overall HR. However, it is worth mentioning that the total training volume is essential in health improvement. A recent study revealed that low-intensity, high-duration exercises enhanced motor recovery in stroke patients.[48] Hence, emphasizing lower-intensity, longer-duration training using the VR system could be a promising alternative rehabilitation strategy for stroke patients, offering effective outcomes while minimizing injury risks.

Implications for Rehabilitation

This pilot study demonstrates the potential of VR systems in improving trunk rehabilitation for stroke patients, especially when performed in a stable sitting position. Findings indicate that game-paced VRTE can produce comparable effects on muscle activation, postural control, and physiological cost to conventional exercises. This suggests the potential of incorporating VR-based exercises into existing rehabilitation programs.

Stroke patients typically recover the ability to sit before they can stand during the early phases of rehabilitation.[49] Therefore, the use VR-based trunk rehabilitation in a seated position early on could offer a safer and more accessible entry point for the patients. In addition, a significant concern for stroke survivors with severe impairments is the increased risk of falls.[21] By enabling exercises in a stable sitting position through the use of our custom-developed VR system, the risk of falls could be mitigated. Furthermore, sustaining patient engagement and motivation is a major challenge in rehabilitation. The immersive nature of VR rehabilitation could enhance patient adherence to treatment plans.[13] By integrating VR technology into existing protocols, physiotherapists may encourage more consistent patient participation in rehabilitation, potentially leading to better outcomes due to the higher consistency and intensity of therapy sessions.[41,42]

LIMITATIONS

This study has several limitations that warrant discussion. Firstly, the relatively small sample size in this study may limit the generalizability of the results. A more extensive longitudinal study could provide an in-depth understanding of the long-term efficacy of VR in stroke patients. Secondly, this study was conducted during the coronavirus-2019 (COVID-19) pandemic. The reduced physical contact and interaction time might have limited the outcomes observed. Finally, trunk activation assessment using EMG was restricted to erector spinae muscles. Future studies should offer a holistic view of trunk muscle activation, including other trunk muscles, such as the external oblique, rectus abdominis, and multifidi. These limitations suggest that the results should be interpreted with caution, and further research is needed to confirm these findings in a larger, more diverse population.

CONCLUSION

The proposed trunk rehabilitation in stable sitting position using the custom-developed VR system demonstrated comparable postural control, muscular activation, and physiological cost to conventional trunk rehabilitation exercises. It was found that game-paced VRTE can promote a higher velocity in both AP and ML axes versus CTE (AP: 4.40±1.80 vs. 4.02±1.20 cm/s; ML:6.40±2.54 vs. 5.42±2.21 cm/s). In contrast, the impact of self-paced VRTE on postural control is less significant than both CTE and game-paced VRTE. The findings suggests that the stable-seated VR system could supplement the existing treatments, providing additional practice time or repetitions for stroke patients with varying levels of disability, particularly when standing posture might pose a risk.

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CONFLICT OF INTEREST

No competing financial interests exist.

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REFERENCES

1. Tyson SF, Hanley M, Chillala J, et al. Balance disability after stroke. Phys Ther 2006;86(1):30-8, doi:10.1093/ptj/86.1.30
2. Houdijk H, ter Hoeve N, Nooijen C, et al. Energy expenditure of stroke patients during postural control tasks. Gait Posture 2010;32(3):321-326
3. Giriko CH, Azevedo RAN, Kuriki HU, et al. Functional status of hemiparetic subjects submitted to group physical therapy. Fisioterapia e Pesquisa 2010;17(3):214-219
4. Joo H, Wang G, Yee SL, et al. Economic Burden of Informal Caregiving Associated With History of Stroke and Falls Among Older Adults in the U.S. Am J Prev Med 2017;53(6s2):S197-s204, doi:10.1016/ j.amepre.2017.07.020
5. Jijimol G, Fayaz RK, Vijesh PV. Correlation of trunk impairment with balance in patients with chronic stroke. NeuroRehabilitation 2013;32(2):323-5, doi:10.3233/nre-130851
6. Verheyden G, Vereeck L, Truijen S, et al. Trunk performance after stroke and the relationship with balance, gait and functional ability. Clin Rehabil 2006;20(5):451-8, doi:10.1191/0269215505cr955oa
7. Van Criekinge T, Truijen S, Schröder J, et al. The effectiveness of trunk training on trunk control, sitting and standing balance and mobility post-stroke: a systematic review and meta-analysis. Clin Rehabil 2019;33(6):992-1002, doi:10.1177/0269215519830159
8. Di Monaco M, Trucco M, Di Monaco R, et al. The relationship between initial trunk control or postural balance and inpatient rehabilitation outcome after stroke: a prospective comparative study. Clin Rehabil 2010;24(6):543-554

9. Duarte E, Morales A, Pou M, et al. Trunk control test: Early predictor of gait balance and capacity at 6 months of the stroke. Neurologia 2009;24(5):297-303
10. Hsieh C-L, Sheu C-F, Hsueh I-P, et al. Trunk control as an early predictor of comprehensive activities of daily living function in stroke patients. Stroke 2002;33 (11):2626-2630
11. Verheyden G, Nieuwboer A, De Wit L, et al. Trunk performance after stroke: an eye catching predictor of functional outcome. J Neurol Neurosurg Psychiatry 2007;78(7):694-8, doi:10.1136/jnnp.2006.101642
12. Burke JW, McNeill M, Charles DK, et al. Optimising engagement for stroke rehabilitation using serious games. The Visual Computer 2009;25(12):1085-1099
13. Rand D, Givon N, Weingarden H, et al. Eliciting upper extremity purposeful movements using video games: a comparison with traditional therapy for stroke rehabilitation. Neurorehabil Neural Repair 2014;28(8):733-739
14. Marques-Sule E, Arnal-Gómez A, Buitrago-Jiménez G, et al. Effectiveness of nintendo wii and physical therapy in functionality, balance, and daily activities in chronic stroke patients. J Am Med Dir Assoc 2021;22 (5):1073-1080, doi:https://doi.org/10.1016/j.jamda.2021.01.076
15. Anwar N, Karimi H, Ahmad A, et al. Virtual reality training using nintendo wii games for patients with stroke: Randomized controlled trial. JMIR Serious Games 2022;10(2):e29830, doi:10.2196/29830
16. Sheehy L, Taillon-Hobson A, Finestone H, et al. Centre of pressure displacements produced in sitting during virtual reality training in younger and older adults and patients who have had a stroke. Disabil Rehabil Assist Technol 2020;15(8):924-932, doi:10.1080/17483107.2019.1629118
17. de Vries A, Willaert J, Jonkers I, et al. Virtual reality balance games provide little muscular challenge to prevent muscle weakness in healthy older adults. Games Health J 2020;9(227-236, doi:10.1089/g4h.2019.0036
18. Staiano AE, Flynn R. Therapeutic uses of active videogames: a systematic review. Games Health J 2014;3(6):351-365
19. Anderson KR, Woodbury ML, Phillips K, et al. Virtual reality video games to promote movement recovery in stroke rehabilitation: a guide for clinicians. Arch Phys Med Rehabil 2015;96(5):973-976
20. Dickstein R, Abulaffio N. Postural sway of the affected and nonaffected pelvis and leg in stance of hemiparetic patients. Arch Phys Med Rehabil 2000;81 (3):364-367, doi:https://doi.org/10.1016/S0003-9993(00)90085-6
21. Mackintosh SF, Hill K, Dodd KJ, et al. Falls and injury prevention should be part of every stroke rehabilitation plan. Clin Rehabil 2005;19(4):441-51, doi:10.1191/0269215505cr796oa
22. Alhwoaimel NA, Alenazi AM, Alhowimel AS, et al. Effects of trunk exercises using virtual reality technology on trunk performance and impairment post stroke: a systematic review and meta-analysis. Topics in stroke rehabilitation 1-10, doi:10.1080/10749357.2023.2261701
23. Lee D, Bae Y. The Effectiveness of Driving Game on Trunk Control and Gait Ability in Stroke. Journal of Motor Behavior 2020;52(1):33-40, doi:10.1080/00222895.2019.1574259
24. Lee MM, Shin DC, Song CH. Canoe game-based virtual reality training to improve trunk postural stability, balance, and upper limb motor function in subacute stroke patients: a randomized controlled pilot study. J Phys Ther Sci 2016;28(7):2019-24, doi:10.1589/jpts.28.2019
25. Julious SA. Sample size of 12 per group rule of thumb for a pilot study. Pharmaceutical Statistics: The Journal of Applied Statistics in the Pharmaceutical Industry 2005;4(4):287-291
26. Hermens HJ, Freriks B, Merletti R, et al. European recommendations for surface electromyography. Roessingh research and development 1999;8(2):13-54
27. Chen I-H, Liang P-J, Chiu VJ-Y, et al. Trunk muscle activation patterns during standing turns in patients with stroke: An electromyographic analysis. Front Neurol 2021;12(doi:10.3389/fneur.2021.769975
28. Cabanas-Valdés R, Boix-Sala L, Grau-Pellicer M, et al. The effectiveness of additional core stability exercises in improving dynamic sitting balance, gait and functional rehabilitation for subacute stroke patients (CORE-Trial): Study protocol for a

randomized controlled trial. Int J Environ Res Public Health 2021;18(12):6615
29. Colombo R, Cusmano I, Sterpi I, et al. Test–retest reliability of robotic assessment measures for the evaluation of upper limb recovery. IEEE Trans Neural Syst Rehabilitation Eng 2014;22(5):1020-1029, doi:10.1109/TNSRE.2014.2306571
30. Babyar SR, Holland TJ, Rothbart D, et al. Electromyographic analyses of trunk musculature after stroke: An integrative review. Top Stroke Rehabil 2022;29(5):366-381, doi:10.1080/10749357.2021.1940725
31. Näf OB, Bauer CM, Zange C, et al. Validity and variability of center of pressure measures to quantify trunk control in stroke patients during quiet sitting and reaching tasks. Gait Posture 2020;76(218-223, doi:10.1016/j.gaitpost.2019.12.011
32. Prieto TE, Myklebust JB, Hoffmann RG, et al. Measures of postural steadiness: differences between healthy young and elderly adults. IEEE Trans Biomed Eng 1996;43(9):956-66, doi:10.1109/10.532130
33. Sousa A, Tavares J. Surface electromyographic amplitude normalization methods: A review. In: 2012; pp. 85-102.
34. Townsend H, Jobe FW, Pink M, et al. Electromyographic analysis of the glenohumeral muscles during a baseball rehabilitation program. Am J Sports Med 1991;19(3):264-72, doi:10.1177/036354659101900309
35. Li C, Rusák Z, Horvath I, et al. Influence of complementing a robotic upper limb rehabilitation system with video games on the engagement of the participants: A study focusing on muscle activities. International Journal of Rehabilitation Research 2014;37(doi:10.1097/MRR.0000000000000076
36. Acosta AM, Dewald HA, Dewald JP. Pilot study to test effectiveness of video game on reaching performance in stroke. J Rehabil Res Dev 2011;48 (4):431-44, doi:10.1682/jrrd.2010.04.0052
37. Soltani P, Figueiredo P, Fernandes R, et al. Muscle activation behavior in a swimming exergame: Differences by experience and gaming velocity. Physiology & Behavior 2017;181(23-28, doi:10.1016/j.physbeh.2017.09.001
38. Jaramillo JP, Johanson ME, Kiratli BJ. Upper limb muscle activation during sports video gaming of persons with spinal cord injury. J Spinal Cord Med 2019;42(1):77-85, doi:10.1080/10790268.2018.1452391
39. Van Criekinge T, Vermeulen J, Wagemans K, et al. Lower limb muscle synergies during walking after stroke: a systematic review. Disabil Rehabil 2020;42 (20):2836-2845, doi:10.1080/09638288.2019.1578421
40. Fujiwara T, Sonoda S, Okajima Y, et al. The relationships between trunk function and the findings of transcranial magnetic stimulation among patients with stroke. J Rehabil Med 2001;33(6):249-55, doi:10.1080/165019701753236428
41. Veerbeek JM, van Wegen E, van Peppen R, et al. What is the evidence for physical therapy poststroke? A systematic review and meta-analysis. PloS one 2014;9(2):e87987
42. Wikström H, Roine RO, Aronen HJ, et al. Specific changes in somatosensory evoked magnetic fields during recovery from sensorimotor stroke. Annals of Neurology: Official Journal of the American Neurological Association and the Child Neurology Society 2000;47(3):353-360
43. Kiper P, Szczudlik A, Agostini M, et al. Virtual reality for upper limb rehabilitation in subacute and chronic stroke: a randomized controlled trial. Arch Phys Med Rehabil 2018;99(5):834-842. e4
44. Hills AP, Mokhtar N, Byrne NM. Assessment of physical activity and energy expenditure: an overview of objective measures. Front Nutr 2014;1(5, doi:10.3389/fnut.2014.00005
45. American College of Sports Medicine Position Stand. The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. Med Sci Sports Exerc 1998;30(6):975-91, doi:10.1097/00005768-199806000-00032
46. Kafri M, Myslinski MJ, Gade VK, et al. Energy expenditure and exercise intensity of interactive video gaming in individuals poststroke. Neurorehabil Neural Repair 2014;28(1):56-65, doi:10.1177/1545968313497100
47. Deutsch JE, James-Palmer A, Damodaran H, et al. Comparison of neuromuscular and cardiovascular

exercise intensity and enjoyment between standard of care, off-the-shelf and custom active video games for promotion of physical activity of persons post-stroke. J Neuroeng Rehabil 2021;18(1):63, doi:10.1186/ s12984-021-00850-2

48. Abbasian S, Rastegar Mm M. Is the intensity or duration of treadmill training important for stroke patients? A meta-analysis. J Stroke Cerebrovasc Dis 2018;27(1):32-43, doi:10.1016/ j.jstrokecerebrovasdis.2017.09.061
49. Sommer B, Haas M, Karrer S, et al. The Effect on Muscle Activity of Reaching Beyond Arm's Length on a Mobile Seat: A Pilot Study for Trunk Control Training for People After Stroke. Arch Rehabil Res Clin Transl 2023;5(4):100289, doi:10.1016/ j.arrct.2023.100289