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Effects of different types of augmented feedback on intrinsic motivation and walking speed performance in post-stroke: A study protocol

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ABSTRACT

Introduction: During recovery from stroke, augmented performance feedback can be applied with simple displays of metrics, as well as enhanced with virtual reality (VR) and exergames. VR, as augmented feedback, can provided to enhance walking speed after six months of stroke onset. There are several mechanisms to induce improved motor performance and motivation. Our objective is to design a study to demonstrate the different effects of augmented feedback, simple VR and exergaming applications on motivation and walking speed performance in post stroke.

Methods: Eighteen individuals with chronic stroke will be recruited and asked to walk as fast and safely as they can while on a robotic, user speed-driven treadmill (KineAssist-MX®) in three conditions: (1) with simple visual augmented feedback, but without a VR interface, (2) with a basic VR interface and (3) with a VR exergame. The main outcome measures are 30 s of fast walking speed and intrinsic motivation measured using the Intrinsic Motivation Inventory-Interest and Enjoyment Subscale. A within-subjects repeated measure ANOVA test and post hoc analysis will be used to determine the differences in changes of maximum walking speeds among the three performance conditions.

Discussion: The additive impact of augmented feedback with or without VR and VR-exergames on motivation and walking speed during stroke rehabilitation is unknown, a gap we aim to address. Our findings will contribute key details regarding the effects of different types of augmented feedback on walking speed and intrinsic motivation and to the refinement of theoretical frameworks that guide the design and implementation of augmented feedback during recovery after stroke.

1. Background

1.1. Significance

After a stroke individuals experience both physical and psychological impairments. One physical consequence of stroke is hemiparetic gait which is characterized by spatiotemporal gait impairments that contribute to decreased walking speed [1]. Slow walking speed in people post-stroke correlates with limitations in their daily activities, as well as restrictions of their participation in social roles [2]. For example, after stroke, individuals might have limited mobility and personal care activities, and community life restrictions due to their slow walking speed [2].

Another important psychological consequence of stroke is that individuals may also develop apathy, which leads to lost interest and reduced motivation during the recovery process [3]. Especially during training sessions, it is important to encourage people to perform at their highest capabilities to get optimum benefit from the session. Even minor levels of reduced motivation resulting from apathy showed significant impacts on post-stroke outcomes, including walking [4,5]. Thus, multifactorial approaches that address both physical (i.e., walking speed) and psychological factors (i.e., motivation) are needed to enhance post-stroke outcomes [5].

There are a variety of strategies used to increase walking speed, regardless of the presence or absence of apathy. These strategies mainly include body weight supported treadmill gait training and robotic as-

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sisted gait training [6]. Of these strategies, some studies found that walking on robotic treadmills might provide a safe and secure performance environment, and produce a more symmetrical pattern of leg muscle activity [7,8]. Clinical practice guidelines recommend gait trainings with augmented feedback to increase patients' engagement to better enhance walking function [6].

Augmented feedback can be provided during walking training as extra information to enhance the body's intrinsic sensory feedback mechanisms [9]. Augmented feedback plays a significant role in enhancing the performer's motivation by (1) directing their focus of attention and (2) providing information about errors and corrective actions [9]. These, taken together, enhance performance and encourage more attempts or a change in the performance of a motor task [9]. The most frequently used type of augmented feedback to enhance walking provides simultaneous real-time visual feedback using technology (i.e. virtual reality) [10].

Clinical practice guidelines suggest that virtual reality can provide augmented feedback to enhance walking speed after six months of stroke onset [11]. However, the clinical practice guidelines do not provide further guidance on which type of VR provides optimal inducement of walking speed in post stroke (i.e., game, and non-game-based VR). The non-game-based VR applications generally use VR features (i.e., immersion and real-time interaction) to mimic the real-world training conditions into the VR environment (i.e., experience constraints with walking in daily life and stepping over virtual objects) [12,13]. Game-based VR applications in rehabilitation, usually referred to as VR exergames (a combination of exertion and video games), have been used as adjuncts to gait training to enhance enjoyment [14,15]. We intended to discover whether providing augmented feedback alone, or with VR and with VR-exergames, will induce different walking speeds and motivational levels when performing fast walking on a robotic treadmill.

1.2. Enhanced OPTIMAL Theory

We developed the Enhanced OPTIMAL Theory by combining two theories, the OPTIMAL Theory (Optimizing Performance Through Intrinsic Motivation and Attention for Learning) [16] and the Theory of Work Gamification [17]. The Enhanced OPTIMAL Theory identifies relevant constructs and mechanisms associated with motivation, fast walking speed, and relevant VR features (i.e., enjoyment and feedback; see Fig. 1). It also depicts several possible constructs and pathways to induce immediate motor performance and motivation changes. In fact, this theory details four pathways (i.e., motivation, attention, informational, and affective) that could be manipulated to induce immediate changes to motor performance.

1.3. Objectives

We describe our protocol, which will seek to demonstrate the additive effects of augmented feedback, provided with and without VR, and VR-game on intrinsic motivation and walking speed performance. We hypothesize that exergaming, through a virtual reality environment, will result in the greatest increases in self-selected fast walking speed and intrinsic motivation, compared to augmented feedback without VR and augmented feedback with simple VR interface.

2. Methods

2.1. Overall study design

The central hypothesis of this study is that individuals' post stroke will demonstrate the most significant changes to fastest walking speeds, intrinsic motivation, and task enjoyment when VR exergaming is applied during a fast-walking performance task. We will use a within-subjects, repeated measures design where each participant will be exposed to each of three different augmented feedback conditions (i.e., augmented feedback without VR interface, augmented feedback with simple VR interface, and augmented feedback with VR interface and exergames). Our primary dependent variables will be walking speed and intrinsic motivation. We received IRB approval from the UAB Institutional Review Board (IRB-300000718). This protocol was registered at clinicaltrials.gov (Identifier: NCT04740060). Data collection will take place at University of Alabama at Birmingham in Spain Rehabilitation Center located in Birmingham, AL.

2.2. Study inclusion and exclusion criteria

We will include individuals with hemiparesis who are in the chronic phase of recovery from stroke (i.e., more than six months after the onset of stroke) who are able to follow instructions (Mini-Mental State Examination > 24) [18,19], and walk independently without using assistive

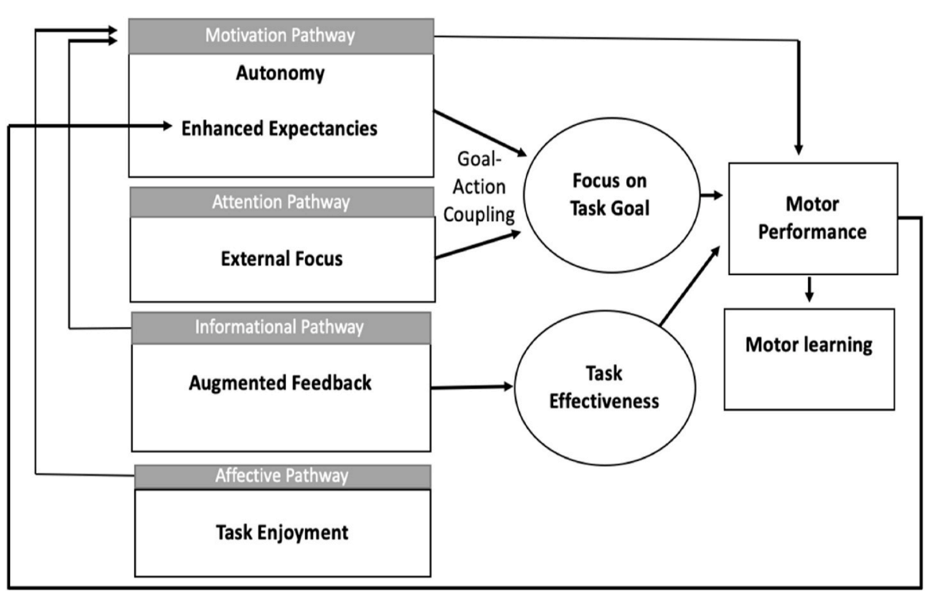

Fig. 1. Enhanced OPTIMAL Theory adapted from the OPTIMAL Theory [16] and the Theory of Work Gamification [17]. The conceptual model depicts several constructs that, through different pathways, induce immediate changes to motor performance and motivation.

devices for at least 3 min without rest. We will exclude people who have coronary heart disease, inability to stand and walk independently and other neurological diseases (besides stroke) that influence balance and mobility. Also, we will exclude people with visual impairments that affect the person's ability to see, focus on, and track movable objects.

A phone screen will be conducted during recruitment to determine participants' eligibility. To screen for walking ability, we will ask about usage of walking assistive devices (i.e., type of the used walking assistive device) and, if applicable, and ability to walk for at least 3 min without assistance from another person. To screen for visual impairments, we will use Cerebral Vision Screening Questionnaire (CVSQ) [20]. The CVSQ contains self-reported questions screening for: visual field loss, visual neglect, visual perception impairments, visual adaption deficits, contrast sensitivity impairment, change in color perception, and visual hallucinations [20]. To screen for ability to follow instructions we will complete the Mini-Mental State Examination in person, prior to initiation of data collection.

2.3. Study materials and equipment

We will use the KineAssist MX which is a robotic treadmill that allows the participant to walk at their self-intended walking speed, allows full freedom of motion, and ensures safety during walking and balance tasks [21]. The KineAssist MX has a pelvic harness system that senses horizontal hip forces used to drive the treadmill at the person's preferred speed in a relatively transparent manner [21]. The "self-drive" mode will be used to allow participants to control or drive the speed of the treadmill's belt. We also will use a large TV screen (i.e., VIZIO-75 Class V-Series, LED 4K UHD, Smart cast TV) that will be placed on a mobile TV cart and a gaming laptop with high processor capacity (i.e., Dell Alienware R4 15.6, Intel Core i7, 8 GB SSD). An ethernet connection cable will be used to connect the laptop to the KineAssist.

We will use a custom-made game built in the Unreal Engine (from here on referred to as "Racing Game"). The Unreal Engine 4 (UE4) is an advanced real-time 3D creation tool developed by Epic Games, using the C++ programming language [22]. The Racing Game is a partial immersion VR (i.e., moderate immersion level). In the Racing Game, there is an avatar racer who represents the participant. This avatar is in the middle of a virtual racing track with other simulated competitors and audiences (Fig. 2). This novel game is designed especially for individuals' post-stroke, aiming to enhance their maximum walking speed. The game provides individuals post-stroke with minimal challenge levels above their attempted performance to win the race game, provide immediate feedback, and make walking tasks more game-like by including avatar competitors with different speeds. Hence, the Racing Game is novel; it has not been used before.

2.4. Experimental conditions

Participants will complete (1) a baseline walking speed test to determine their self-selected fastest walking speed without augmented feedback and (2) three experimental conditions with varying levels of augmented feedback. During the baseline test participants will walk for 10 m. During each experimental condition, participants will only walk for 30 s to avoid fatigue as to avoid causing reduced walking speeds as the protocol progresses. Similar studies (i.e., low volume high-intensity training protocol) have also used bursts of 30 s of maximum walking speed followed by at least 2 min recovery period [23,24].

The VR exergaming application was designed to include four motivational elements (Fig. 2). To implement the comparison conditions, we masked certain elements to remove those influences, as follows:

Condition 1. Augmented feedback without a VR interface: the participant only receives visible real-time display of his/her walking speed (m/s; Fig. 2A). In this condition, we will mask everything on the screen except the real time measure of walking speed, time left for walking, and distance covered. The participants' goal is to keep the displayed walking speed as high as possible.

Condition 2. Augmented feedback with a simple VR interface: includes the feedback in the first experimental condition (Fig. 2A) and a representative avatar walker, using real-time walking speed data from the KineAssist, in a VR environment (Fig. 2B). The participants' goal is to make the avatar walker representative walk as fast as possible.

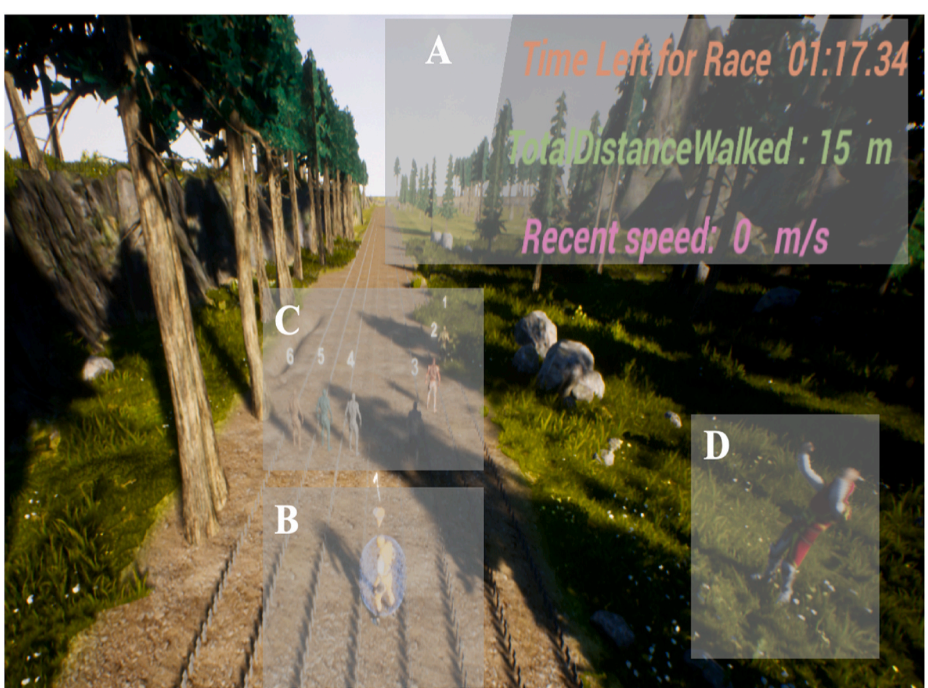

Fig. 2. Racing Game with motivational elements labeled. **A**. Real time measure of walking speed. **B**. Representative avatar walker in VR environment. **C**. Pre-set Competitors. **D**. Cheering audience.

Condition 3. Augmented feedback with VR and exergaming: includes the feedback in the first and second experimental conditions (Fig. 2A and B), as well as six other racers with pre-set speeds (Fig. 2C) and an audience cheering for the racers (Fig. 2D). In this condition, there will be three pre-set competitors to the right and another three pre-set competitors to the left of the participant's representative avatar racer. Each pre-set competitor on the right will walk at a pre-determined speed faster than the participant's baseline speed (i.e., fastest participant speed + 0.1, +0.2, +0.3 m/s). Each competitor to the participant's left will walk slower than the participant's baseline speed (i.e., fastest participant speed – 0.1, −0.2, −0.3 m/s). Thus, the participant's goal in this exergame is to beat the pre-set racers and finish, after 30 s, in the first place of the race. To win, a participant will need to walk, on average, up to 0.3 m/s faster than his or her baseline speed.

2.5. Application of the Enhanced OPTIMAL Theory to experimental conditions

Table 1 presents the pathways and constructs of the Enhanced OPTIMAL Theory and their application based on the three experimental conditions detailed above. Based on this theoretical application, we expect Condition 3 (augmented feedback with VR-exergame) to induce the largest changes in motor performance and motivation. For a detailed explanation of the original OPTIMAL Theory please refer to “Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL Theory of motor learning” by Wulf and Lewthwaite [16].

2.6. Measurements and evaluations

Participant characteristics and baseline measurements: We will gather demographic variables like age, gender, ethnicity, and race. Video games and VR experience questions (i.e., have you ever played video games? Have you ever experienced virtual reality (VR) technology before?) will be asked to evaluate participants' experiences and thoughts regarding video games in general. We will measure blood pressure before starting the protocol and after completing the protocol using a digital blood pressure machine with an upper arm cuff. We will measure heart rate at the beginning of the protocol, before and after each condition, and at the end of the protocol using a fingertip pulse oximeter. We will use The Apathy Evaluation Scale-Self rated version (AES-S) to quantify and characterize apathy [25]. The AES-S consists of 18 questions on an ordinal scale (i.e., not at all, slightly, somewhat, a lot). We will evaluate balance self-efficacy using the Activities-Specific Balance Confidence Scale (ABC). The ABC Scale is a 16-item self-report measure in which patients rate their balance confidence for performing various activities rating from 0 to 100 (i.e., a score of zero represents no confidence, a score of 100 represents complete confidence) [26,27]. We will measure comfortable walking speed three times on the KineAssist as Ten Meter Walk Test [21].

Primary dependent variables: Fast walking speed will be measured on the KineAssist as 30 s of fast walking. Intrinsic motivation will be measured immediately after each condition using the Intrinsic Motivation Inventory (IMI), which consists of 22 questions rating from 1 to 7 where a score of 1 means not at all true and 7 means very true in four subscales (interest/enjoyment, perceived competence, perceived choice, and pressure/tension). The psychometric properties of the IMI have been extensively studied [28,29]. The IMI has also been used in several post-stroke studies to evaluate intrinsic motivation [30–33].

The interest/enjoyment subscale is the only subscale that assesses intrinsic motivation in this instrument [34]. Although, all the IMI Subscales will be administered after each condition, and only results of the IMI- Interest and Enjoyment Subscale will be used as the indicator of participants' motivation level. The other IMI subscale results (i.e., perceived competence, perceived choice, and pressure/tension) will be used as secondary descriptive variables that might impact participants' motivation. The perceived choice and competence are theorized to be positive predictors of intrinsic motivation, while pressure/tension is theorized to be a negative predictor of intrinsic motivation [34].

Table 1
Summary of the Enhanced OPTIMAL Theory pathways and constructs and their presented elements (✓) into different experimental conditions.

Pathways	Constructs	Explanation	Elements	Condition 1 Augmented feedback without VR interface	Condition 2 Augmented feedback with simple VR interface	Condition 3 Augmented feedback With VR interface and exergame
Motivation	**Autonomy**	Self-selected fastest performance	Self-control of the treadmill belt	✓	✓	✓
	Expectancies	Prediction of outcome due to one's performance	Real-time walking speed (m/s)	✓	✓	✓
			Real-time walking distance (m)	✓	✓	✓
			Optical flow		✓	✓
			Other avatar racers			✓
			Place in race			✓
Attention	**External focus**	Pay attention to an external aspect while performing a motor task	Real-time walking speed (m/s)	✓	✓	✓
			Real-time walking distance (m)	✓	✓	✓
			Avatar walker		✓	✓
			other racers			✓
Information	**Augmented feedback**	Access to enhanced visual information in real-time about performance	Real-time walking speed (m/s)	✓	✓	✓
			Real-time walking distance (m)	✓	✓	✓
			Optical flow		✓	✓
			Other avatar racers			✓
			Place in race			✓
Affective	**Task enjoyment**	Elements added to the condition to make it more amusing	Avatar walker		✓	✓
			Other avatar racers			✓
			Audience cheering			✓
			Music			✓

2.6.1. Secondary dependent variables

The Borg Rating of Perceived Exertion (RPE) will be administered immediately after each walking condition [35]. We will hold up the scale on a clipboard and asked participants, "how hard are you working?". The Short Flow State Scale (SFS) will be administered after each condition [36]. The SFS is a positive experiential state that occurs when the performer is connected to the performance in a situation where personal skill equals the required challenge [37]. The SFS consists of 9-items in nine subscales representing the dimensions of flow using a Likert scale with five levels (i.e., strongly disagree, disagree, neither agree nor disagree, agree, strongly agree) [36].

2.7. Study protocol

Participants will be helped into the KineAssist, which will be adjusted to apply 4 kg (8.818 lbs.) body weight support to account for the weight of the pelvic mechanism. The KineAssist implements unweighting by applying a constant force upwards so the patient's weight on the floor will be lessened by 8.818 lbs. We will allow movement in all degrees of freedom by unlocking the KineAssist's locking mechanism to allow hip side to side movement, horizontal rotation, and hip hiking. We will use a catch height of up to 6 inches as default setting where the KineAssist can detect a patient fall via a drop-in the height of the pelvic harness (i.e., 6 inches). This is a safety mechanism to avoid contact with the floor. We will use a back-harness that is strapped to the pelvic mechanism, which will be adjusted (less than 45°) as a safety procedure to avoid flipping over and limit excessive forward trunk flexion.

Participants will be given an opportunity to become familiar with the operation of the self-intent walking mechanism of the KineAssist. Participants will be given time to walk on the KineAssist and experience a simulated fall while in the KineAssist. Once participants express that they feel comfortable in the KineAssist, as well as confident controlling the self-intent walking, we will begin the protocol.

Participants will then be asked to walk for 30 s at each of the three experimental conditions. We will counterbalance the order of the three experimental conditions. By doing so, we make sure that every possible sequence of the conditions will be given at least once every 6 participants. In addition to counterbalance, randomization will be employed for participants to be assigned to any of the six possible sequences using simple a randomization generated in Microsoft Excel (2018). After each walking condition we will provide adequate rest periods (i.e., 2 min) to allow the heart rate to return within 20 beats/min of standing values from baseline heart rate value.

2.8. Sample size calculations and statistical analyses plan

The effect size of virtual reality on lower extremity function in post stroke has been established as 0.424 [38]. Also, the effect size of walking speed was 0.34 in a study that included one group exposed to VR [39]. In addition, the effect size of intrinsic motivation was estimated at 0.380 based on the means and standard deviations of the Intrinsic Motivation Inventory (IMI- Interest/Enjoyment) between two VR-approaches (i.e., multi-user VR and single-user VR) [40]. For our sample size estimations, we sat alpha level as 0.05 and power as 0.80. Our estimated sample size was based on the power calculations for walking speed (18 participants) and intrinsic motivation (15 participants). Thus, we intend to recruit up to 24 individuals with a minimum target of at least 18 individuals with complete data. We used G*Power3.1 software to estimate the sample size, a general stand-alone power analysis program for statistical tests commonly used in social and behavioral research [41].

Data will be analyzed using IBM SPSS Statistics 26.0 (Armonk, NY: IBM Corp). Descriptive statistics will indicate the mean, median, maximum, minimum, and standard deviation in walking speed at each walking condition, as well as participants' characteristics. We will use the baseline measurements of fast walking speed to calculate the change in fast walking speed in each condition. So, each condition walking speed value will be subtracted from the baseline walking value to calculate the change.

The change in walking speed value will be used in the repeated measures ANOVA to determine statistically significant differences in changes of maximum walking speeds among the three performance conditions (i.e., augmented feedback without VR interface, augmented feedback with simple VR interface, and VR interface with exergames). In this case, the ANOVA independent factor will be the performance conditions, while the dependent factor will be the changes in walking speed. We will conduct a post hoc analysis (i.e., Tukey test) to precisely highlight the differences between the performance conditions.

For each condition, we will use correlation analyses (i.e., Pearson/Spearman) to identify: (1) if the change in walking speed is correlated with the IMI-Interest and Enjoyment Subscale score for each experimental condition, (2) if the maximum walking speed is correlated with SFS scores, and (3) if there is a correlation between having previous VR and videogames experience and changes in walking speed. Analysis of Covariance (ANCOVA) will be used to analyze impacts of apathy and balance confidence on walking speed and intrinsic motivation for the three-walking conditions.

3. Discussion

Slow walking speed in individuals post stroke is correlated with activity limitations and participation restrictions [2]. To enhance walking in post-stroke, walking on robotic treadmills might provide a safe and secure performance environment and produce a more symmetrical pattern of leg muscle activity [7,8]. In addition to robotic treadmills, augmented feedback is provided during the performance (i.e., walking speed) as the addition of information used to enhance the body's intrinsic sensory feedback mechanisms [9].

Regarding locomotor recovery in post stroke, current clinical practice guidelines recommend using virtual reality (VR) to provide augmented feedback as an effective way to enhance walking after six months on stroke onset [11]. Currently, VR is used in various forms (i.e., non-game-based VR applications and game-based VR applications). Non-game-based VR applications usually use haptic sensations, sounds, and different forms of movement visualizations and optical flow as real-time movement feedback [12,13]. To enhance walking and provide motivation, even more, game-based VR applications (usually referred to as VR exergames) are being developed and used in the clinic [14,15]. Both VR and VR exergames enhance enjoyment and provide augmented feedback to influence motivation and walking performance positively. Thus, it is unknown whether providing augmented feedback alone, with VR and with VR-exergames, will induce different walking speeds and motivational levels when performing fast walking on a robotic treadmill.

We aim to conduct more research in this area comparing the effects of different types of feedback on motivation and spatiotemporal gait performance during training after stroke. We will evaluate the immediate change in motor performance and motivation with/without the VR exergame as three performance conditions. We will use a novel approach in which a novel VR exergame was designed, especially for individuals post stroke, to encourage their fastest walking speed. The VR exergame was designed to provide individuals post stroke with minimal challenge levels above their attempted performance, provide immediate and comparable visual feedback, and make walking tasks more play-like.

Although this protocol has a theoretical framework, some limitations might need to be considered when designing or implementing an intervention study based on this protocol. To begin with, the sample size in this protocol might be too small to generalize the results to the post-stroke population. Even though this protocol measures the immediate impacts of different types of augmented feedback on walking speed and motivation, the short time of taking between measurements might impact the strength of the results (i.e., all outcomes measured in a single session). Another limitation of this protocol is that the game condition might have more enjoyment and motivational elements (i.e., other racers and audience sheering) which will not allow us to parse out the differential effects of adding each motivational element.

Our findings will contribute key details regarding the effects of different types of feedback on walking speed in post stroke. Additionally, our findings will contribute to the refinement of the existing theoretical framework that can help future researchers and clinicians who are designing and using VR exergames. Future studies would be designed as clinical trials to test the efficacy of our developed VR exergame, while also evaluate key outcomes related to inducing walking speed after stroke.

Conflict of interest

David Brown declares the following financial interests and personal relationships which may be considered as potential competing interests: He is a named inventor on the intellectual property associated with the KineAssist and does receive a share of royalties for any sales of this robotic treadmill. Saleh Alhirsan and Carmen Capo-Lugo do not have any conflicts of interests to declare.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: As conflict of interest in this study, Saleh Alhirsan and Carmen Capo-Lugo do not have any conflicts of interests to declare. David Brown declares the following financial interests and personal relationships which may be considered as potential competing interests: He is a named inventor on the intellectual property associated with the KineAssist and does receive a share of royalties for any sales of this robotic treadmill.

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