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RESEARCH ARTICLE

Development of a virtual reality-based intervention for community walking post stroke: an integrated knowledge translation approach

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ABSTRACT

Purpose: To develop a virtual reality (VR) based intervention targeting community walking requirements.

Methods: Two focus groups each involving 7 clinicians allowed exploring optimal features, needed support and perceived favorable/unfavorable factors associated with the use of the VR-based intervention from the clinicians' perspective. Three stroke survivors and 2 clinicians further interacted with the intervention and filled questionnaires related to acceptability and favorable/unfavorable perceptions on the VR intervention. Stroke participants additionally rated their perceived effort (NASA Tax Load Index), presence (Slater-Usoh-Steed) and cybersickness (Simulator Sickness Questionnaire).

Results: Results identified optimal features (patient eligibility criteria, task complexity), needed support (training, human assistance), as well as favorable (cognitive stimulation, engagement, representativeness of therapeutic goals) and unfavorable factors (misalignment with a natural walking pattern, client suitability, generalization to real-life) associated with the intervention. Acceptability scores following the interaction with the tool were 28 and 42 (max 56) for clinicians and ranged from 43 to 52 for stroke participants. Stroke participants reported moderate perceptions of effort (range:20-33/max:60), high levels of presence (29-42/42) and minimal cybersickness (0-3/64).

Conclusion: Findings collected in the early development phase of the VR intervention will allow addressing favorable/unfavorable factors and incorporating desired optimal features, prior to conducting effectiveness and implementation studies.

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Cerebrovascular accident; mobility; omnidirectional treadmill; rehabilitation; virtual reality

IMPLICATIONS FOR REHABILITATION

- This study presents the development process of a new virtual reality (VR) intervention for community walking and participation in stroke survivors.
- Results from the focus group and hands-on pilot trial suggest that the VR intervention is feasible and accepted by clinicians and stroke survivors.
- Addressing favorable/unfavorable factors and incorporating features desired by clinicians in the development of the VR tool should promote its eventual implementation in clinical setting.

Introduction

Stroke is one of the leading causes of disability in Canada and globally [1,2]. Common limitations after stroke encompass sensorimotor, perceptual and cognitive impairments [3] that may reduce independence and well-being [4]. While *getting out and about in the community* is a major concern for most stroke survivors [5], only a minority achieve independent community walking at the time of discharge from rehabilitation [6,7]. In fact, most individuals with stroke do not reach the minimal requirements in terms of walking speed (0.8 m/s) and endurance (≥367 meters in 6 min) for independent community walking [6]. In addition, stroke survivors experience difficulties in adapting their walking to environmental demands (stairs, slopes) [6] and many necessitate assistance or supervision when ambulating in public spaces like local stores or shopping malls [8].

Evidence-informed stroke best practice guidelines recommend the use of task-specific interventions that are individually tailored, goal oriented, meaningful, engaging, progressively adapted and of sufficient intensity and duration to optimize sensorimotor recovery [9]. As these principles are incorporated into contemporary practice, locomotor rehabilitation remains largely focused on training rhythmic locomotor movements (e.g., regular & split-belt treadmill walking, weight supported ambulation, robot-guided locomotion, etc.) [10]. Such training strategies, however, underestimates the need for: 1) walking adaptability in varied and meaningful ecological contexts [11]; 2) interactions of sensorimotor, perceptual, and cognitive systems

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[12]; and 3) development of problem-solving skills/proactive strategies for community ambulation [13].

Very few intervention paradigms in stroke rehabilitation target community ambulation and, to date, there is insufficient evidence on their effectiveness [14]. Real-world field training (FT), which promotes ambulatory skills practice in the community, shows no superiority over conventional training [15], possibly due to limited therapeutic dosage (as low as 7 h over a 4-month period [16]). FT, however, was shown to increase walking abilities in individuals with stroke when used as an adjunct therapy [17]. Barriers to FT can include the difficulty to negotiate with crowded environments (avoiding moving obstacles), with the physical environment (e.g., stairs, slopes, static obstacles) and with meteorological constraints (e.g., rain, ice). Such issues could be overcome, at least in part, by using virtual reality (VR) to control for the presence and/or intensity of those constraints, while ensuring a safe training environment. VR refers to the "use of interactive simulations created with computer hardware and software to present users with opportunities to engage in environments that appear and feel similar to real world objects and events" [18]. VR can be delivered via different displays providing different levels of immersion, whether it be large project screens or head mounted displays (HMD).

Small intervention and feasibility studies, the vast majority of which have used large non-immersive rear-projected VR displays (except [19] which used an HMD) have shown promising results for stroke rehabilitation, with post-intervention gains in selected outcomes such as gait speed [19–21] and community walking time [20] (for a review, see [22]). Limitations remain, however, in terms of the technology which does not allow speed and trajectory adjustments (as in fixed speed, unidirectional treadmills) and thus limit the practice of essential community ambulation skills (e.g., gait speed adjustments, pedestrian navigation). Furthermore, current VR-based interventions for most lack clinician's and patient's input in the intervention design and, as a consequence, they may not be optimally designed to meet user's needs [23,24]. Poor match between client's needs and goals (e.g., selecting appropriate systems, matching games to client needs, grading games for difficulty, progressing treatment) and the actual VR system capabilities was shown to be a barrier to the use of VR [23]. Although balancing these needs and the technology requirements is challenging, there is considerable benefits of soliciting early on the input of end users: a better match between VR technology and client/therapist needs leads to increased clinical uptake of this technology and to improved end-user involvement in all stages of VR implementation research [24]. Involving users in the initial phases of developing a VR intervention is therefore not only important to identify needs but is also crucial to support optimal knowledge translation.

Ambulating independently and safely in community environments requires the skills to cope with multiple and simultaneous dimensions such as walking speed and distance, traffic level (obstacle avoidance), postural transitions (turning), and cognitive demands (multi-tasking, distractors) [11]. These skills remain compromised in the majority of stroke survivors due to insufficient or lack of targeted practice [7,25]. To address this problem, we propose to conduct a multi-centered study that involves the development and testing of a new, individually tailored intervention based on the best evidence in community ambulation [11,26], principles of motor learning [9,27], and participatory action research [28], and the most recent advances in *low-cost* VR technology. This intervention toolkit combines VR and FT practice to enhance community walking after stroke. It is designed to provide targeted, intensive, and repeated practice of locomotor adaptations in varied community environments to tackle multiple requirements of community walking [11]. The VR component involves the use of an HMD and a self-paced omnidirectional treadmill, allowing changes in speed and walking in any direction. Such innovative combination of technologies is new in rehabilitation, especially as omnidirectional treadmills have only been recently developed by the gaming industry. A similar omnidirectional treadmill was used in a recent study from our team to evaluate changes in walking speed [29] and complex walking tasks such as obstacle avoidance and dual tasking [30,31] in either or both healthy young adults and stroke survivors, supporting the feasibility of using such technology in an intervention study with a stroke population.

First and foremost, the initial phase of this project aimed to develop the VR intervention prototype, including the selection of equipment and creation of training scenarios. The created VR intervention prototype allows individuals to train on complex, ecologically based locomotor tasks as required for community walking. The second phase involved potential users (i.e., stroke survivors and clinicians) in the process of refining the VR intervention to ensure its relevance, acceptability, and its applicability in real-life clinical settings. Involving potential users throughout the research process (from early development to implementation) using an integrated knowledge translation approach [32] could help identify factors that facilitate or hinder its optimal use as well as promote acceptance of VR technology for rehabilitation purposes.

The specific objectives of this study were thus [1] to identify, via focus groups, optimal features of the VR-based tool (i.e., favorable/unfavorable features of the VR tool) and needed support (i.e., organizational support, resources and assistance) as perceived by clinicians [2]; to explore, via hands-on sessions and post-encounter questionnaires, acceptability and favorable/unfavorable factors associated with the use of the VR tool from the perspective of clinicians and stroke survivors. Additionally, we aimed [3] to document the perceived effort, sense of presence (the participant's sense of "being there" in the virtual environment [33]), and potential cybersickness symptoms in stroke survivors participating in the hands-on sessions. Findings from this study will be used to refine and optimize the VR intervention for its potential users, in preparation for future effectiveness and implementation trials.

Materials and methods

A qualitative descriptive approach, using a triangulation validation strategy, was used. Specifically, a focus group methodology was complemented with hands-on sessions to explore clinicians' and patients' perspective on a VR-based training prototype to improve community walking for stroke survivors. The focus groups were conducted with rehabilitation professionals (clinicians) working on a stroke rehabilitation unit. In addition, hands-on sessions with the VR intervention prototype and its equipment were conducted with stroke survivors, under the supervision clinicians. The multi-centered project involved two clinical sites and was approved by the Research Ethics Committee of the Center for Interdisciplinary Research in Rehabilitation of Greater Montreal as well as the Research Ethics Committee of the Centre Intégré Universitaire de Santé et de Services Sociaux de la Capitale-Nationale (certificate number: CRIR-1183-1116). Each participant signed a consent form prior to their involvement in the present study and the goals of the research were explained. Guidelines of the consolidated criteria for reporting qualitative research (COREQ) were followed to report methodological details and results in this manuscript [34].

Participants

Focus groups

Using purposive sampling, all rehabilitation professionals working on the in- and out-patient stroke units of a rehabilitation center (Centre Intégré Universitaire de Santé et de Service Sociaux de la Capitale-Nationale [CIUSSS-CN], Quebec City, Canada) were invited to participate in the focus groups via email. They could participate in the study regardless of their prior experience with the use of VR and their level of experience in the field of stroke rehabilitation. No relationship was established with potential participants prior to study commencement.

It is proposed that a focus group with four to six participants is advantageous in encouraging members to engage in the discussion [35]. Given the number of participants that volunteered participate ($n = 14$ clinicians), we opted for two focus groups of 7 participants each.

Hands-on sessions

The hands-on sessions involved a convenience sample of two clinicians and three stroke participants. Clinicians were recruited amongst rehabilitation professionals working in the in- and out-patient stroke rehabilitation units of another rehabilitation centre (Jewish Rehabilitation Hospital-CISSS de Laval, Laval, Canada) who presented ≥6 months of experience in stroke rehabilitation were invited to participate in the focus groups. Three chronic stroke survivors were additionally recruited among discharged patients of the same rehabilitation center. Inclusion criteria for stroke participants were: 1) first-ever supratentorial unilateral stroke 9-24 months ago (such chronicity will ensure being discharged from in- or outpatient rehabilitation and steady-state mobility [36] while reducing the likelihood of long-term disuse-related changes); 2) mild-to-moderate hemiparesis (Chedoke-McMaster Stroke Assessment stages 4/7-6/7 on postural control, leg & foot impairment inventory); 3) ability to walk independently with/without walking aids for at least 1 min at a speed between 0.4 and 0.9 m/s (i.e., a mobility level not sufficient for functional community ambulation [8], shopping (~1.1 m/s) [5] and street crossing (~1.2 m/s) [37]); 4) intact or mildly affected cognitive function (MoCA scores ≥ 22/30 [38]); and 5) intact to moderately affected visual-perceptual function (positive scores on a max. of 3/6 tasks on the Behavioural Inattention Test) [39]. Individuals with comorbidities interfering with walking or visual perception, or without medical clearance for exercise, were excluded.

VR intervention prototype

VR intervention prototype involves participants walking on an omnidirectional treadmill (Virtualizer, Cyberith Austria) that allows for self-control over the speed and direction of walking. The treadmill is fitted with a safety harness which prevents a full fall, such that a participant losing balance would remain in an upright position without the need to bear weight through the lower limb (Figure 1). Participants viewed the virtual environment (VE) in an HTC Vive head-mounted display (HMD) (HTC Corporation). These technologies were chosen based on the fact that they are commercially available at a relatively low-cost and easy to use, the goal being to be realistic for clinical settings to eventually purchase and use the equipment. The VEs representing sections of a shopping mall in Montreal were developed in Maya LT (Autodesk, USA) and Blender (Blender Foundation, The Netherlands) and controlled in real time during the experiment with the UnityPro

Figure 1. Set-up of the hands-on sessions. Participants walked on an omnidirectional treadmill while secured with a safety harness. Participants viewed the virtual environments in an HTC Vive head-mounted display. A Vive controller was used to track upper extremity movements in the virtual environments.
Photograph of an individual walking on an omnidirectional treadmill under the supervision of therapist. The individual is secured with a safety harness and is wearing an HTC Vive head-mounted display to visualize the virtual environments. A Vive controller attached to the left wrist of the individual also allows to track upper extremity movements.

game engine (Unity Technologies, USA). The software was developed in-house by our research team in the Unity game engine, which was selected as it is widely used, accessible and free. The training program was designed such that it is adjustable in terms of parameters and progression (as opposed to purchasing a ready-to-use software) and it can be easily migrated towards new technologies. Real measurements from the mall as well as high-resolution store textures were used to create a realistic ecological scene which included 120 m of the walking area with approximately 50 - 60 stores. The parking garage was similarly modeled after the parking garage of the mall with approximately 40 different types of cars modeled precisely with high-resolution textures to simulate real cars. Both scenes had extremely realistic light rendering implemented based on photos captured of the real environment. The viewpoint of the participant in the virtual environment is rendered from a first-person perspective thus enabling the shopper to observe the environment as it would be viewed in the real world. Navigation both in terms of position and rotation in the virtual environment is controlled by the omnidirectional treadmill that uses a flat, low friction walking surface and a rotating containment ring. The orientation of the ring defines the walking direction which can be anywhere between 0 and 360 degrees. The device's ring contains an adjustable belt system so that people with different body types can fit in (waist circumference of up to 140 cm). Its vertical movement is also flexible, and it can adapt to people of different heights (the harness, positioned at ASIS height, can be adjusted to a height ranging from 50 cm to 110 cm in relation to the ground). The integration of the treadmill was made feasible with the device's Software Development Kit. The user's movement and orientation were detected by the treadmill's sensors while the user's location and head orientation were identified by the HMD sensors. We utilized the Vive Trackers to track the position and rotation of the wrist.

The training scenarios were developed according to community walking demands and ambulation challenges (referred to as dimensions) and were determined using the existing literature [11]. Each of the 6 training dimensions included in the prototype presented with 3 levels of increasing difficulty. Level 1 (baseline) was tailored according to the participant's individual walking capacity based on the 6-min Walk Test (6MWT). Participants progressed to level 2 and 3 according to pre-established success criteria. For this hands-on component of the study, participants and clinicians interacted with dimensions 1 to 3 which pertained, respectively, to the dimensions of walking endurance (Dimension 1), speed (Dimension 2), and postural transitions (Dimension 3). In Dimension 1, participants were requested to walk in the shopping mall to a specific store and buy an item, walking a distance corresponding to the distance they walked at 1 min (level 1), 2 min (level 2) and 3 min (level 3) on the 6MWT measured *a priori*. Dimension 2 was similar to Dimension 1 with a fixed distance corresponding to their performance at 2 min on the 6MWT, but this time around participants had a time limit to complete the task. Walking speed requirements in level 1 corresponded to 75% of overground gait speed calculated at 2 min on the 6MWT, progressing to 100% at level 2 and 125% at level 3. and increased in subsequent levels as described for Dimension 1. In Dimension 3, participants were requested to walk in the mall and to pop balloons placed on either side of their walking path which caused them to reach beyond their base of support. For all 3 levels, they started at a distance from the target and a time limit corresponding to their walking distance and 100% of their overground speed at 2 min on the 6MWT. In level 1 and 2, the balloons are positioned at shoulder level (80% of overground height), whereas in level 3, the balloons are placed either at 80% or 50% of overground height. The path is straight in level 1 and included turns in level 2 and 3.

Data collection

Focus groups

Based on the Technology Acceptance Model [40], a focus group interview guide was developed to stimulate discussion about clinicians' perceptions on the VR intervention prototype and its required equipment (Appendix,Supplementary Material). The focus groups took place in June 2019 within the Cirris rehabilitation centre and began with a 15-min presentation, led by research team members (AKB and ADB), on the role of the research team members, on community ambulation requirements, existing VR-based therapies for post-stroke mobility, and a description of the proposed VR intervention prototype and its required equipment. Afterwards, two experienced moderators (moderator 1: research professional at Cirris since 2012, bachelor's and master's degree in nutrition, and expertise in qualitative studies as part of her work as a research professional; moderator 2: project coordinator since 2011 and knowledge broker since 2014 at Cirris, bachelor's degree in kinesiology and master's degree in community health, and experience in qualitative studies acquired during her master's degree), independent from the study, asked pre-determined structured questions and guided the discussions related to the perception on intention to use, usefulness, ease of use and motivation. No one else was present during the discussion beside the two research team members, the moderators and the participants. Clinicians were also asked to discuss about the VR components that they liked/disliked, the factors that they perceived as favorable or unfavorable, and potential modifications to the intervention. Finally, open-ended discussion questions were conversed amongst participants on perception of the VR dimensions, knowledge of performance provided and material/set-up, as well as the preferred format (i.e., written; video; web-based) of instructional material on VRFT intervention. Results of the focus groups are reported according to the Consolidated criteria for reporting qualitative research [34]. Each focus group discussion was audio recorded. Discussions were conducted in French, as per participants' preference and as the official language used in the rehabilitation centre. We also documented their perception on the use of VR in rehabilitation, as well as the therapeutic modalities used in their clinical practice for community ambulation training with multiple-choice questions. The entire process lasted approximatively 75 min. Field notes were taken during discussions by AKB and ADB, who also managed dialog time. No individual interviews were carried out.

Hands-on sessions

Prior to the hands-on sessions with the stroke participants, clinicians received a short user guide that included a description of the dimensions and levels of training. They further attended an individual, 1-h familiarization period with the VR system, under the supervision of two research team members (a researcher and an engineer). During this familiarization session, clinicians learned about the general procedure, how to operate the VR prototype, including the material and software, and they further experimented themselves the different VR training dimensions and levels that would later be presented to stroke participants.

The actual hands-on sessions involved clinician-stroke participant dyads (3 dyads in total) who each interacted with the VR prototype for two 1-h sessions taking place two days apart, under the supervision of the same team members as during familiarization. As for the focus groups, the hands-on sessions took place in June 2019. During the hands-on sessions, feedback on task performance was provided to stroke participants and clinicians. At the end of each trial, the results were displayed on the screen, including total time taken to complete the level, distance traveled, participant's speed, task accuracy (for Dim. 3), as well as success or failure. At the end of the second hands-on session, we also collected information on stroke participants' perceived level of mental and physical demands (NASA Tax Load Index [41]), sense of presence (Slater-Usoh-Steed (SUS) questionnaire [33]), and cybersickness (16-items Simulator Sickness Questionnaire (SSQ) [42]. Acceptability of the VR-based intervention from the perspective of stroke participants' and clinicians' was collected using a questionnaire based on the Technology Acceptance Model (TAM-2) [43] in addition to open-ended questions (Appendix,Supplementary Material). These complementary questions were chosen to add qualitative information about the participant's experience with the technology used in the present study and were based on similar studies in VR [44]. Filling out questionnaires lasted approximately 30 min.

Data analysis

Descriptive statistics were used to summarize the paper-pencil questionnaire data related to the focus groups and hands-on sessions. Focus groups' audio recordings were transcribed verbatim by a research assistant and reviewed for consistency by a research team member (ADB). Transcripts and results were not returned to the participants for comment and/or correction. However, field notes taken during discussions served in ensuring validity in verbatim transcriptions. The verbatim transcriptions were imported into the NVivo software (QSR International, Australia) for analysis following a hybrid inductive/deductive thematic approach [45] alongside a reflexive thematic analysis process [46].

First, one reviewer (TO), not present during the focus groups, read the transcriptions to get a general idea of the content and generated main emerging themes. Themes were verified and approved by all team members. Then, the transcriptions were analysed by generating an initial set of codes (i.e., subthemes) for all meaningful ideas emerging from data. Using the established coding scheme, transcriptions were then independently coded by a second reviewer (ADB). It was followed by a discussion between reviewers to ensure that their agreement reached 100% [47]. Following this, the first reviewer (TO) performed a last round of analyses to ensure that all relevant statements were coded.

For the purpose of results reporting, each participant of the focus groups was assigned a code that included the focus group number, profession and identification number, and years of experience < *or* ≥ 4 years [e.g., *G1PT1 (< 4 yrs)*, corresponding to group 1, physiotherapist (PT) 1, less than 4 years of experience]. For the hands-on sessions, as only one PT and one occupational therapist (OT) were recruited, a code referring to the profession and years of experience was assigned [e.g., *OT (≥ 4 yrs)* corresponding to an OT having 4 years or more of experience].

Results

Participant's descriptive variables

Focus groups

Two focus groups included fourteen (*n* = 14) clinicians: 7 in group 1 and 7 in the group 2. Table 1 presents their personal and professional characteristics. Most participants (*n* = 10/14, 71.4%) were between 31 and 50 years old. Clinicians were physiotherapists (PT, 42.8%), occupational therapists (OT, 21.4%) or other rehabilitation professions (physiotherapy technologist (PhysT), neuropsychologist (NP) and specialized educator (SE), 35.8%) with 16.21 ± 8.91 years since graduation on average. Nearly 60% of participants had between 4 and 10 years of experience in the fields of stroke and progressive encephalopathies. The majority (71.4%) reported relatively positive perception towards the use of VR in rehabilitation. In terms of the walking training modalities used in their clinical practice, while most participants (50.0% – 78.5%) rely on treatment modalities including walking inside/outside of the rehabilitation center, in public places, using obstacles or different walking surfaces, stairs, and dual-task walking (e.g., adding a cognitive load while walking), only 21.4% report using treadmill training.

Hands-on sessions

Hands-on sessions included two clinicians (> 15 years of experience) and three patients with stroke. One clinician interacted with 1 patient and the other one interacted with 2 patients. Clinicians were a PT with no experience with VR and an OT who had 5 h/year of experience with a non-immersive Kinect-based exergame system. Individuals with stroke were aged 57 to 67 years and sustained a stroke 0.67-3.5 years previously in the right hemisphere. Their comfortable overground walking speed ranged from 0.63 to 0.84 m/s (Table 2).

No participant dropped out during the study in both the hands-on sessions and focus groups.

Favorable vs unfavorable factors

Focus groups

An excellent agreement of 97.4 ± 2.6% was obtained between the two independent raters in coding focus group transcripts. The thematic analysis revealed several natural groupings under unfavorable factors (*n* = 10) and favorable factors (*n* = 12) related to the proposed VR intervention shown in Table 3. Favorable and unfavorable factors were identified in 49 and 62 statements, respectively. Key themes bearing most weight (i.e., those underlined by 10% or more of the total utterances per grouping) are described below with the salient underlying utterances.

Favorable Factor – Cognitive stimulation (n = 16/49 utterances; 32.6%):

Clinicians reported that the tasks and activities used in the VR toolkit target cognitive and visuo-perceptual functions and could be useful in providing the stimulation needed to enhance community walking after stroke.

> I find that for the aspect of double tasking, [the VR toolkit] is very interesting. This is what we have most difficulty in getting here. Sometimes we want to go for a walk [with a patient] and encounter people, and sometimes during the appointment time we do not meet anyone. However, [the VR toolkit activities] are more standardized, [where] you are sure to face obstacles, to have the [cognitive] tasks. G1PT2 (≥ 4yrs)

> I have a client, an in-patient, who is walking very, very well, but he has hemineglect, he is not scanning the environment, he has trouble orienting himself. Maybe yes, for a client like him, this would be pertinent {…}. G2PT3 (≥ 4yrs)

Favorable Factor – Representativeness of therapeutic goals (n = 6/49 utterances; 12.2%):

Table 1. Participants characteristics: focus groups.

Age (years)	N	Profession	n	Time since graduation (years)	n	Experience in stroke (years)	n	Therapeutic modalities used for community walking training (many possible answers)	n	Perception of VR use in rehabilitation	n
<30	2	PT	6	0–5	2	<1	3	Inside center	11	Very positive	1
31–40	6	Physiotherapy technologist	1	6–10	0	1–3	2	Outside	11	Somewhat positive	10
41–50	4	OT	3	11–15	5	4–10	6	Public space	7	Neutral	3
51–60	2	Neuropsychologist	3	16–20	4	<10	3	Obstacles	7	Somewhat negative	0
		Specialized educator	1	21–25	1			Different surfaces	7	Very negative	0
				26–30	1			Stairs/slope	9		
				31–35	0			Double task	9		
				36–40	1			Treadmill	3		

Legend: Physiotherapist (PT); Occupational Therapist (OT); Virtual reality (VR).

Table 2. Descriptive and hands-on session results: participants with stroke.

		Time since stroke	WALKING SPEED	EFFORT	PRESENCE	CYBERSICKNESS	ACCEPTABILITY
Participant	Age (years)	(years)	5MWT (m/s)	NASA TXL Index (max = 60)	SUS (max = 42)	16-Item SSQ (max = 64)	TAM-Q (max = 56)
S1	61	0.67	0.63	33	29	3	52
S2	67	3.5	0.84	20	42	2	43
S3	57	3.5	0.79	28	42	0	48

Legend: 5MWT (5 m Walk Test); NASA Tax Load Index (NASA TXL); 1. Slater-Usoh-Steed questionnaire (SUS); Simulator Sickness Questionnaire (SSQ).

Table 3. Facilitators and barriers: focus groups.

THEME	UTTERANCE n (%)
FACILITATORS (44.1% of all utterances)	
Cognitive stimulation	16 (32.6)
Representativeness of therapeutic goals	6 (12.2)
Functional component	4 (8.1)
Progressive increase in task complexity	4 (8.1)
Adaptation to client characteristics (walking aids, age, preferences)	4 (8.1)
Installation easiness	4 (8.1)
Time efficiency	3 (6.1)
Environment versatility	2 (4.0)
Repeated trainings & principles of recovery	2 (4.0)
Professional's personality, views and outlook	2 (4.0)
Performance feedback	1 (2.0)
Image clarity	1 (2.0)
Total	**49 (100)**
BARRIERS (55.9 % of all utterances)	
Misalignment with natural walking pattern	16 (25.8)
Client suitability	16 (25.8)
Misalignment with therapeutic goals	9 (14.5)
Generalizability to real-life performance	8 (12.9)
Set-up & start-up: equipment requirements and safety	5 (8.0)
Virtual reality side effects	3 (4.8)
Professional requirements, authorizations to use	2 (3.2)
Accessibility & space requirements	1 (1.6)
Infection control	1 (1.6)
Scoring system	1 (1.6)
Total	**62 (100)**

Clinician perceived that the activities within the VR toolkit are in line with the therapeutic goals they are normally setting for their patients with stroke while undergoing rehabilitation.

> {…} It targets many aspects that we work on in rehabilitation, it works on the physical level and on the cognitive level. Those are all the things we work on, so it could work well. G1PT2 (≥ 4yrs)

> I think that it allows to also work on balance reactions. Maybe with a client that we will not necessarily evaluate right away with many people in a crowd [in real world]; therefore, it allows [us] to observe how [the client] reacts in double-tasks, but not only in terms of cognitive abilities, but also on the physical level - if it creates instances of disequilibrium. When we are not sure, for instance, if [the client] has the necessary endurance to get to a place where there are a lot of people {…}. G1PT1(< 4yrs)

Unfavorable factor– Misalignment with a natural walking pattern (n = 16/62 utterances; 25.8%):

Clinicians perceived that the walking pattern adopted within the VR prototype were not in line with a natural walking pattern and raised concerns regarding this mismatch and its effects on re-learning and adopting safe walking skills and abilities.

> I am really doubtful regarding the walking pattern and the endurance because [the VR toolkit] does not target the same walking pattern at all. You really have to push as if you were on skates {…}. So, [the VR toolkit] is good cognitively, for double-tasking, but regarding the walking pattern, it is more doubtful. G1PhysT1(< 4yrs)

> Similarly, concerning the walking pattern, our stroke patients often present with a knee hyperextension and not a good foot dorsiflexion – they will really slide. {…} Will this aggravate some problems with the knee extension? G1PT1 (< 4yrs)

Unfavorable factor– Client suitability (n = 16/62 utterances; 25.8%):

Clinicians reported several barriers to the use of the VR toolkit for patients with stroke with different characteristics (e.g., use of walking aids, age, level of endurance):

> It must be [a patient] who does not rely on walking aids at all. G1PT2 (≥ 4yrs) {…}. This eliminates certain… certain/many categories [of suitable patients who can benefit from this tool]. G1SE1 (< 4yrs)

> On the cognitive level, [patients] who are very affected and present with very severe deficits, I think that [participation in the VR toolkit tasks] risks being complicated. G1NP1 (≥ 4yrs) {…} Those with vestibular issues, we have to see, issues with proprioception as well. G1PT2 (≥ 4yrs) {…} I am not sure if age can play a role G1SE1 (< 4yrs) …maybe… age and interest in technologies. I had clients whom I asked to phone and they say 'No, no, this is too complicated for me!'. Because of lack of interest… 'Are you using a tablet, email?' 'No, no, no, I do not do that!'. I think it takes a minimum interest from the client. G1OT1 (≥ 4yrs)

Unfavorable factor– Misalignment with therapeutic goals (n = 9/62 utterances; 14.5%):

Clinicians reported that the nature of the VR toolkit activities may not align with their therapeutic goals:

> First of all, me as a physio[therapist], I would choose to prioritize a more natural walking pattern than to go towards using [the VR treadmill prototype]. I would make this choice when I have to prioritize {…}. G2PT4 (< 4yrs)

> {…} It is really about targeting a walking pattern that would avoid [the patient] tripping over, stumbling. But with [the VR toolkit], it does not reproduce this, it does not work on the [patient's] balance.

Unfavorable factor– Generalizability to real-life performance (n = 8/62 utterances; 12.9%):

Clinicians reported concerns with regards to the generalizability of learned skills into real-life performance:

> I wonder to what extent it can be transposed afterwards, generalized. G1NP1 (≥ 4yrs)

> {…} I, too, have my doubts that it will transfer to reality. G2PT1 (≥ 4yrs)

Hands-on sessions

Similar to the focus group results, some favorable factors related to cognitive/physical stimulation and engaging environment, and some unfavorable factors related to misalignment with a natural walking pattern emerged during the hands-on sessions:

> *Favorable factor – Cognitive stimulation/engaging technology and environment:*
>
> Different stroke participants: "[I liked the most that it was] almost real." [I liked the most is the] effort [that it] required for ambulation and concentration". "The technology was good in terms of the treadmill". "[I liked the most was the virtual] environment, and the walking pedestrians". "[What I liked the most was that] it was challenging". "[I liked the most that it was] fun."
>
> Clinician: [I liked the most that] the immersion in the community environment seems very real". "[What I liked the most was] the difficulty of the activity on the physical and the cognitive levels [in terms of] attention." OT (≥ 4yrs)
>
> *Unfavorable factor– Misalignment with a natural walking pattern:*
>
> Stroke participants: "[What I liked less is that it was] difficult walking with the left leg." "[What I liked less is that] standing up with one leg was tiring."
>
> Clinician: "[What I liked less is] the walking pattern that is not natural. For neurological clients, we aim to get the automatisms, the central set {…}" PT (≥ 4yrs)

Proposed recommendations to improve the VR-based tool & needed support

Focus groups

Eleven themes emerged from clinicians' responses that were categorized into suggestions for optimal features and needed supports (Table 4). Nearly 30% of utterances ($n = 15/56$, 26.8%) were suggestions for what could be the eligibility criteria for patients to be able to participate in the VR task and benefit from it. Those mainly consisted of cognitive (e.g., level of attention/ability to concentrate, response to instructions/judgement) and physical (e.g., balance, endurance levels, lower extremity function) must-haves. Further, in 14.2% of statements ($n = 8/56$), clinicians indicated the need for adequate training to be provided before they feel comfortable in using the VR tool with their clientele; and 10.7% ($n = 6/56$) reported that they would benefit from a resource person/technical assistance and follow-up on training once they start using the VR setup. Eight propositions to improve the task complexity/adding novel features to the existing tool were put forward by clinicians. Those include tasks targeting talking simultaneously while walking; reaching tasks and simultaneous perception of avatar/hand; naming/locating perceived objects in the environment; using different walking surfaces (slope, stairs, different directions); including passing by cars in the scene

Table 4. Optimal features of the virtual reality toolbox: focus groups.

FEATURE	DESCRIPTION	RECOMMENDATION SUMMARY	UTTERANCE n (%)
Patient eligibility criteria	Refers to patient's characteristics that would make them eligible to engage and benefit from the VR tool tasks participation.	1. A minimum level of balance, endurance, and physical/mobility abilities (e.g., ability to stand with support of a device for 10 minutes, ability to walk/glide at a certain speed for a number of minutes, etc.). 2. A minimum level of cognitive functions (attention, orientation, ability to follow instructions, ability to learn/cognitive flexibility). 3. A minimum level of visual, perceptual and vestibular functions. 4. Client's interest in using VR technology.	15 (26.8)
Training prior application	Refers to needed training on the use of the VR toolkit prior its application in the clinical setting.	Hands-on training, trials, electronic format supports, live training.	8 (14.2)
Task complexity & novel features	Refers to additional elements suggested for the VR mobility tool to increase task complexity and performance outputs.	Tasks can include: 1. Talking simultaneously while walking. 2. Reaching tasks and simultaneous perception of avatar/hand. 3. Naming perceived objects in the environment. 4. Finding & locating objects in the environment. 5. Diversity walking surfaces (slope, stairs, different directions, etc.) 6. Include passing by cars in the scene of the parking lot. 7. Include moving objectives in the scene of shopping mall (e.g., motorized wheelchair). 8. Ability to create/include objects of interest by clinician.	8 (14.2)
Resource personnel, technical assistance & follow-up	Refers to what kind of supports are needed to use the tool in clinical setting.	Having access to a resource/support person, technical assistance when using the setup and follow-up on training and application of the tool.	6 (10.7)
Ease of access & physical space requirements	Refers to accessibility and required space.	Easily accessible within the clinical setting and in proximity to the OT/PT treatment area.	4 (7.1)
Scoring system	Refers to how the scoring system and feedback on performance could be enhanced.	User-friendly report with scores following use of the tool; re-visualization of performance.	4 (7.1)
Platform	Refers to the design of the walking platform.	Treadmill, omni-directional treadmill with possibility of changing directions; platform slowing changes in surfaces planes to simulate slopes/stairs.	4 (7.1)
Environment	Refers to enhanced environment features.	Include possibility of performing the task in a dark environment (e.g., simulating evening, night-time lighting).	3 (5.3)
Ease of installation and start-up	Refers to installation and start-up features of the VR tool	User-friendly and easy to initiate the tasks, set-up the patient with needed equipment.	2 (3.5)
Participation time	Refers to the optimal length of participation.	1 h for out-patients; < 1 h for inpatients with breaks.	1 (1.7)
Professional suitability	Refers to which rehabilitation professional would be suitable to use the VR mobility tool in their practice.	PTs and OTs.	1 (1.7)
Total			**56 (100)**

of the parking lot and moving objectives in the scene of the shopping mall (e.g., motorized wheelchair); and the ability to create/include objects of interest by clinicians. Participants emphasized on the need for easy access to toolkit and dedicated physical space within their clinical settings (7.1% of utterances) along with user-friendly installation and start-up procedures (3.5% of utterances); boosts to the scoring system (7.1% of utterances) and more options for the environment (e.g., walking in the dark) (7.1% of utterances). Possible application of other walking platforms (e.g., omnidirectional treadmill) was also discussed.

Hands-on sessions

Two optimal feature recommendations emerged from the hands-on sessions. One patient recommended to design a more adaptable setup for getting in and out of the device given that currently, the ring (holding the harness) does not go low enough to allow easy access for individuals with difficulties lifting their lower extremities. One clinician recommended to modify the walking surface of the device with one that can elicit a more natural walking pattern (i.e., which is more similar to overground gait).

Acceptability, perceived effort, sense of presence and cybersickness

Hands-on sessions

The acceptability (TAM-2) of participating clinicians was 28/56 (PT) and 42/56 (OT). From the perspective of stroke participants, the perceived effort, sense of presence, cybersickness, and acceptability are displayed in Table 2. Stroke participants reported that the VR mobility task required medium effort. Overall, high levels of presence (29 to 42/42) and acceptability (43 to 52/56) were noted, along with low reports of cybersickness (0 to 3/64).

Discussion

The purpose of this project was to refine a VR-based community ambulation training toolkit prototype developed by our team, using low-cost and commercially accessible equipment, as part of the first phase of a broad multi-centered study with stroke survivors. More precisely, we aimed to identify favorable and unfavorable factors related to the proposed intervention as well as optimal features of VR-based tool and needed supports, using clinicians' and patients' perspectives. Finally, we wanted to explore acceptability, perceived effort, sense of presence and cybersickness. Stemming from the Technology Acceptance Model [43] used in the development of the focus group guide, we were able to identify several factors (e.g., client suitability) that could potentially influence the usability, acceptance, and the intention to use this tool. Understanding what factors can support or hinder the uptake of this technology can promote translatability and sustainable adoption of it in the future. The selected method of analysis for the present study was a hybrid strategy that incorporated two qualitative methods of thematic analysis, including a deductive/top-down [48] and an inductive/bottom-up [49] methods. Provided that the focus groups with clinicians were semi-structured and were guided with discussion questions determined *a priori* (based on the Technology Acceptance Model), the deductive/top-down approach was used by reviewers to organize data into categories to maintain alignment with these discussion questions and the framework. On other hand, the inductive approach allowed us to code the utterances and ideas as they emerge, to make meaning from the data and identify representational data to support our findings. Blending deductive and inductive coding strategies is suggested and viewed to capture the qualitative richness of the explored phenomenon by promoting reviewer's reflectivity and reflexivity [50–52]. Moreover, factors such as the large focus group sample size of fourteen participants, the included recap of points that were discussed, as well as the follow-up questions at the end of the discussion on any new emerging ideas, contributed to ensuring data saturation.

In this qualitative study, we found that healthcare professionals working in stroke rehabilitation had an overall positive attitude towards the use of VR for post-stroke community walking rehabilitation. One central favorable factor included the presence of cognitive stimulation and its grading, which was emphasized by participants in both the focus groups and the hands-on sessions. According to clinicians participating in the study, offering an adjustable level of cognitive/attentional load was perceived as a positive asset to improve community walking. This point of view was shared by stroke participants who tried the toolkit and liked the amount of concentration effort required to perform the different dimensions. Likewise, in a study exploring clinicians' perspectives on the use of VR for post-stroke visual neglect management, it was found that the ability to adjust the level of difficulty was a facilitator for implementation and adherence to the use of a VR-based tool [53]. The tasks proposed as part of the toolkit were also perceived as representative of therapeutic goals typically set by patients and rehabilitation professionals. Clinicians explained that it also provides a safe and engaging way to evaluate functional capacities and train patients in more challenging situations and environments than what they would typically have access to in a clinical setting. For instance, clinicians would feel more comfortable if their patients were walking in a crowd or walking longer distances in a VR setting, as they are not sure whether they have enough endurance and/or balance to ambulate safely in a real-world setting. Collectively, these results suggest that the VR toolkit was perceived as addressing a tangible rehabilitation need, while offering a safe means to improve patients function through key principles of motor relearning such specificity, intensity, and saliency [27].

The study, however, also allowed identifying unfavorable factors that need to be considered in the refinement of the toolkit and a future implementation in the clinical setting. First, some clinicians expressed concerns about the intervention potentially not being suitable for all patients which present with different characteristics and degrees of severity. Such concern is actually shared by our research team who aims, in the context of the upcoming intervention study, to recruit stroke participants having different levels of cognitive, walking, and visual-perceptual deficits to determine who best responds to this type of intervention. This concern also emphasizes the necessity to allow clinicians adjusting the level of difficulty of the training dimensions in terms of walking speed, walking distance and attentional/memory load, in order to tailor the intervention to each patient profile and allow for a broad range of patients to use it. The idea that older patients are less motivated by technology and less comfortable using it was also mentioned as a potential limitation. It is important to note, however, that this concern was not shared by the 3 stroke participants who tried the training prototype, and who were aged between 57 and 67 years. Those participants reported that they found the training 'fun' and 'challenging' and that enjoyed being immersed into the virtual environment. The latter observation is also in accordance with other studies using VR in older participants and which reported positive results regarding acceptance and using the VR technology [54–56].

Clinicians also raised concerns related to the choice of equipment. While there were no comments pertaining to the use/choice of HMD, the treadmill was perceived as promoting an unnatural gait pattern. In fact, the cyclic walking-like pattern on the omnidirectional treadmill requires participants to "slide" their feet over the ground surface as well as to slightly bend forward and lean on the harness ring during forward propulsion, leading participants to adopt a 'cautious gait' characterized by smaller step lengths and higher cadences in relation to similar walking speeds overground [29]. In addition, clinicians expressed the feeling that the training may not be addressing balance due to the presence of the safety harness, and that it would therefore not promote the acquisition of safe walking abilities. However, a recent study involving the same omnidirectional treadmill and healthy young adult participants showed that balance may in fact be more challenged on the omnidirectional treadmill compared to overground [29]. In addition, the present training protocol included tasks that challenged postural transitions (e.g., dimension 3), making sure that dynamic balance would be targeted. Finally, clinicians and 1 stroke participant raised the issue of difficultly getting in and out of the harness, which might limit accessibility to stroke patients with decreased mobility or balance. While these equipment-related limitations are, in our perspective legitimate and should be kept in mind, they also highlight the challenges encountered when using, in rehabilitation, low-cost VR tools developed by the games industry that are intended for healthy young adults. As the team further develops and tests the VR toolkit, other omnidirectional treadmill options that promote a more a natural gait pattern and easier access will hopefully hit the market at an affordable price. Collaborating with all stakeholders, including the industry, and developing training protocols that are 'exportable' to new evolving technology become crucial, so as to advance the development of adapted and sustainable VR-based applications in rehabilitation. No positive/negative comments emerged concerning the software and the user interface it provided for clinicians. Participating clinicians in the hands-on sessions, however successfully delivered intervention sessions with stroke participants after being provided a brief user guide and a 1-h training session by team members. Such observations suggest that the design of the software and user interface, in its current format, was user-friendly and did not pose any particular issue.

The generalizability of the training intervention to real-life performance and transfer of the acquired skills during the training to improved walking abilities was also questioned. This is consistent with the current literature on the use of VR in stroke rehabilitation [57]. This general concern reinforces the importance of combining VR training with field training that could help consolidate the skills acquired into everyday situations. We believe that this multi-faceted training design will ensure that participants not only get sufficient repetition but also get a complete walking training that includes both progressively adapted ecological challenging situations done in a safe and supervised environment, with real-life walking to promote skills transfer.

In terms of optimal features of the VR-based tool and needed support, clinicians felt the need to obtain support with training as well as available human assistance once they start using the tool. This is consistent with previous studies, which showed that factors predictive of intention to use VR included perceived usefulness as well as therapist self-efficacy towards VR [23]. Main barriers included lack time, funds, and space, whereas primary facilitators were related to therapist knowledge, client motivation, management support and social influences [23,58]. Accordingly, we plan to use facilitating implementation strategies and create resources for clinicians (i.e., training guide, detailed procedures, technical assistance) once the toolkit is ready in order to support clinical integration.

Finally, we found that acceptability and sense of presence were high, combined with low cybersickness, which are factors that are advantageous. These results are in line with other VR studies using HMDs with older adults [59] and stroke survivors [60].

Limitations

Main limitations of the current study include a small sample size of stroke participants/therapists' dyads for the hands-on sessions. The involvement of patients at the development stage of the scene was also missing. In addition, participants in the hands-on sessions were presented the 3 dimensions that were ready for the prototype testing, but the final toolkit was planned to include 6 dimensions. Future directions for research include involving patients, clinicians and program managers in future development processes and implementation planning, as well as conducting a larger clinical trial.

Conclusion

In this study, we used an integrated knowledge translation approach to support the development of a clinically relevant, acceptable, and feasible VR-based tool for post-stroke community walking, to be included as part of a larger intervention that would comprise of VR and a field training component. Perceptions of clinicians and a few individuals with stroke towards the VR tool were explored through focus groups as well as through hands-on sessions with the VR tool prototype. Results collectively support the acceptability of the intervention, as well as its potential feasibility, although they will need to be expanded across a larger sample of participants. Feedback gathered in terms of favorable and unfavorable factors to the use of the VR tool, desired features to be included, and needed support, provides essential information that will be considered in the refinement phase of the intervention. We suggest that such integrated knowledge translation approach and refinement process will optimize positive outcomes for future steps, including intervention effectiveness testing and an eventual implementation of the intervention in the clinical setting.

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Data availability Statement

Data will be made available upon request.

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