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Effects of Different Types of Augmented Feedback on Spatiotemporal Gait Performance and Intrinsic Motivation With Individuals Post Stroke

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EFFECTS OF DIFFERENT TYPES OF AUGMENTED FEEDBACK ON SPATIOTEMPORAL GAIT PERFORMANCE AND INTRINSIC MOTIVATION WITH INDIVIDUALS POST STROKE

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ABSTRACT

After a stroke, an individual can be left with physical and psychological deficits, including decreased walking speed, reduced step length, and reduced intrinsic motivation. These deficits affect their performance during rehabilitation sessions, limit daily activities such as walking and stepping, and restrict participation in social roles that involve mobility. Current clinical practice guidelines recommend providing augmented feedback using virtual reality (VR) to enhance walking outcomes after six months of stroke onset. This dissertation shows two novel VR applications designed, especially for individuals' post-stroke, to induce their fast-walking speed and maximum step length performance, and intrinsic motivation. Three performance conditions were designed as 1. Augmented feedback alone. 2. simple VR interface. 3. VR-exergames. Thus, we intended to test the immediate effects of these different types of augmented feedback on fast walking speed performance, maximum step length performance, and intrinsic motivation in post-stroke. Study 1 showed a theoretical framework (i.e., Enhanced OPTIMAL Theory) that combines two theories to comprehensively identify constructs and mechanisms associated with motivation and motor performance as well as relevant VR and VR-exergames features. The Enhanced OPTIMAL Theory depicts four pathways that directly or indirectly impact motor performance with several constructs that can be manipulated to enhance motivation and performance after stroke. Study 2 showed that individuals could walk slightly faster with all types of augmented feedback after stroke than their fast-walking speed without feedback, while VR-exergame offered a greater advantage and immediate effect on intrinsic motivation and enjoyment. Study 3 showed that individuals after stroke could slightly increase their maximum step length with all types of feedback than they could without feedback. The augmented feedback condition revealed an immediate significant effect on inducing paretic maximum step length performance and revealed a slightly higher motivation than VR-game and simple VR interface. In summary, this dissertation demonstrated the immediate effects of augmented feedback delivered with and without VR and exergames on motivation and performance and the refinement of theoretical frameworks that may guide the design and implementation of augmented feedback during recovery after stroke.

Keywords: Stroke; Augmented Feedback; Virtual reality; Exergames; Intrinsic motivation; Walking Speed; Step Length.

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LIST OF ABBREVIATIONS

ABC: Activities Specific Balance Confidence Scale

AES: Apathy Evaluation Scale

ANOVA: Analysis of Variance

HMD: Head Mounted Display

IMI: Intrinsic Motivation Inventory

IQR: Interquartile Range

KA: KineAssist

OPTIMAL: Optimize Performance Through Intrinsic Motivation and Attention for Learning

RPE: Rating Perceived Exertion

SD: Standard Deviation

SFS: Short Flow Scale

SPSS: Statistical Package for the Social Sciences

UE: Unreal Engine

VR: Virtual Reality

INTRODUCTION

A stroke occurs when there is a reduction or interruption of blood supply to an area of the brain which causes the brain cells to die within seconds[1]. Globally, data on stroke incidence provides evidence of variation among countries and changing magnitudes of burden among countries[2]. In Saudi Arabia, stroke incidence is rapidly increasing and is considered a significant cause of disability and mortality[3]. In the United States stroke occurs every 40 seconds and reduces mobility in more than half of stroke survivors[4]. After a stroke, many individuals are left with neurologic and psychological deficits, including, but not limited to, hemiparesis and post stroke depression[5,6]. These deficits limit activities, restrict participation and impact quality of life after stroke[7–9].

Hemiparetic Gait Dysfunction

According to the American Stroke Association, hemiparesis is a weakness in one side of the body[5]. In turn, hemiparetic gait is characterized by abnormal spatiotemporal gait impairments, including decreased walking speed, prolonged swing time and double stance bilaterally, and reduced step length compare to non-impaired individuals[10,11]. These spatiotemporal impairments result in a slow and asymmetric walking pattern, which eventually leads to decreased stability and poor efficiency of locomotion[12].

Psychological Consequences

Post stroke depression is a common neuropsychiatric sign that has been reported to negatively affect functional recovery[6]. Depression is described as a bad mood, lack of interest, and pleasure that persists for at least two weeks[13]. Post stroke depression includes apathy, which can occur as an independent syndrome or occur within a more elaborate presentation of depression[14]. Apathy is described as the loss of interest and lack of motivation present in a third of patients after stroke[15]. It has been shown that apathetic patients tend to have worse functional outcomes and lower quality of life[15,16]. Even minor levels of reduced motivation resulting from apathy showed essential and statistically significant impacts on stroke outcomes[17].

Impact of Intrinsic Motivation on Activities Performance

Intrinsic motivation is conceptualized as the act of engaging in a task or activity due to the inherent enjoyment or challenge involved rather than to seek external rewards or avoid punishments[18]. The opposite of intrinsic motivation is extrinsic motivation, where the focus is on external rewards or avoidance of punishment[19]. Intrinsic motivation is associated with performance of daily living activities, particularly crucial after stroke[18]. In post stroke rehabilitation, one study found that most patients are extrinsically motivated during rehabilitation, and their intrinsic motivation slightly increased towards the end of the rehabilitation[20]. This increase in intrinsic motivation seemed to result in improvement in their ability to perform activities of daily living[20]. In this case, intrinsic motivation may be regarded as an essential construct that reflects recovery and adaptation[18,19].

Optimizing Performance Through Intrinsic Motivation

The Optimizing Performance through Intrinsic Motivation and Attention for Learning (OPTIMAL) theory suggests that both motivational and attentional constructs contribute to performance and learning by strengthening the link/connection between goals and actions[21] (Figure 1). Based on this theory, several other constructs also influence performance and learning, including enhanced expectancies, autonomy, and an external focus of attention[21].

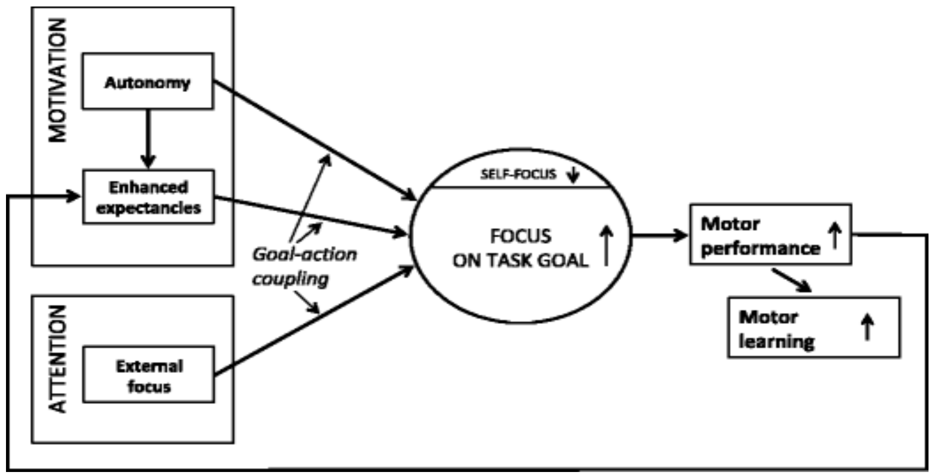

Figure 1. Optimizing performance through intrinsic motivation and attention for learning (OPTIMAL Theory)[21].

Expectancies refer to a range of forward-directed anticipatory or predictive cognitions or beliefs about what is to occur[21] . Expectancies are enhanced by the type of feedback received (i.e. positive or negative) and they reflect people's implicit knowledge[21]. For example, if you are in a racing competition with other competitors, you can estimate your ability to win the race based on where you are in the race. The racers behind you indicate that you are walking faster than they are while the racers in front of you indicate that you are walking slower than they are. Thus, you can expect that if you increase your walking speed, you might catch up to the racer in front of you while you might lose your current position to the race behind you if you slow down.

Autonomy is describing as a sense of volition people have during task performance (i.e., self-control). Finally, the external focus of attention refers to the skill and the ability to control the concentration on the task at hand and not the movement of individual body segments by filtering out information when there are distractions[21]. The OPTIMAL Theory classifies autonomy and enhanced expectancies as motivational constructs. It also classifies external focus as an attentional construct. Both motivational and attentional constructs impact motor performance and motor learning via enhance focus on task goals and minimize self-focus[21]. Thus, it is expected that individuals with high motivation might perform motor tasks better than those with low or lack of motivation.

Role of Feedback on Motivation and Performance

During gait training sessions, clinicians provide feedback in various forms, including verbal remarks and demonstrations[22]. These methods allow patients to become aware of how they move and to correct their compensatory movement strategies. There are mainly two types of performance feedback: (1) intrinsic feedback, which refers to the sensory-perceptual information that each of the sensory systems provides during a task and (2) augmented (external) feedback, described as the addition to or improvement of the body's intrinsic feedback mechanism[23].

Augmented feedback can be provided in several forms and times (i.e., before, during, and after movement)[23] . Before the movement, the instructor or coach might provide information (instructions) to augment how the performer thinks about or conceptualizes approaching the task[23] . During movement, information might be provided when a person performs a continuous task (i.e., walking)[23]. This type of feedback is often termed as concurrent feedback because it is concurrently with an ongoing movement, and it is used to alter an ongoing movement[23].Augmented feedback can be provided as knowledge of performance or knowledge of results. Knowledge of performance provides information about the movement that has just been made and sometimes is referred to as kinematic feedback[23]. Knowledge of results provides information related to the outcome; it is based on achieving the goal or task, and it is redundant with the internal feedback[24].

Augmented feedback plays significant roles in enhancing the performer's motivation by (1) directing their focus of attention and (2) providing information about errors and corrective actions. These, taken together, enhance performance and encourage more attempts in a motor task[23]. However, augmented feedback in a virtual reality system provided during the movement (i.e., knowledge of performance) allowed better movement patterns and motor learning than augmented feedback given after completing the motor task (i.e., knowledge of results) in individuals after stroke[25]. Clinical practice guidelines suggest providing augmented feedback with virtual reality (VR) to enhance walking after six months of stroke onset[22].

Virtual Reality to Deliver Augmented Feedback

VR as technology has been used for different purposes, including rehabilitation. For rehabilitation purposes, VR has been delivered and used in various forms (i.e., non-game-based VR applications and game-based VR applications). The non-game-based VR applications generally use VR features (i.e., immersion or presence and real-time interaction) to mimic and simulate the real-world training conditions into the VR environment without game scoring systems (i.e., experience constraints with walking in daily life and stepping over virtual objects with vibrotactile stimulus)[26,27]. These systems usually use haptic sensations, sounds, and different movement visualizations and optical flow (i.e., avatar movement visualization) to provide real-time movement feedback[24,26,27].

Besides, the 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[28,29]. VR exergames implement game features into activities and tasks that are not themselves games to increase task enjoyment and motivation by making tasks feel more play-like[28,29]. Feedback, challenge, and rewards are the fundamental mechanisms by which exergames provide enjoyable training environments[30]. For example, interacting with a game that uses simple visual feedback results in improved accuracy of a movement (i.e., performing the right and correct motor task) compared to performing an exercise from memory or with limited feedback (e.g., instructional video or demonstration)[28]. Also, VR exergames can provide objective feedback for both therapists and patients. For example, it can provide feedback on the quality of movement, allowing the patient to adjust their movements and focus their treatment[28]. The work gamification theory suggests that gamification provides motivational and performance benefits through two main pathways, informational and affective[29] (Figure 2). The informational pathway includes access to visual and immediate feedback while the affective pathway includes task enjoyment[29].

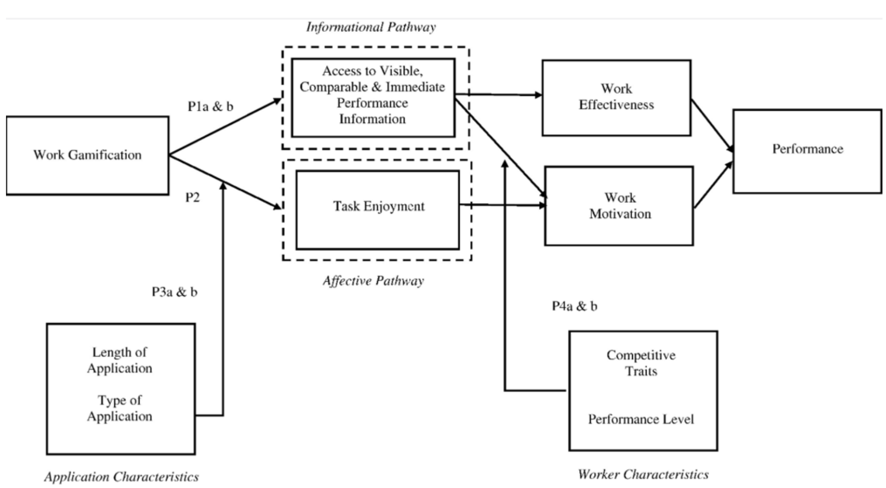

Figure 2. Schematic of A Theory of Work Gamification[29].

Specific Aims

Providing augmented feedback alone, with VR, and with VR exergames may induce different levels of performance and intrinsic motivation in post stroke. Thus, the purpose of this dissertation is to provide a theoretical based approach describing all possible constructs that can be manipulated to enhance intrinsic motivation and spatiotemporal gait performance in post stroke. As well as comparing the effects of different types of feedback (i.e., with and without VR and VR-exergames) on motivation and spatiotemporal gait performance during training after stroke. The central hypothesis is that individuals' post-stroke will demonstrate the greatest changes to spatiotemporal gait parameters, intrinsic motivation, and task enjoyment when VR exergaming is applied.

Our findings will contribute key details regarding the effects of different types of feedback on performance of fast walking speed and maximum step length as well as intrinsic motivation. Additionally, our findings will contribute to the refinement of a 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 the efficacy of our developed VR exergames, while also evaluate key outcomes related to walking and social participation.

Specific Aim 1. Demonstrate the immediate effects of augmented feedback, VR, and exergaming on motivation and fast walking speed performance. In a repeated measures study design, 18 individuals post stroke walk as fast as possible without feedback and in three conditions where augmented feedback is provided (1) without VR, (2) with VR, and (3) with VR exergaming. Hypothesis: Individuals' post-stroke would immediately increase their fast-walking speed performance with different types of augmented feedback than their fast-walking speed without feedback; their greatest intrinsic motivation would be with VR-exergame condition.

Specific Aim 2. Demonstrate the immediate effects of augmented feedback, VR, and VR game on motivation and maximum step length performance. In a repeated measure study design, 12 individuals post stroke were asked to take the longest step possible (i.e., maximum step length) without feedback and in three conditions where augmented feedback is provided (1) without VR, (2) with VR, and (3) with VR game. Hypothesis: Individuals' post-stroke would immediately increase their maximum step length performance with different types of augmented feedback than their maximum step length performance without feedback; their greatest intrinsic motivation would be with VR-exergame condition.

EFFECTS OF DIFFERENT TYPES OF AUGMENTED FEEDBACK ON INTRINSIC MOTIVATION AND WALKING SPEED PERFORMANCE IN POST-STROKE: ASTUDY PROTOCOL

by

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Contemporary Clinical Trails Communications

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 seconds 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.

BACKGROUND

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 assisted 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.

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 Figure 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.

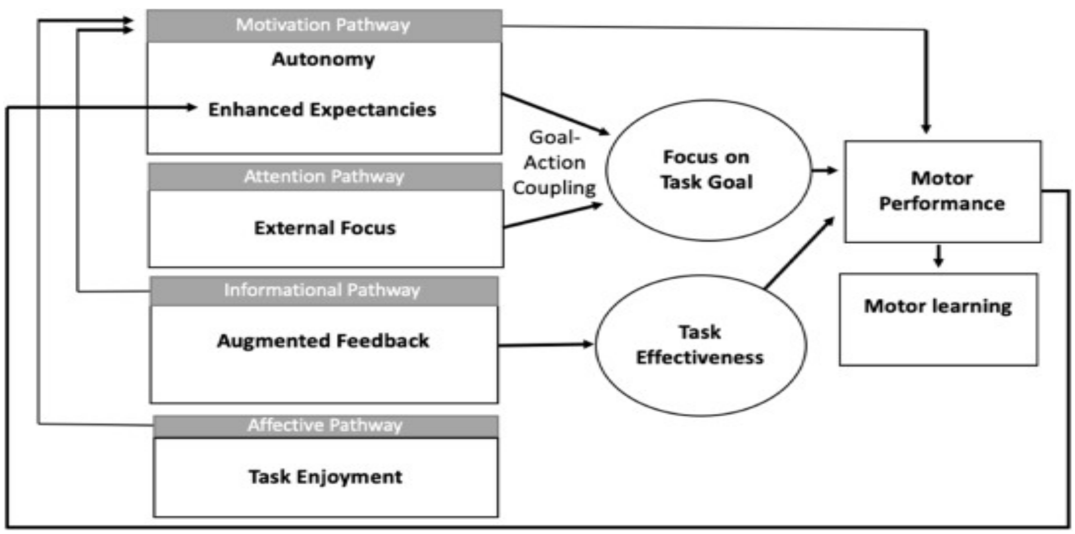

Figure 3. Enhanced OPTIMAL Theory adapted from the OPTIMAL Theory[16] and the Theory of Work Gamification[17]. The conceptual model depicts several constructs that, through different pathways, induce immediate changes to motor performance and motivation.

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.

METHODS

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.

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 devices for at least three minutes 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 minutes 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.

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, 8GB 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 (Figure 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.

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 meters. During each experimental condition, participants will only walk for 30 seconds 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 seconds of maximum walking speed followed by at least two minutes recovery period [23,24].

The VR exergaming application was designed to include four motivational elements (Figure 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; Figure 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 (Figure 2A) and a representative avatar walker, using real-time walking speed data from the KineAssist, in a VR environment (Figure 2B). The participants' goal is to make the avatar walker representative walk as fast as possible.

Condition 3: Augmented feedback with VR and exergaming: includes the feedback in the first and second experimental conditions (Figure 2A and 2B), as well as six other racers with pre-set speeds (Figure 2C) and an audience cheering for the racers (Figure 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 seconds, 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.

Figure 4. 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.

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].

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			✓

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 0-100 (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 seconds 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].

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].

Study Protocol

Participants will be helped into the KineAssist, which will be adjusted to apply 4kg (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 degrees) 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 seconds 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., two minutes) to allow the heart rate to return within 20 beats/min of standing values from baseline heart rate value.

Sample Size Calculations and Statistical Analysis 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.

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.

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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.

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THE IMMEDIATE EFFECTS OF DIFFERENT TYPES OF AUGMENTED FEEDBACK ON FAST WALKING SPEED PERFORMANCE AND INTRINSIC MOTIVATION AFTER STROKE

by

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ABSTRACT

Introduction: Providing augmented feedback during training sessions is a strategy for enhancing walking outcomes and motivation after stroke. During stroke recovery, simple metrics displays and virtual reality (VR) and exergames can provide augmented feedback. We examined the immediate effects of these different types of augmented feedback on walking speed and intrinsic motivation in post-stroke.

Methods: Eighteen individuals with chronic stroke were included. Participants were asked to walk as fast and safely as they could for 13 meters without feedback before each experimental condition and walk for 13 meters in each of the three experimental conditions: (1) augmented feedback, (2) simple VR interface, and (3) VR-exergame. Participants' intrinsic motivation was measured using the Intrinsic Motivation Inventory (IMI).

Results: Although the differences were not statistically significant, fast-walking speed was higher in the augmented feedback (0.86 $\pm$ 0.44 m/s); simple VR interface (0.87 $\pm$ 0.41 m/s); VR-exergame (0.87 $\pm$ 0.44 m/s) conditions than in the fast-walking speed without feedback (0.81 $\pm$ 0.40 m/s) condition. Type of feedback had a significant effect on intrinsic motivation ($p = 0.04$). IMI scores were highest in the VR-exergame condition (Median= 6.57, IQR= 7.00-5.96), followed by simple VR interface (Median= 6.07, IQR= 6.71-4.57), followed by augmented feedback (Median= 5.86, IQR= 6.50-5.00). Participants' intrinsic motivation was positively correlated with their perceived competence for all types of augmented feedback.

Conclusion: Augmenting feedback affected the intrinsic motivation and enjoyment of adults with stroke asked to walk fast on a robotic treadmill; more elaborate feedback

resulted in greater motivation and enjoyment. Moreover, perceived competence was positively associated with intrinsic motivation. Additional studies with larger samples are warranted to examine the relations among these aspects of motivation and ambulation training outcomes.

INTRODUCTION

Stroke is the second leading cause of death and the third leading cause of disabilities worldwide[1]. Many individuals after stroke are left with physical and psychological issues, including slow walking speed due to hemiparesis[2,3] and reduced motivation due to apathy[4]. Walking speed after stroke is negatively associated with their balance confidence[5]. Hence, slow walking speed might lead to participation restrictions in social roles related to responsibilities, employment, community life, and recreation[6].

In addition to slow walking speed, apathy is one of the psychological issues after a stroke that is described by loss of interest and lack of motivation present in a third of stroke survivors[7]. Lack of motivation due to apathy might negatively impact activities of daily living and functional recovery after stroke[8,9]. So, motivation is one of the facilitators that enhance walking recovery during rehabilitation sessions after stroke[10]. Therefore, providing motivational strategies during gait training sessions might help in improving adherence and better enhance walking outcomes (i.e., walking speed) in stroke survivors[11].

Augmented feedback as extra information provided during training sessions is important for enhancing walking outcomes and motivation for individuals after stroke[12]. Augmented feedback enhances motivation by directing performers' attention toward the movement goal and providing information about errors and corrective actions[13]. These, taken together, enhance performance and encourage more attempts in a motor task[13]. In turn, clinical practice guidelines suggest providing augmented feedback using virtual reality (VR) to enhance walking after six months of stroke onset[14]. Also, there is evidence that gait training with VR enhances the walking speed better than non- VR gait training for individuals in chronic stages of stroke[15].

Some VR applications were recently developed and investigated to improve walking outcomes and motivation for individuals post stroke[16–19]. Based on their natures, these VR applications can be generally classified as non-game-based VR applications and game-based VR applications. The non-game-based VR applications were used in several studies as mimicking the conventional gait training sessions into the VR environment (i.e., hallway walking, street crossing, and park walk)[20]. On the other hand, the game-based VR applications are called exergames or a combination of exertion and videogames used to add more engagement, enjoyment, and challenges into the training tasks[21]. These exergames make motor tasks more play like by simulating a task goal into gaming scenarios (i.e., to enhance balance and weight shifting, a game was played as standing below a tree with a basket on the avatar head, so a person tries to shift his/her body weight and adjust posture to catch the fruits dropping from the tree)[22]. It is unknown if these game-based VR applications would add benefits to walking speed and intrinsic motivation in individuals with post-stroke compared with non-game-based VR applications and augmented feedback in general.

We recently published a study protocol based on a theoretical framework (i.e., Enhanced OPTIMAL Theory) utilizing augmented feedback, simple VR interface, and VR-exergame on walking speed and intrinsic motivation after stroke[23]. The Enhanced OPTIMAL details four pathways that directly or indirectly impact motor performance (Figure 1)[23]. Based on the theory, augmented feedback as an information pathway can impact motor performance indirectly through enhancing task effectiveness and providing motivation[23]. Motivation, however, can also be impacted by affective pathway as task enjoyment (i.e., VR and exergames)[23]. Thus, we intended to test the immediate effects of these different types of augmented feedback on fast walking speed performance and intrinsic motivation after stroke and discover some factors associated with walking speed performance and intrinsic motivation.

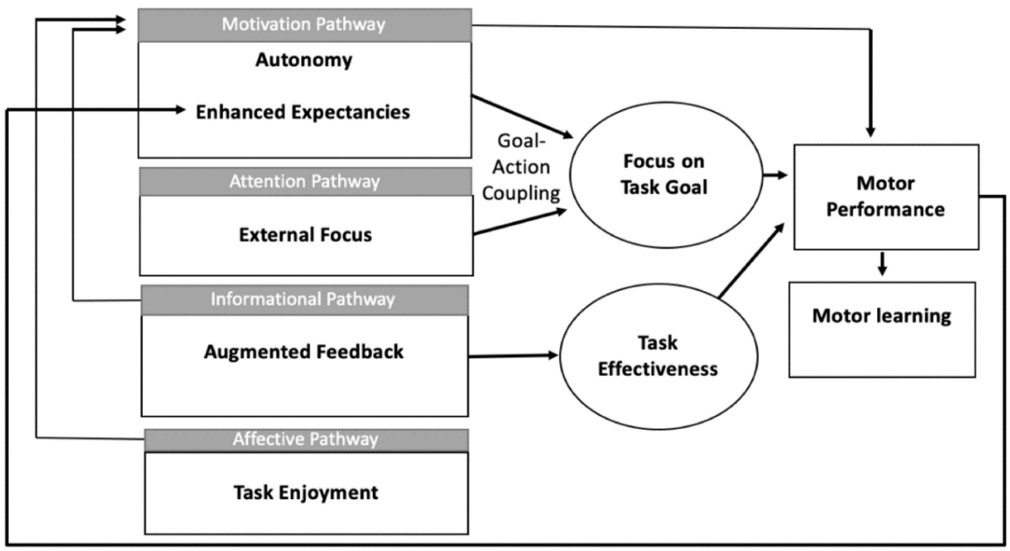

Figure 1. The Enhanced OPTIMAL Theory with several pathways and constructs to induce motivation and motor performance[23].

METHODS

Participants

Eighteen adults with chronic stroke participated in the study at the Spain Rehabilitation Center, University of Alabama at Birmingham. The study had a within-subjects design. All conditions were presented to all participants during a single visit with counterbalancing of conditions conducted across subjects. Participants were included if they had a stroke onset more than six months, had a Mini-Mental State Examination score higher than 24 (i.e., no cognitive impairment)[24,25], and could walk independently for at least three minutes without physical assistance. Participants were excluded if they had coronary heart disease, other neurologic diseases known to impact balance and walking, or significant visual impairment (i.e., blinding, double vision, and visual hallucination). We administered the Cerebral Vision Screening Questionnaire (CVSQ) over the telephone during the recruitment process to screen for visual impairments[26]. The study protocol was approved by the University of Alabama at Birmingham's institutional review board, and all participants signed an informed consent before data collection began.

KineAssist-MX and VR game

KineAssist-MX Robotic Treadmill was used to allow for self-drive of the treadmill belt, complete freedom of pelvic movement, and safe walking environment via the catch height setting and the pelvic sensors that detect lack of upright posture and activate the harness system to prevent falls[27–29]. In addition, we used a custom-made partial immersion VR exergame (i.e., The Racing Game) designed especially for individuals after stroke to enhance their walking speed. The game was connected to the KineAssist-MX treadmill via an ethernet connection cable and displayed on a large TV screen (i.e., VIZIO-75 Class V-Series, LED 4K UHD, Smart cast TV) placed in front of the treadmill.

The Racing Game (Figure 2) can challenge participants to exceed their best previous performance, provides a real-time measure of walking speed, and gamifies the walking task by including avatar competitors (i.e., racers) with different speeds higher than and lower than a participant's pre-captured baseline fast walking speed. There are six pre-set competitors assigned to the right and left of the participant as representative avatar racers, and those competitors walk faster or slower than the participant's average fast baseline speed (i.e., a participant's average fast baseline speed $\pm$ 0.1, 0.2, 0.3 m/s).

Study Protocol

After consenting participants, we measured their blood pressure and administered several questionnaires, including demographics, Apathy Evaluation Scale (AES)[30], and Activity Specific Balance Confidence Scale (ABC)[31,32]. The AES contains eighteen items rating from 1 (Not at all) to 4 (A lot) with total scores ranging from 18 to 78 (i.e., low score indicating more apathy)[30]. The ABC contains sixteen items rating from 0% (No confidence) to 100% (Complete confidence)[32].

Participants were helped to get into the KineAssist-MX robotic treadmill and given walking and setting practices to be familiar with the device. Ten Meters Walking Test (10 MWT) was performed three times, with participants self-selected comfortable walking speed. Then, participants were asked to walk with their self-selected fast walking speeds for 13 meters before each of the following three experimental conditions in which we used the same VR-exergame (i.e., Racing Game) with masking some of its components (i.e., we stuck crafted cardboard pieces on the TV screen to cover some of the game components).

Experimental Conditions

1. Fast walking with augmented feedback: In this condition, participants were asked to walk for 13 meters while showing a real-time measure of their walking speed and distance (Figure 2 A). The instruction was, "Look at the screen and keep your walking speed number as high as possible." The participant's goal was to keep the real-time measure of their walking speed number as high as possible.

2. Fast walking with a simple VR interface: In this condition, participants were asked to walk for 13 meters while they were shown an avatar walker in addition to the real-time measurement of their walking speed (Figure 2 A and B). The instruction was, "Look at the screen and make the avatar walker representative walk as fast as possible." The participant's goal in this condition was to move their avatar walker as fast as possible.

3. Fast walking with the VR-exergame: Participants were asked to walk for 13 meters in this condition while all the game components were presented, and the participant's goal was to beat these avatars and finish in the first place. The instruction was, "Look at the screen and make the avatar walker representative walk ahead of the other avatar racers."

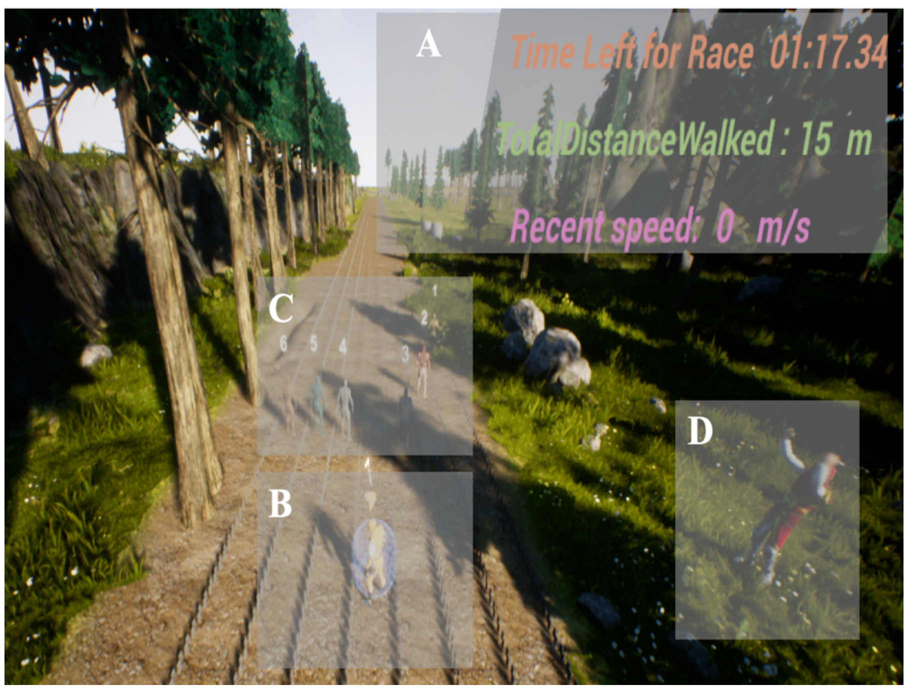

Figure 2. Racing Game with components labeled. A. Real time measure of walking speed. B. Representative avatar walker in VR environment. C. Pre-set Competitors. D. Cheering audience.

The order of the three experimental conditions was counterbalanced for six possible orders, and participants were randomly assigned to any of these possible six orders of the conditions. After each experimental condition, participants were given a seat for at least two minutes as a resting period.

Outcome Measurements

Fast walking speed without feedback and within each experimental condition was measured on the KineAssist-MX Robotic treadmill as the covered distance in meters (13m) over completion time in seconds (m/s). Intrinsic motivation was measured immediately after each walking condition using the Intrinsic Motivation Inventory (IMI)-Interest and Enjoyment Subscale, the only subscale that assesses intrinsic motivation in this instrument[33]. The IMI is a multidimensional measure of motivation that contains 22 items rating from 1 (Not at all true) to 7 (Very much true) in four subscales (i.e., interest and enjoyment, perceived choice, perceived competence, and pressure and tension)[34].The IMI has been widely used to evaluate intrinsic motivation in post-stroke studies[35–37], and its psychometric properties have been extensively studied[38,39]. After conducted the IMI, participants were asked to complete the Short Flow Scale (SFS)[40]. The SFS is a measure of positive experience state, a personal skill equals the required challenge, that contains nine items rating from 1 (Completely disagree) to 5 (Completely agree)[40].

Statistical Analysis

Descriptive statistics were used to illustrate participants' characteristics including age, gender, race, stroke onset, affected side, Apathy Evaluation Scale (AES), Balance Confidence (ABC), and comfortable walking speed. Spearman's rho Correlation with a two-tailed test of significance performed to determine the relationships (r) between participants’ comfortable walking speed, Apathy Evaluation Scale (AES), and Activities Specific Balance Confidence.

Fast walking speed without feedback was calculated as the average of the three fast speeds that were performed before each experimental condition. To determine statistically significant increases in walking speed among fast walking without feedback (i.e., performed before each experimental condition) and fast walking with feedback in each experimental condition, a one-way repeated measures analysis of variance (ANOVA) was used. Walking speed data was normally distributed, as assessed by Shapiro-Wilk's test ($p > 0.05$). The assumption of sphericity was met, as assessed by Mauchly's test of sphericity, $X^2(2) = 8.65$, $p = 0.125$.

A non-parametric Friedman test with a two-tailed test of significance was run with a Bonferroni correction for multiple comparisons to determine the effects of feedback types on intrinsic motivation based on the IMI-Interest and Enjoyment subscale among the three experimental conditions. Median and interquartile range (IQR) were used as descriptive for a Friedman test analysis. The relationships (r) between IMI-subscales, and SFS in each experimental condition were examined using Spearman's rho Correlation with a two-tailed test of significance. The data were analyzed using IBM SPSS Statistics 27.0 (Armonk, NY: IBM Corp).

RESULTS

Participants Characteristics

Eighteen participants were included in the analysis with mean age of 55.67 ± 13.63 years, and median stroke onset of 36 (24, 81) months. Most of participants were male (77.8%) and African American (66.7%). Participants were able to walk at an average comfortable speed while on the KineAsist-MX robotic treadmill of 0.48 m/s ± 0.23. Participants' average apathy score (AES) was 58.89 ± 5.36 and their average balance confidence (ABC) was 66.15% ± 15.97. Table 1 describes participants' characteristics.

There was a statistically significant positive correlation between apathy and balance confidence r (16) = 0.490, p= 0.03 indicating that participants with high scores in Apathy Evaluation Scale AES (i.e., less or absence of apathy) had high balance confidence scores in Activities Specific Balance Confidence Scale (ABC). Balance confidence was also positively correlated with comfortable walking speed, r (16) = 0.479, P= 0.04, indicating that participants with low balance confidence tended to walk slower and vice versa. However, there was no correlation between participants' comfortable walking speed and apathy scores, r (16) = 0.29, P= 0.25.

Table 1. Participants Characteristics (N=18)

Sex, N (%)	Female	4 (22.2)
	Male	14 (77.8)
Race, N (%)	African American	12 (66.7)
	Caucasian	6 (33.3)
Affected side, N (%)	Left	11 (61.2)
	Right	7 (38.9)
Age, year	Mean (SD)	54.5 (13.6)
Time since stroke onset, month	Median (IQR)	36 (24, 81)
Apathy Evaluation Scale (AES)	Mean (SD)	58.89 (5.36)
Activities Specific Balance Confidence (ABC)	Mean (SD)	66.15 (15.97)
Comfortable Walking Speed (m/s)	Mean (SD)	0.48 (0.23)

*SD= Standard Deviation

*IQR= Interquartile Range

*AES scores rating from (18 to 72), lower scores indicate greater apathy.

*ABC scores rating from (0% to 100%), lower scores indicate poor balance confidence.

Fast Walking Speed Performance

Participants were able to perform fast-walking speed without feedback (0.81 ± 0.40 m/s), with augmented feedback (0.86 ± 0.44 m/s), with simple VR interface (0.87 ±

0.41 m/s), and with VR-exergame (0.87 $\pm$ 0.44 m/s). Figure 2 shows participants average fast walking speed without feedback (i.e., before each condition) and average fast walking speed with each type of feedback. Participants' increase and decrease in walking speed performance from fast walking without feedback to fast walking with each experimental condition are described in Table 2.

Figure 3. Fast walking speed without feedback and with each of three experimental conditions. Each column represents mean value $\pm$ SEM.

Table 2. Changes in Experimental Conditions Fast Walking Speed from Fast Walking Speed Without Feedback (n=18)

Change Form Fast Walking Speed Without Feedback		N (%)	Mean (SD)
Augmented feedback	Increased	10 (55.6)	0.12 (0.12)
	Decreased	8 (44.4)	0.05 (0.03)
Simple VR interface	Increased	13 (72.2)	0.09 (0.07)
	Decreased	5 (27.8)	0.04 (0.04)
VR-exergame	Increased	13 (72.2)	0.12 (0.10)
	Decreased	5 (27.8)	0.01 (0.07)

*SD= Standard Deviation

A one-way repeated measures ANOVA was conducted to evaluate the null hypothesis that there is no change in participant's fast walking speed when measured without feedback and with each of the experimental conditions (i.e., augmented feedback, simple VR interface, VR-exergame) with a group of patients with chronic stroke (n=18). The results of the ANOVA indicated no significant experimental effect, Wilk's Lambda=0.996, F (3, 15) =2.890, p=0.070, Eta Squared=0.366.

Intrinsic Motivation

Table 3 describes Intrinsic Motivation Inventory (IMI) subscales and Short Flow Scale (SFS) results for each experimental condition.

Table 3. Median and Interquartile Ranges (IQR) of Intrinsic Motivation Inventory (IMI)-Subscales and Short Flow Scale (SFS) in each experimental condition (n=18)

Condition	IMI-Interest and Enjoyment Subscale	IMI-Perceived Competence Subscale	IMI-Perceived Choice Subscale	IMI-Tension and Pressure Subscale	Short Flow Scale (SFS)
	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)
Augmented Feedback	5.9 (5.0, 6.5)	4.4 (3.8, 6.2)	6.9 (6.4, 7.0)	2.7 (1.5, 3.7)	4.1 (3.7, 4.4)
Simple VR Interface	6.1 (4.6, 6.7)	5.1 (3.0, 6.0)	6.8 (6.6, 7.0)	2.8 (1.6, 3.3)	4.1 (3.9, 4.4)
VR-Exergame	6.6 (6.0, 7.0)	5.0 (4.0, 6.1)	7.0 (6.6, 7.0)	3.2 (1.9, 4.0)	4.2 (3.6, 4.5)

*IMI scores rating from (1=not at all true to 7=very much true), higher scores represent higher concept described in the subscale name.

*SFS scores rating from (1=completely disagree to 5=completely agree), higher scores represent higher flow state.

Friedman test results revealed a significant effect of feedback types on participants' intrinsic motivation based on their scores on IMI-Interest and Enjoyment subscale $X^2(2) = 6.426$, *p*= .04. Post hoc analysis adjusted p-values with Bonferroni correction for multiple tests revealed borderline significance between IMI-interest and enjoyment between VR-exergame and augmented feedback (*p*= 0. 091). The medians of IMI-Interest and Enjoyment scores among the three types of feedback indicated that participants' intrinsic motivation was highest with VR-exergame (Median= 6.57, IQR= 7.00-5.96), followed by simple VR interface (Median= 6.07, IQR= 6.71-4.57), followed by augmented feedback (Median= 5.86, IQR= 6.50-5.00), as shown in Figure 3.

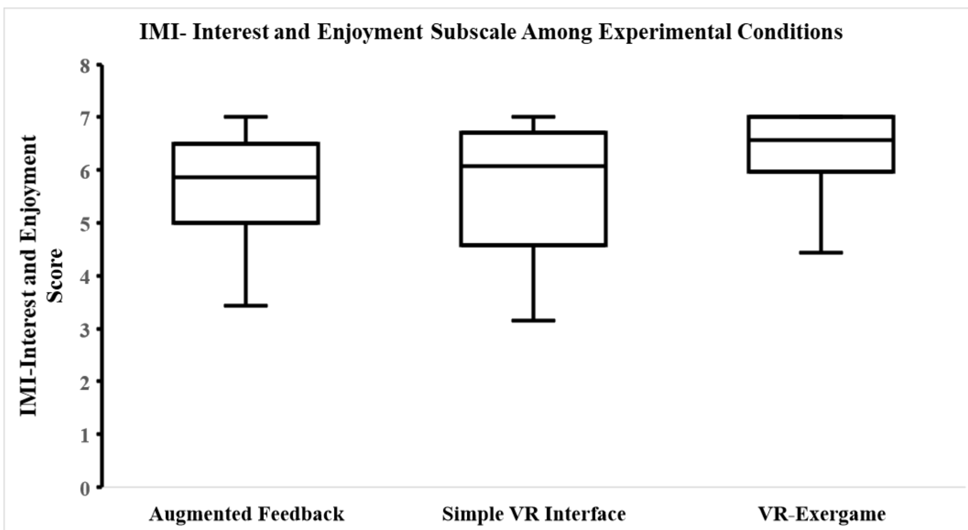

Figure 4. Intrinsic motivation based on Intrinsic Motivation Inventory (IMI)- Interest and Enjoyment subscale among experimental conditions. Each box plot represents median value, interquartile range [IQR] with minimum and maximum scores.

Intrinsic Motivation Inventory (IMI) Subscales and Short Flow Scale (SFS)

Tables 4 show Spearman’s rho correlation matrix between Intrinsic Motivation Inventory (IMI) subscale and Short Flow Scale (SFS) with experimental conditions. The IMI- Interest and Enjoyment subscale was statistically significant and positively correlated with IMI- Perceived Competence subscale in all the experimental conditions as follows; with augmented feedback *r* (16) = .824, P= 0.01; with simple VR interface *r* (16) = .597, *P*= 0.01; with VR-exergame *r* (16) = .486, *P*= 0.04. IMI-Interest and Enjoyment subscale was positively correlated with SFS only with the VR-exergame condition *r* (16) = .680, *P*= 0.01.

Table 4. Spearman's Rho Correlation matrix between Intrinsic Motivation Inventory (IMI) subscales and Short Flow Scale (SFS) in Experimental Conditions (n=18)

Augmented Feedback Condition	1	2	3	4	5
1.IMI-Interest and Enjoyment	-				
2.IMI- Perceived Competence	.82**	-			
3.IMI-Percived Choice	.19	.06	-		
4.IMI-Pressure and Tension	.02	-.24	.15	-	
5. Short Flow Scale	.39	.40	-.03	-.03	-

Simple VR Interface Condition	1	2	3	4	5
1.IMI-Interest and Enjoyment	-				
2.IMI- Perceived Competence	.60**	-			
3.IMI-Percived Choice	-.04	-.26	-		
4.IMI-Pressure and Tension	.26	.21	-.17	-	
5. Short Flow Scale	.32	.39	-.04	-.08	-

VR-Exergame Condition	1	2	3	4	5
1.IMI-Interest and Enjoyment	-				
2.IMI- Perceived Competence	.49**	-			
3.IMI-Percived Choice	.40	-.14	-		
4.IMI-Pressure and Tension	-.36	-.34	-.11	-	
5. Short Flow Scale	.68**	.44	.19	-.26	-

**Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

DISCUSSION

We intended to test the immediate effects of three different types of augmented feedback (i.e., augmented feedback alone, simple VR interface, and VR-exergame) on inducing fast walking speed performance and intrinsic motivation and discover factors associated with walking speed and intrinsic motivation after stroke. Although there was no statistically significant immediate effect of augmented feedback on inducing fast walking speed, participants showed slight increases in their fast-walking speed with all types of feedback (i.e., 0.1 m/s) faster than their fast-walking speed without feedback. The slightly higher speeds with simple VR interface and VR-game are compatible with the evidence that walking training associated with VR showed better results than walking training without VR in post stroke[15]. The observed slight increases in walking speed are in line with clinical practice guidelines suggestion to provide augmented feedback with VR to enhance walking outcomes after six months of stroke onset[14]. Hence, these different types of augmented feedback had different effects on intrinsic motivation. VR-exergame induced the highest motivation level, followed by a simple VR interface, followed by augmented feedback. The highest intrinsic motivation with the VR-exergame condition is in line with existing research findings suggesting that feedback with VR-games has high intrinsic motivation and high acceptance by individuals after stroke than without VR-games[41]. Another study results with healthy individuals also suggested that exercising with the therapeutic exergaming system result in a greater level of interest and enjoyment (i.e., intrinsic motivation) than doing similar physical training without the game system[42].

Our results also revealed some factors associated with walking speed performance and intrinsic motivation after stroke. Participants with low balance confidence had slow walking speed, and those with high balance confidence had high walking speed at baseline. The positive correlation between balance confidence and walking performance was illustrated as individuals with low balance confidence demonstrate impaired control of quiet standing as well as walking characteristics associated with cautious gait strategies[5]. Also, Kongsuk found a positive correlation between balance confidence and fast walking speed on treadmill with older adults[43]. Interestingly, balance confidence was also associated with individuals' apathy as those who had less, or no apathy had high balance confidence and vice versa. High apathy after 12 months of a stroke found to negatively impacted overall physical function[44].

Additionally, enjoyment was associated with perceived competence in all three experimental conditions indicating that individuals who had high motivation levels based on their interest and enjoyment also had high perceived competence and vice versa. The perceived competence was theorized to be a positive predictor of intrinsic motivation[45]. Navarro et al. suggested that competition may improve the effectiveness and enjoyment of rehabilitation therapies and address post-stroke attention problems[46]. We observed that our participants paid more attention to the VR-exergame condition, which was later found to have the highest interest and enjoyment level. In this condition, participants were competing against other avatar competitors which might helped participants to be at the highest level of enjoyment and motivation compared with other conditions. Thus, giving highly competitive augmented feedback may have more benefits on motivation than less or no competitive augmented feedback. Moreover, participants' interest and enjoyment were associated with their high immersion in walking performance and their positive experience with VR-exergame. The relationship between Short Flow Scale (SFS) and the Intrinsic Motivation Inventory (IMI)- Interest and Enjoyment subscale may suggest agreement between these two measures on measuring intrinsic motivation after stroke.

The immediate slight changes we observed with fast walking speed performance with all three types of augmented feedback than fast walking speed without feedback are in line with the Enhanced OPTIMAL Theory, which classifies augmented feedback as an information pathway that impacts motor performance by enhancing task performance effectiveness[23]. Based on the Enhanced OPTIMAL Theory, motivation is directly impacted by the information pathway (i.e., augmented feedback) and affective pathway (i.e., task enjoyment)[23]. Our results revealed an agreement with the theory that the highest motivation was observed with VR-exergame (i.e., more enjoyment elements were displayed), followed by simple VR interface (i.e., fewer enjoyment elements were displayed), followed by augmented feedback (i.e., no enjoyment elements were displayed).

Study Limitations

Although we tested the immediate effects of different types of augmented feedback on walking speed performance and intrinsic motivation after stroke, some limitations should be considered when interpreting our findings or implementing an intervention study based on our results. The small sample size is one of the study limitations that may limit generalizing its findings to the post-stroke population. Although we counterbalanced the conditions and provided a resting period, all the study outcomes were measured as repeated measures in a single session for each participant, considered a limitation for this study. In addition, all the walking measures were performed on a robotic treadmill, so it is important to notice that participants may provide different performance levels overground or on regular treadmills.

Future Directions

Future studies may consider a larger sample size with a longer duration to compare the effects of augmented feedback with and without VR and VR exergames on enhancing fast walking speed and motivation after stroke. The slight increases in fast walking speed that we observed in this study should be examined over time to evaluate gains in walking speed concerning each type of feedback. It is also essential to know if the different types of augmented feedback would transfer (i.e., result in motor learning) the gained fast-walking speed into other walking characteristics (i.e., step length, cadence, and walking symmetry) after stroke. In terms of intrinsic motivation, future studies may evaluate intrinsic motivation changes over time for each type of augmented feedback (i.e., with and without VR and exergames). The strong relationship between intrinsic motivation and perceived competence may encourage further studies to explore factors that may mediate or moderate this relationship.

CONCLUSION

Comfortable walking speed after stroke was positively associated with balance confidence while balance confidence was negatively associated with apathy. Augmented feedback, in general, did not show a significant immediate effect on inducing fast walking speed after stroke. However, individuals after stroke could walk slightly faster with simple VR interface, VR-exergame, and augmented feedback than their fast-walking speed without feedback. Different types of augmented feedback (i.e., augmented feedback alone, simple VR interface, and VR-exergame) revealed a significant effect on intrinsic motivation, and VR-exergame induced the highest motivation level. Several factors were associated with walking speed performance and intrinsic motivation after stroke, including balance confidence, apathy, competence, and flow state. The strong relationship between enjoyment and perceived competence among the experimental conditions suggests that augmented feedback may enhance perceived competence which may in turn enhance fast walking speed performance after stroke.

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THE IMMEDIATE EFFECTS OF AUGMENTED FEEDBACK AND IMMERSIVE VIRTUAL REALITY TECHNOLOGY ON MAXIMUM STEP LENGTH PERFORMANCE AND INTRINSIC MOTIVATION AFTER STROKE

by

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ABSTRACT

Background: During gait and stepping training sessions, augmented feedback can be delivered alone or embedded with virtual reality (VR) and VR games. Thus, we designed and developed a novel stepping feedback application to test the immediate effects of these different types of augmented feedback on maximum step length performance and intrinsic motivation and discover factors associated with maximum step length performance and intrinsic motivation in each type of feedback.

Methods: Twelve individuals with chronic stroke participated in the study. Participants were asked to take the biggest step they could perform several times with their paretic and non-paretic leg. Maximum step length was performed without feedback and with each of the three stepping conditions: (1) augmented feedback alone, (2) simple VR interface, and (3) VR-game. Participants Intrinsic Motivation was measured immediately after each stepping condition using the Intrinsic Motivation Inventory (IMI).

Results: Participants in general had longer non-paretic step length than their paretic step length. Participants were able to increase their paretic and non-paretic maximum step length with all types of augmented feedback than their maximum step length without feedback. Augmented feedback condition had an immediate significant effect on participants' paretic maximum step length $X^2(3, n=12) = 10.300$, $p= 0.016$ while there was no immediate significant effect of feedback types (i.e., experimental conditions) on participants' non-paretic maximum step length $X^2(3, n=12) = 6.800$, $p= 0.079$. Participants intrinsic motivation was not significantly differed among different types of augmented feedback but was slightly higher with augmented feedback (Median= 6.21, IQR= 6.89-5.21), followed by VR-game (Median= 6.07, IQR= 6.78-4.71), followed by

simple VR interface (Median= 5.64, IQR= 6.28-4.75). Intrinsic motivation was positively correlated with perceived competence, but perceived competence was negatively correlated with pressure and tension with simple VR interface and VR-game.

Conclusion: Individuals after stroke could reach longer paretic and non-paretic maximum step length with all types of augmented feedback than their maximum step length without feedback. The relationships between enjoyment, competence, and pressure and tension suggests that increase pressure and tension may have negative impacts on intrinsic motivation during step training for adults after stroke.

INRODUCTION

Reduced step length due to hemiparesis after a stroke is a common gait dysfunction that impacts mobility [1]. Individuals after stroke often take longer paretic steps than non-paretic steps during the walking, resulting in a slow and asymmetric walking pattern[2]. Stroke survivors also have challenges with stepping tasks, including negotiating obstacles, placing them at high risks of perturbations and falls[3]. These risks lead individuals after stroke to avoid performing tasks that require taking long steps[4].

In addition to post-stroke hemiparesis, individuals after stroke may develop apathy resulting in reduced intrinsic motivation and impact their functional performance and recovery[5–7]. After a stroke, the performance of daily activities tasks (i.e., walking and climbing stairs) was higher with individuals with a high level of intrinsic motivation than individuals with a lower level of intrinsic motivation[8]. Thus, motivational strategies are encouraged to enhance performance and adherence in rehabilitation sessions after stroke[9].

Stepping over virtual objects and providing augmented visual feedback of performance are the recently used approaches to enhance locomotion after stroke[10–12]. Augmented feedback improves gait outcomes, including single limb support, and suggests a crucial method to motivate individuals after stroke during rehabilitation sessions[13]. Virtual obstacle training provides evidence on enhancing clinical gait performance in post-stroke hemiplegia[10]. VR training was also suggested to improve community ambulation after stroke and significantly enhance step length[14]. Delivering augmented feedback through VR games may also provide individuals after stroke with better performance and motivation[15].

Augmented feedback improves gait outcomes, including single limb support, and suggests a crucial method to motivate stroke[13]. Delivering feedback with VR games may provide individuals after stroke with better performance and motivation[15]. Hence, augmented feedback can be delivered with or without using VR interface[10,13]. The immediate effects of augmented feedback with and without VR and VR-games on increasing maximum step length performance and intrinsic motivation after stroke remain unclear. Also, it is unclear whether providing augmented feedback alone, with a simple VR interface, or with VR-game would add different benefits to maximum step length performance and intrinsic motivation in individuals post stroke.

Our recent work conceptualized the effects of augmented feedback, including VR and VR games, on intrinsic motivation and motor performance after stroke[16]. Based on our proposed conceptual model (Figure 1), "The Enhanced OPTIMAL Theory," motivation and motor performance can be enhanced with several constructs, including augmented feedback and enjoyment elements[16]. Thus, we designed and developed a novel stepping feedback application (i.e., StepOver) to deliver real time measures of step length feedback with and without a simple VR interface and VR-game. The purpose of this study is to test the immediate effects of augmented feedback alone, augmented feedback with a simple VR interface, and augmented feedback with a VR-game on maximum step length performance and intrinsic motivation, as well as discover factors that associate with maximum step length performance and intrinsic motivation in each type of feedback.

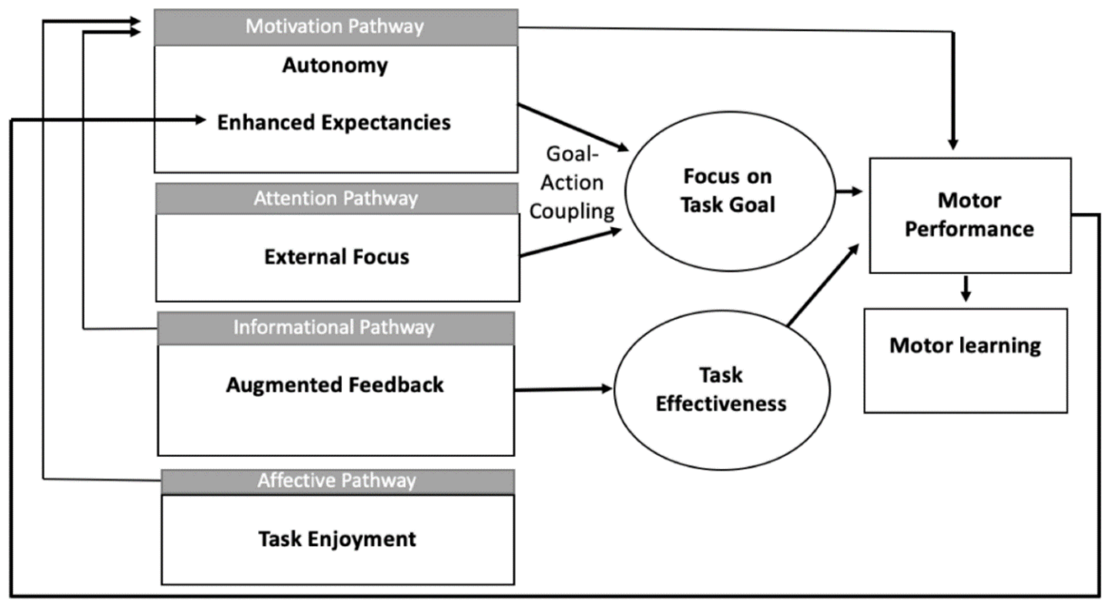

Figure 1. The Enhanced OPTIMAL Theory to induce performance and motivation[18].

METHODS

Participants and design

Twelve individuals with post-stroke hemiparesis participated in the study at the School of Health Professions, University of Alabama at Birmingham. The study was conducted as a single visit within participants repeated measures. The study's inclusion criteria were a chronic and stable stage of stroke (i.e., more than six months after the onset of stroke), ability to follow instructions, and standing and walking independently without physical assistance. During phone screening, we asked individuals if they could stand and walk up to three minutes independently without using an assistive device, and we used Mini-Mental State Examination (MMSE) to assess cognitive impairments with a cut-off score of 24 out of 30[19,20]. Exclusion criteria were coronary heart disease, inability to stand and walk independently, and other neurological diseases that impact balance and mobility other than stroke. Also, we excluded individuals who had significant visual impairments that may impact their ability to see, focus on and track movable objects based on the Cerebral Vision Screening Questionnaire (CVSQ)[21]. The CVSQ contains self-reported questions screening for: visual field loss, neglect, visual perception impairments, visual adaption deficits, contrast sensitivity impairment, change in color perception, and visual hallucinations—all these exclusion criteria obtained through phone screening during the recruitment process. The University of Alabama at Birmingham's institutional review board (IRB) authorized the study protocol, and all participants signed an informed consent.

Overhead track and harness

Biodex FreeStep Ambulation System (SAS) was used to ensure participants' safety and prevent falls[22] (Figure 2). The Biodex FreeStep (SAS) can support up to 750 lb and be manually adjusted to different heights[22]. We asked participants to squat while in the harness to adjust the harness length to the optimal level to avoid giving them extra weight support and catch them if they fall below the adjusted height level.

VR hardware and setup:

We used HTC Vive equipment, including a Vive headset, two base stations, and two HTC Vive trackers[23] (Figure 2). The Vive headset is a virtual reality (VR) headset from HTC that displays a three-directional, 100-degree field of view compatible with multiple interfaces and outlets, including Bluetooth, HDMI, USB 2.0, and it has a 3.5mm audio jack[24]. The HTC Vive base stations power the presence and immersion of room-scale VR by helping the Vive headset and controllers track their exact locations[24]. The HTC Vive trackers help detect the segment movement via a wireless and seamless connection between the tracker and the VIVE system[24]. The HTC Vive tracking system accurately detected spine rotational movements compared with a commonly used threedimensional motion capture system (Vicon)[25]. Also, the HTC Vive tracking system has been used as a gait analysis system to analyze spatiotemporal gait parameters[26].

Figure 2. Biodex FreeStep Ambulation System and HTC Vive equipment (i.e., headset, trackers, and base station).

StepOver Software

We designed a novel VR application (i.e., StepOver) to enhance step length for post-stroke individuals (Figure 3). The StepOver application was developed using Unity, a cross-platform game engine, and coded with the C# programming language[27]. Two main calibration processes are necessary to synchronize the avatar leg movement with the actual leg movement in StepOver. First, the HTC Vive headset calibration to orient the VR world's sidewalk parallel with the participants standing position and direction. Second, the HTC Vive foot trackers calibration to correct orientation of the HTC Vive trackers and detect the participants' feet when standing and taking a step.

The StepOver application allows for three training options. First, a non-VR session which allows projecting a feedback window showing baseline step length (i.e., previous step length in cm), in session or current step length (cm), and allows to type a number (i.e., new goal max) as targeted step length value in cm (Figure 3. A). Second, a simple VR interface session in which a head-mounted display (HMD) is required to be standing on a VR sidewalk with representative avatar feet and numbered blocks (i.e., numbered from 0 to 10) on each left and right side. The distance between each numbered block to the next numbered block is 7 cm (Figure 3. B). In the simple VR interface session, a feedback window shows baseline and current step length that can be seen when left the head up. Ultimately, VR-game session is more play-like by stepping over avatar animals (i.e., cat or dog) with adjustable length while standing on a VR sidewalk (Figure 3. C). If successfully stepping over the avatar animal, a success sound, falling flowers, and green avatar feet will be applied. Conversely, a failure sound and red avatar feet will be applied if step on the avatar animal.

Baseline measures of Step Length

Participants' comfortable step length was measured three times by taking forward steps with each paretic and non-paretic leg. Participants then were asked to take the biggest step they could with each paretic and non-paretic leg, and when they did so, they were given three chances to take an even bigger step until they failed the three chances to step longer than their latest attempted maximum step length value (i.e., 1 cm longer than the previously attempted step length).

Experimental Conditions

1. Augmented feedback: In this condition, we projected a feedback window showing participants' baseline step length in cm, new maximum step length goal, and a real-time measure of their current step length as session max number (Figure 3. A). Participants were instructed to get a number for their session max higher than the new maximum step length goal value. In this condition, the participant's goal was to keep the real-time measure of their step length number higher than their baseline step length and their new maximum step length goal. Participants were given three chances to take longer steps (i.e., 1 cm longer than their new maximum step length goal).

2. Simple VR interface: In this condition, participants were wearing a head-mounted display (HMD) to see their avatar feet standing on a sidewalk where they can see numbered blocks beside and along the sidewalk, as well as a feedback window showing their baseline step length and the real-time measures of current step length (Figure 3. B). Participants were instructed to move their avatar foot to the farthest block number. In this condition, the participant's goal was to move their avatar foot to the farthest numbered block located on each side of the sidewalk. Participants were given three chances to reach for a longer block number with their leading foot.

3. VR-game: In this condition, participants were also wearing a head-mounted display (HMD) and were in the same previously described simple VR interface condition environment, but there was an animal underneath and game score value in the feedback window (Figure 3. C). As the game progressed, the avatar animal length was incremented by 7 cm added to the participants' baseline step length. Participants were instructed to step over the avatar animal without stepping on the animal. Thus, the participant's goal in

this condition is to step over the avatar animal without touching the animal with a foot in three attempts.

Each of these conditions was performed with paretic and non-paretic feet. The order of the three experimental conditions and leading feet were counterbalanced for six possible orders, and participants were randomly assigned to any of these possible six orders of the conditions. After each experimental condition, participants were given a resting period equal to their stepping time in the condition.

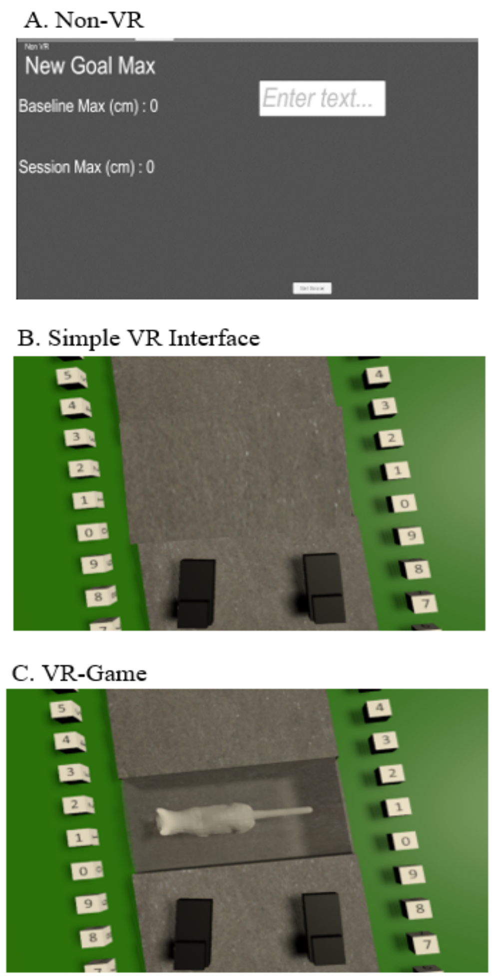

Figure 3. StepOver software with its three training options that were used as experimental conditions. A. A feedback window shows real-time measure of step length in cm and space to type a new stepping goal value. B. Representative avatar foot standing on VR sidewalk with numbered blocks on each side. C. An avatar (i.e., cat) underneath.

Outcome measurements

Maximum step length performance without feedback and within each experimental condition measured as traveled distance by the foot in cm. The Intrinsic Motivation Inventory (IMI)-Interest/Enjoyment subscale measured intrinsic motivation immediately after each experimental condition. The IMI is a 22-item 7-point Likert scale multidimensional measure of motivation with four subscales (i.e., interest and enjoyment, perceived choice, perceived competence, and pressure and tension)[28]. However, the interest and enjoyment subscale of the IMI is known as the self-report measure of intrinsic motivation from 1(not at all true) to 7 (very much true)[29]. The IMI has been widely utilized in post-stroke studies to assess intrinsic motivation[30–32], and its psychometric properties have been thoroughly researched[33,34]. Participants were asked to complete the Short Flow Scale (SFS) as secondary outcome measure after the IMI. The Short Flow Scale is a 9-item 5-point Likert (I.e., 1=completely disagree, 5=completely agree) scale that measures pleasant experience state, a personal competence that equals the required challenge[35].

Statistical Analysis

Descriptive statistics were used to illustrate participants' characteristics including age, gender, race, stroke onset, affected side, and comfortable step length for each paretic and non-paretic leg. Descriptive statistics were also used to show participants greatest step length performance with paretic vs. non-paretic leg.

To test if there were statistically significant increases in maximum step length between maximum step length without feedback and maximum step length with each type of feedback (i.e., for each paretic and non-paretic leg), A non-parametric Friedman test with a two-tailed test of significance was used with pairwise comparison. Significance values were adjusted by Bonferroni correction for multiple tests. A non-parametric Friedman test was utilized due to a limited number of participants. The median and quartiles of maximum step length values were used as descriptive variables for a Friedman test analysis.

A non-parametric Friedman test with a two-tailed test of significance was also used to investigate the effects of feedback on intrinsic motivation based on the Intrinsic Motivation Inventory (IMI) Interest and Enjoyment subscale among the three experimental conditions. The median and IQR were used as descriptive variables for a Friedman test analysis. Spearman's rho was used to examine the relationships (r) between IMI- subscales, and Short Flow Scale (SFS) in each experimental condition. Correlation with a two-tailed significance test. The data were analyzed using IBM SPSS Statistics 27.0 (Armonk, NY: IBM Corp).

RESULTS

Participant's characteristics

Twelve participants were included in the analysis with mean age of 53.25 $\pm$ 11.48 years, and stroke onset of (Median= 36, IQR= 24, 93) months. Participants were able to step at a median comfortable step length of (Median= 35, IQR= 30, 40) cm with paretic leg and (Median= 38, IQR= 29, 45) cm with the non-paretic leg. Most of the participants 66.7% had longer non-paretic step length than their paretic step length. Table 1 describes participants' characteristics (Table 1).

Table 1. Participants Characteristics (n=12)

Sex, N (%)	Female	1 (8.3)
	Male	11 (91.7)
Race, N (%)	African American	9 (75.0)
	Caucasian	3 (25.0)
Affected side, N (%)	Left	7 (58.3)
	Right	5 (41.7)
Age, year	Mean (SD)	53.3 (11.5)
Time since stroke onset, month	Median (IQR)	36 (24, 93)
Paretic comfortable step length, cm	Median (IQR)	35 (30,40)
Non-paretic comfortable step length, cm	Median (IQR)	38 (29,45)
Greatest comfortable step length, N (%)	Paretic	4 (33.3)
	Non-paretic	8 (66.7)
Greatest maximum step length (without feedback), N (%)	Paretic	4 (33.3)
	Non-paretic	8 (66.7)

* SD= Standard Deviation
* IQR= Interquartile Range

Maximum step length performance

For paretic maximum step length, Friedman test results revealed a significant effect of feedback types (i.e., three experimental conditions) on participants' paretic maximum step length $X^2(3, n=12) = 10.300$, $p= 0.016$. Post hoc analysis revealed statistically significant differences in participants paretic maximum step length from maximum step length without feedback (Median= 69.02, IQR= 49.83-85.95 cm) to augmented feedback (Median= 77.41, IQR= 61.13-102.89 cm) ($p= 0.009$), but not to simple VR interface (Median= 76.97, IQR= 60.89-93.88 cm) ($p= 0.239$) and VR-game (Median= 72.37, IQR= 64.60-97.97 cm) ($p= 0.492$). Figure 4 shows paretic maximum step length without feedback and with the three experimental conditions.

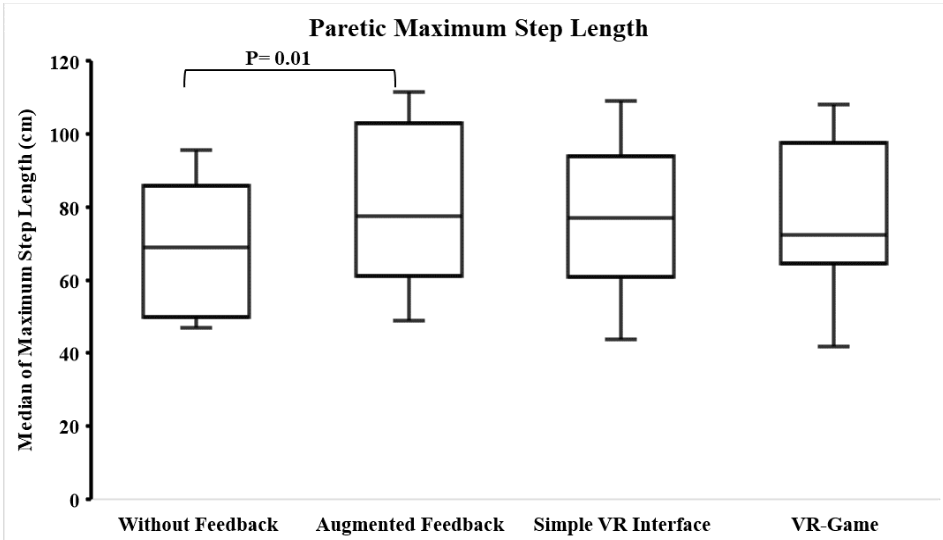

Figure 4. Maximum step length (cm) for paretic leg without feedback and with each of augmented feedback, simple VR interface, and VR-game. Each box plot represents median value, interquartile range [IQR] with minimum and maximum scores.

For non-paretic maximum step length, Friedman test results revealed a non-significant effect of feedback types (i.e., three experimental conditions) on participants' non-paretic maximum step length $X^2(3, n=12) = 6.800$, $p= 0.079$. Participants non-paretic maximum step length slightly increased from maximum step length without feedback (Median= 76.96, IQR= 58.59-97.98 cm) to augmented feedback (Median= 88.02, IQR= 66.23-108.12 cm), simple VR interface (Median= 81.97, IQR= 58.25-103.90 cm) and VR-game (Median= 78.13, IQR= 67.29-108.23 cm). Figure 5 shows non-paretic maximum step length without feedback and with each of the three experimental conditions.

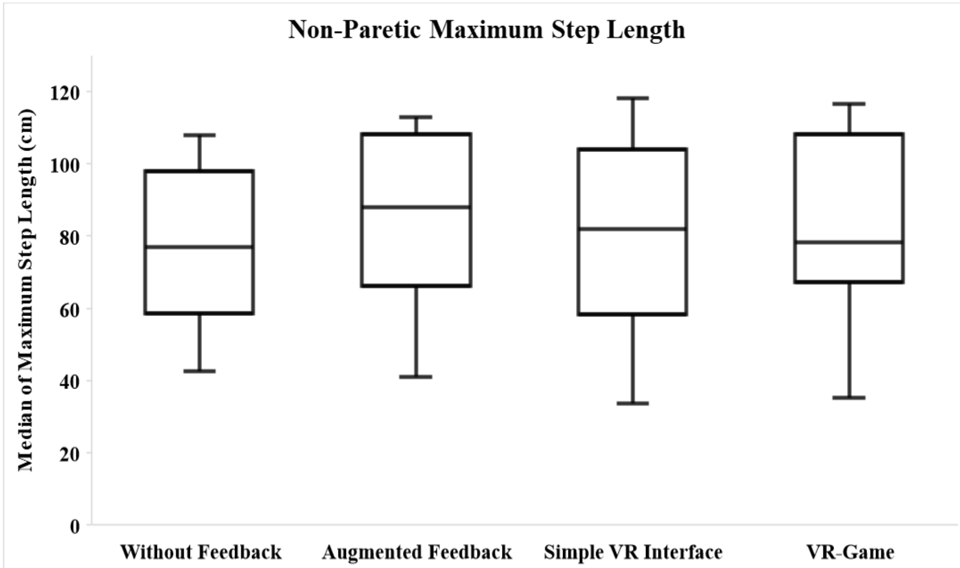

Figure 5. Maximum step length (cm) for non-paretic leg without feedback and with each of augmented feedback, simple VR interface, and VR-game. Each box plot represents median value, interquartile range [IQR] with minimum and maximum scores.

Intrinsic Motivation

Means and standard deviations (SD) of Intrinsic Motivation Inventory (IMI) subscales and Short Flow State (SFS) were described for each experimental condition as presented in Table 2.

Friedman test results revealed a non-significant effect of feedback types (i.e., three experimental conditions) on participants' intrinsic motivation based on IMI-Interest and Enjoyment subscale median scores $X^2(2, n=12) = 0.585$, $p= 0.75$. The medians indicated that participants' intrinsic motivation was highest with augmented feedback (Median= 6.21, IQR= 6.89-5.21), followed by VR-game (Median= 6.07, IQR= 6.78-4.71), followed by simple VR interface (Median= 5.64, IQR= 6.28-4.75).

Table 2. Median and Interquartile Ranges (IQR) of Intrinsic Motivation Inventory (IMI)-Subscales and Short Flow State (SFS) in each experimental condition (n=12)

Condition	IMI-Interest and Enjoyment Subscale	IMI-Perceived Competence Subscale	IMI-Perceived Choice Subscale	IMI-Tension and Pressure Subscale	Short Flow State (SFS)
	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)
Augmented Feedback	6.2 (5.2, 6.9)	6.0 (4.7, 6.7)	6.9 (6.1, 7.0)	2.3 (1.5, 3.6)	4.4 (4.1, 4.6)
Simple VR Interface	5.6 (4.8, 6.3)	4.8 (3.7, 5.7)	6.6 (6.3, 7.0)	2.6 (1.4, 4.2)	4.2 (3.7, 4.3)
VR-Game	6.1 (4.7, 6.8)	5.4 (3.9, 6.2)	6.6 (6.2, 7.0)	2.3 (1.7, 4.5)	4.2 (3.6, 4.4)

*IMI Scores rating from (1=not at all true to 7=very much true), higher scores indicate higher concept described in the subscale name.

*SFS Scores rating from (1=completely agree to 5=completely disagree), Higher scores indicate higher flow state.

Intrinsic Motivation Inventory (IMI) and Short Flow Scale (SFS)

Table 3 shows the correlation matrix between Intrinsic Motivation Inventory (IMI) subscales and Short Flow Scale (SFS) in experimental conditions. In augmented feedback condition, Spearman's rho correlation results revealed a statistically significant positive correlation between IMI- Interest and Enjoyment subscale and the IMI-Perceived Competence subscale *r* (10) = 0.733, *P*= 0.01. There was a statistically significant negative correlation between IMI- Interest and Enjoyment subscale and IMI-Pressure and

Tension subscale *r* (10) = 0.733, *P*= 0.01. Short Flow Scale (SFS) significantly positively correlated with IMI-Interest and Enjoyment *r* (10) = 0.710, *P*= 0.01. There was also a statistically significant positive correlation between SFS and IMI-Perceived Competence *r* (10) = 0.616, *P*= 0.03.

There were several correlations between IMI subscales and SFS in simple VR interface. Spearman's rho correlation results revealed statistically significant positive correlations between IMI- Interest and Enjoyment subscale and the IMI-Perceived Competence subscale *r* (10) = 0.809, *P*= 0.01. There was also a statistically significant negative correlation between IMI- Perceived Competence subscale and IMI-Pressure and Tension subscale *r* (10) = -0.762, *P*= 0.01. SFS was positively correlated with IMI-Interest and Enjoyment subscale *r* (10) = 0.610, *P*= 0.03 as well as IMI-Perceived Competence subscale *r* (10) = 0.716, *P*= 0.01.

In VR-game condition, Spearman's rho correlation results revealed statistically significant positive correlations between IMI- Interest and Enjoyment subscale and IMI-Perceived Competence subscale *r* (10) = .836, *P*= 0.01, while there was a statistically significant negative correlation between IMI-Interest and Enjoyment subscale and IMI-Pressure and Tension subscale *r* (10) = -0.794, *P*= 0.01. There was also a statistically significant negative correlation between IMI-Pressure and Tension subscale and IMI-Perceived Competence subscale *r* (10) = -0.74, *P*= 0.01, 5. SFS was significantly positive correlated with each of IMI-Interest and Enjoyment subscale *r* (10) = 0.762, *P*= 0.01 as well as IMI-Perceived Competence subscale *r* (10) = 0.580, *P*=0.04. SFS was also statistically negatively correlated with IMI-Pressure and Tension subscale *r* (10) = -0.833, *P*= 0.01.

Table 3. Spearman's Rho Correlation matrix between Intrinsic Motivation Inventory (IMI) subscales and Short Flow Scale (SFS) in Experimental Conditions (n=12)

Augmented Feedback Condition	**1**	**2**	**3**	**4**	**5**
1.IMI-Interest and Enjoyment	-				
2.IMI- Perceived Competence	.73**	-			
3.IMI-Percived Choice	.29	.37	-		
4.IMI-Pressure and Tension	-.60*	-.50	-.04	-	
5.Short Flow Scale	.71**	.62*	.28	-.56	-

Simple VR Interface	**1**	**2**	**3**	**4**	**5**
1.IMI-Interest and Enjoyment	-				
2.IMI- Perceived Competence	.81**	-			
3.IMI-Percived Choice	-.04	.30	-		
4.IMI-Pressure and Tension	-.56	-.76**	-.23	-	
5.Short Flow Scale	.61*	.71**	.00	-.49	-

VR-Game Condition	**1**	**2**	**3**	**4**	**5**
1.IMI-Interest and Enjoyment	-				
2.IMI- Perceived Competence	.84**	-			
3.IMI-Percived Choice	.36	.50	-		
4.IMI-Pressure and Tension	-.79**	-.74**	-.51	-	
5.Short Flow Scale	.76**	.58*	.43	-.83**	-

**Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

DISCUSSION

We wanted to see how three different types of augmented feedback (augmented feedback alone, augmented feedback with a simple VR interface, and augmented feedback with a VR-game) affected maximum step length performance and intrinsic motivation, as well as what factors influenced maximum step length performance and intrinsic motivation in each type of feedback. The results showed that paretic maximum step length performance was significantly increased with augmented feedback condition than maximum step length performance without feedback. When stepped with their non-paretic leg, participants did not reach a significant increase in maximum step length with all feedback conditions than their maximum step length performance without feedback. However, participants in general had longer step length performance with all three types of feedback than their maximum step length performance without feedback. Yu and Kang find that augmented feedback showed improvement in stride length and single limp support than training without augmented feedback withing four weeks[34]. In terms of intrinsic motivation, there was no significant effect of feedback types on participants' motivation. The highest motivation scores were observed in the augmented feedback condition, followed by the VR-game and simple VR interface conditions.

The data shows an overall slightly longer step length with a non-paretic leg than a paretic leg in general. Also, some participants reported that they could push their non-paretic leg farther and better control lifting their non-paretic leg than their paretic leg. The differences between paretic and non-paretic step length was also found during walking and it can be related to weakness in the paretic limb as paretic leg power generation is diminished, limiting the contribution of the paretic leg to forward propulsion and leg swing initiation[35].In addition, maximum step length performance among experimental conditions was higher with augmented feedback than maximum step length with a simple VR interface and VR game. Notice that, with augmented feedback condition, there was no head-mounted display (HMD) while participants were wearing an HMD in simple VR interface and VR-game. It may give insight into impacts of degree of immersion (i.e., full vs partial) on the stepping performance.

Additionally, participants' enjoyment was positively correlated with perceived competence in all three types of feedback, indicating that individuals with high competence had high motivation and enjoyment. Enjoyment was also positively correlated with the flow state, indicating that highly immersed individuals with high positive experience also had high enjoyment. Theoretically, perceived competence is a good predictor of intrinsic motivation[27]. According to Navarro et al., competition may improve the effectiveness and enjoyment of rehabilitation therapies and the treatment of post-stroke attention issues[36].

Interest and enjoyment in augmented feedback and VR-game conditions were negatively correlated with pressure and tension. Pressure and tension were also theorized to be negative predictors of intrinsic motivation[37]. So, increased pressure and tension can indicate decreased enjoyment in these conditions. Intrinsically, pressure and tension were correlated with competence only in simple VR interface and VR-game conditions. This relationship may explain why individuals had longer maximum step length performance and slightly higher intrinsic motivation with augmented feedback condition than simple VR interface and VR-game. Thus, a head-mounted display (HMD) may have a negative impact on motivation and maximum step length performance by reduce competence and induce pressure and tension. Further investigations should compare delivering feedback with different immersion levels (i.e., partial vs. full) and their impact on competence and physical performance after stroke as well as intrinsic motivation.

The immediate slight changes we observed with maximum step length performance with all types of augmented feedback compared to maximum step length performance without feedback align with the Enhanced OPTIMAL Theory, which classifies augmented feedback as an information pathway that impacts motor performance by enhancing task performance effectiveness[16]. According to the Enhanced OPTIMAL Theory, the information pathway (i.e., augmented feedback) and affective pathway (i.e., task enjoyment) directly impact motivation[16]. Our findings, however, demonstrated a link between enjoyment, competence, and pressure, implying that increased pressure and stress may harm motivation.

Study Limitations

Although we investigated the immediate effects of various types of augmented feedback on step length performance and intrinsic motivation following a stroke, the small sample size in this study should be considered when interpreting our findings or planning an intervention study based on our findings. Even though the conditions were balanced, and rest breaks were offered, all the study outcomes were measured as repeated measures in a single session for each subject, which could have affected their performance or motivation. Furthermore, all the stepping measurements were taken with an overhead harness overground a single forward step; therefore, it is essential to mention that while walking and stepping or stepping on robotic treadmills, participants may provide different performance or use alternative stepping mechanisms.

Future Directions

The next step in this line of research is to discover the long-term effects of different types of augmented feedback on enhancing paretic and non-paretic step length after stroke with larger sample size. Future studies may also explore the gain in step length when trained with different types of augmented feedback and how it impacts hemiparetic gait characteristics (i.e., walking speed, cadence, and step length symmetry). Future research on intrinsic motivation could look at how intrinsic motivation evolves for each sort of augmented feedback (i.e., with and without VR and VR-game). A head-mounted display (HMD) may negatively impact motivation and maximum step length performance by reducing competence and inducing pressure and tension. Thus, further investigations should compare delivering feedback with different immersion levels (i.e., partial vs. full) and their impact on competence and physical performance after stroke and intrinsic motivation.

CONCLUSION

Augmented feedback, i.e., simply displaying step length, relative to no feedback, induced greater paretic leg maximum step length in adults with chronic stroke. Similar advantages relative to no feedback were not observed for the simple VR interface and VR-game conditions. When stepping with their non-paretic leg, participants could not reach a significant longer maximum step length with feedback than without feedback. Participants, in general, had slightly longer step length with non-paretic leg compared to paretic leg. Different types of augmented feedback (i.e., augmented feedback alone, simple VR interface, and VR-game) did not significantly affect intrinsic motivation. Several other factors were associated with maximum step length performance and intrinsic motivation after stroke, including competence, flow state, and pressure and tension. The relationship between enjoyment and competence suggests that increase pressure and tension may have negative impacts on intrinsic motivation during step training after stroke. Pressure and tension were negatively correlated with perceived competence only in simple VR interface and VR-game. It is possible that using a head-mounted display (HMD) in these conditions may reduce competence and induce more pressure and tension.

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SUMMARY AND CONCLUSION

This dissertation demonstrates two innovative virtual reality applications created, specifically for people who have had a stroke, to improve their fast-walking speed and maximum step length performance, as well as their intrinsic motivation. The following three types of augmented feedback were used: 1. Augmented feedback only. 2. a simple virtual reality interface 3. Virtual reality games. As a result, we sought to explore how these various types of augmented feedback immediately affect fast walking speed performance, maximum step length performance, and intrinsic motivation after stroke. Also, we discover factors associated with fast walking speed performance, maximum step length performance, and intrinsic motivation in each type of feedback.

Study 1 established a protocol for inducing fast walking speed and intrinsic motivation, as well as a theoretical framework (Enhanced OPTIMAL Theory) that combines two theories to identify possible constructs and mechanisms associated with motivation and motor performance, as well as relevant VR and VR-exergames features. The Enhanced OPTIMAL Theory displays four pathways (i.e., motivation, attention, information, and affective pathway) that directly or indirectly influence motor performance, as well as many constructs that can be manipulated to help improve motivation and motor performance.

Study 2 used a novel VR-exergame (i.e., Racing Game) to examine the immediate effects of different types of augmented feedback (i.e., augmented feedback alone, simple VR interface, and VR-exergame) on fast walking speed performance and intrinsic motivation in post-stroke. In general, augmented feedback had a slight and non-significant immediate effect on inducing fast walking speed following a stroke. Individuals after stroke were able to walk slightly faster with all types of feedback than they could without it, while there was an immediate significant effect on intrinsic motivation and enjoyment. The highest motivation was with VR-exergame, followed by a simple VR interface and augmented feedback. Because perceived competence was positively correlated with intrinsic motivation, augmented feedback, in general, may help individuals after stroke to feel more competent and motivated when performing fast walking speed.

Study 3 used a novel stepping application (i.e., StepOver) to investigate the immediate effects of different types of augmented feedback and immersive virtual reality technology (i.e., augmented feedback alone, simple VR interface, and VR-game) on maximum step length performance and intrinsic motivation after stroke. Individuals after stroke were able to take longer step lengths with all types of feedback than their maximum step length without feedback. Augmented feedback had an immediate significant effect on inducing participants' paretic maximum step length, while there was no immediate significant effect of different types of augmented feedback on inducing participants' non-paretic maximum step length performance. Among the three conditions, intrinsic motivation did not significantly differ. Perceived competence was positively correlated to intrinsic motivation and was negatively correlated to pressure and tension. The relationship between enjoyment and competence suggests that increased pressure and tension may negatively impact maximum step length performance and intrinsic motivation after stroke.

Studies 2 and 3 results revealed agreement with our theoretical framework discussed in study 1 (i.e., The Enhanced OPTIMAL Theory). The theory suggested that motor performance could be impacted with an informational pathway (i.e., augmented feedback) and motivation. Motivation, however, can be impacted by augmented feedback and task enjoyment (i.e., simple VR and VR games). The findings of study 1 supported the idea that the highest motivation was found with VR-exergame (i.e., more enjoyment aspects were presented), then simple VR interface (i.e., fewer enjoyment elements were displayed), and finally augmented feedback (i.e., no enjoyment elements were displayed). Fast walking speed performance was slightly higher with augmented feedback, simple VR, and VR-exergame than fast walking speed without feedback. The findings of study 3 revealed no significant effects of feedback types on participants intrinsic motivation. Hence, types of augmented feedback might be impacted by individuals' self-preference. Intrinsically, we found a strong positive correlation between perceived competence and motivation (i.e., interest and enjoyment) in studies 1 and 2. Study 2 found that pressure and tension were negatively correlated with perceived competence only with simple VR and VR-game. Thus, perceived competence and pressure may further explain how augmented feedback and task enjoyment impact motivation which may mediate or moderate the relationship between augmented feedback, task enjoyment, and intrinsic motivation.

CLINICAL IMPLICATIONS

The Enhanced OPTIMAL Theory that we developed by combining two theories may assist in designing and implementing augmented feedback and virtual reality to rehabilitation settings to motivate individuals after stroke to enhance their motor performance. Also, the theory will help clinicians and therapists enhance their clients' motivation and motor performance by implementing its constructs in training sessions. Delivering augmented feedback during training sessions with added enjoyment elements could motivate a high level of performance and encourage more attempts in a motor task. Augmented feedback can be delivered in various forms, which may also help individuals after stroke enhance their expectancies (i.e., predicting the performance outcomes) and increase their attention toward a motor task. Task enjoyment can also be provided in various ways, making motor tasks more amusing and motivational.

Based on the slight immediate effects of different types of augmented feedback delivering augmented feedback with or without VR and exergames might be beneficial in rehabilitation settings if added to gait training to optimize fast walking speed performance after stroke. VR exergames may provide extra benefits on motivation and enjoyment by making walking performance more play-like. However, it is also essential to have a safe performing environment (i.e., we used a robotic treadmill with a pelvic harness) when training individuals at fast walking speed after a stroke. In study 3, our participants were able to perform maximum step length tasks with each of their paretic and non-paretic legs and were able to slightly increase their maximum steps with all types of augmented feedback. it might be beneficial to use several feedback strategies (i.e., with or without VR and games) during stepping training sessions to encourage for the maximum step length performance after stroke.

Some factors should be considered to implement our discussed protocol into a clinical setting, including training room spaces and a clinical environment availability. Using technology (i.e., hardware and software) to deliver augmented feedback may require enough space to set up the equipment and multiple accesses to electric plugs. These applications we used also required some extra time to calibrate and sync with equipment. Hence, we spent time before each research session to set up the equipment and run calibration. However, it is still possible to use this application to deliver augmented feedback in some clinical settings. Thus, the second study (i.e., walking study using racing game) was conducted in a clinical setting, which may give an example of using technology-based augmented feedback in clinical environments.

FUTURE DIRECTIONS

Since we developed The Enhanced OPTIMAL Theory, more studies are needed to test the validity of the theoretical constructs and pathways on inducing motor performance and intrinsic motivation after stroke and discover more factors that may correlate with the theoretical constructs. Future studies may also consider a larger sample size with a longer duration to compare the long-term effects of augmented feedback with and without VR and VR games on enhancing fast walking speed, step length, and intrinsic motivation after stroke.

Future research could examine whether different types of augmented feedback will help transfer the gained change in a motor task into other hemiparetic gait characteristics (i.e., walking speed, cadence, and step length symmetry). VR and VR games can be delivered with different degrees of immersion; thus, future studies may compare the effectiveness of using highly immersive vs partially immersive VR systems in motor performance and intrinsic motivation after stroke.

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APPENDIX A

IRB APPROVAL

THE UNIVERSITY OF ALABAMA AT BIRMINGHAM
Office of the Institutional Review Board for Human Use

470 Administration Building
701 20th Street South
Birmingham, AL 35294-0104
205.934.3789 | Fax 205.934.1301 | irb@uab.edu

APPROVAL LETTER

TO: Capo-Lugo, Carmen E

FROM: University of Alabama at Birmingham Institutional Review Board
Federalwide Assurance # FWA00005960
IORG Registration # IRB00000196 (IRB 01)
IORG Registration # IRB00000726 (IRB 02)
IORG Registration # IRB00012550 (IRB 03)

DATE: 24-Feb-2022

RE: IRB-300000718
IRB-300000718-024
Major Research Instrumentation Program: Development of an Innovative Instrument on Robot-Aided Virtual Rehabilitation for Intelligent Physical Training of Individuals with Disabilities (iRAPID)

The IRB reviewed and approved the Continuing Review submitted on 17-Feb-2022 for the above referenced project. The review was conducted in accordance with UAB's Assurance of Compliance approved by the Department of Health and Human Services.

Determination: Approved
Approval Date: 24-Feb-2022
Approval Period: One Year
Expiration Date: 08-Feb-2023

The following apply to this project related to informed consent and/or assent:

- Waiver (Partial) of HIPAA

Documents Included in Review:

- consent.clean.211101