Development of an active video game for gait training in Augmented reality: a prospective study on the impact of virtual feedback on walking speed

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Abstract* - Integrating augmented reality (AR) games into gait training programs could increase motivation and engagement in rehabilitation sessions. Does such AR game with visual feedback help to achieve or exceed target walking speed without increasing variability in walking speed? Is there an effect of the different feedback modalities? 15 participants walked on 30 m with 5 mini-games with different feedback modalities and a control scene without feedback. Participants had to walk at target walking speed (WS), recorded previously during calibration. The mean and standard deviation of WS during each condition were compared after ANOVA and Dunnett correction. Participants' opinions on the game and device were also collected. Mini-games did not cause any disturbance in the mean WS (p>0.05 for all mini-games vs. Control). The mini-games MG4 and MG5 resulted in high variability in WS. Participants reported high satisfaction with the game session (5/5,IQR 1). Participants judged the game effective in helping them reach the target speed (4/5,IQR 1). Specific recommendations include knowledge of results feedback, body-locked content, and clarifying game objectives. Feedback modalities influenced gait speed and variability. These results encouraged further development and evaluation of AR for gait training with careful consideration of the feedback modalities presented.

Keywords: gait training; augmented reality; virtual reality; feedback; active video game, walking ability

I. Introduction

Gait in a patient with neurological disorders (ND) is characterized by a slower walking speed (WS), a shorter-stride length, a lower cadence, and more time spent in double support. [1] Gait quality, especially WS, is often hard to improve for people with ND. [2] The improved walking ability has a positive impact on the achievement of daily activities and motivates social engagement. [2]

Current motor learning theories recommend task-specific, variable, and high-intensity practice. [3] New technologies, such as augmented reality (AR), appear to be an excellent way to combine repetition, practice specificity, motivation, feedback, and reward, both in a clinical context and at home. [4] AR that delivers virtual elements superimposed on the person's real-world view could be used for gait training without a treadmill. Using a mixed-reality system combining an AR head-mounted display (HMD) and a sensor-based motion capture system, a case study showed that a patient adapted his gait performance. [5] However, AR promotes patients' engagement in therapy and potentiates therapeutic gains by increasing motivation. [6,7]

While the potential of AR feedback, particularly for enhancing motivation, has been demonstrated, few studies have delved into how different forms or presentations of AR feedback may impact gait parameters and performance. [8] One concern to AR feedback for people with ND during gait training is how much it may distract or increase cognitive load. Previous studies have shown that gait performance decreases for people with ND as dual-task cognitive load increases. [9] Moreover, several studies demonstrated that a high gait variability, including variability of WS, results in walking instability and a higher risk of falling. [10]

In this study, we investigate the impact of different forms of visual AR feedback on gait speed in typically developing adults before future studies, including people with ND. The primary research questions are: Can AR feedback be used to help individuals achieve or exceed a target WS? Does AR feedback result in increased variability in WS? We hypothesize that a game with AR feedback can help individuals to maintain or exceed a target WS without significantly affecting WS variability. The secondary objectives were to determine participants' comprehension, satisfaction, and discomfort, with the different scenarios.

II. Materials and Methods

A. *Subjects & Protocol*

This is a prospective one-arm pilot study. A total of 15 participants (36.3 +/- 9.8y, 11 women/4 men) with typical or corrected-to-typical vision were recruited for this study through convenient sampling, which is a comparable sample size to the previous studies [11,12]. The National Ethical Committee approved the study, and all participants completed written consent. The study was conducted in July 2020. The protocol is detailed in Figure 1.

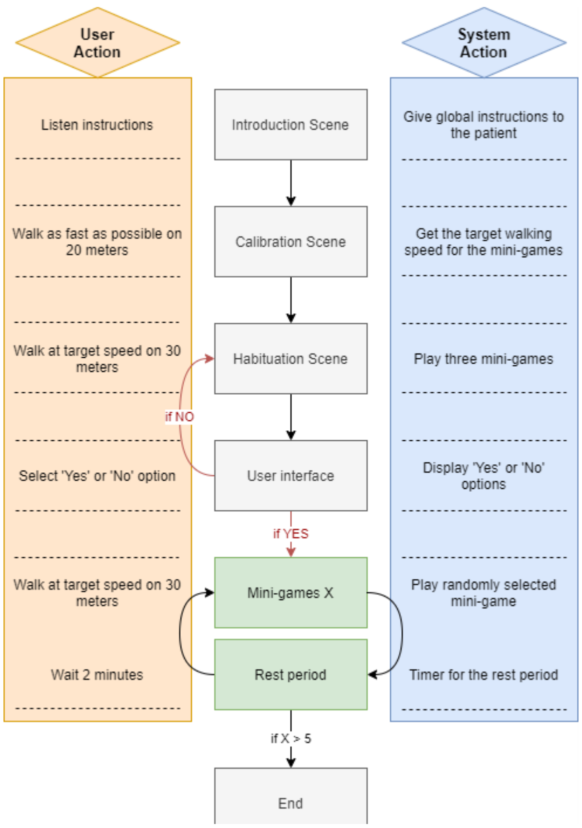


Figure 1. Protocol design of the global game, including the five mini-games

B. *Characteristics of tested mini games*

To investigate our hypothesis, five mini games using different feedback were developed (Figure 2 and supplementary material video S1). The Hololens AR HMD was selected because its technical characteristics matched the identified requirements. [13] It has also been demonstrated to be sufficiently accurate to evaluate the head pose and WS of the user without time drift in the global environment. [14]

Feedback is characterized by modalities that define their functioning, their role, or their form of presentation: [15]

- Focus of attention: knowledge of result (KR) focusing on the outcome of a movement or knowledge of performance (KP) addressing qualities of the movement itself,
- Method of presentation: simple visual content or richer effect (animation),
- Frame of reference: hologram can be world-locked (stationary frame of reference) or body-locked (attached frame of reference).

C. *Evaluation Criteria*

1. WS was calculated with the AR HMD (100Hz). The three first and last meters (acceleration/deceleration) were excluded from the analysis.
2. A questionnaire with a 5-point Likert scale from 1 to 5 (strongly disagree/agree) was completed to assess this experiment.

D. *The AR game and feedback development framework*

This work followed the development framework PROGame [16] the team (therapists, researchers, engineers) identified the need for the serious game and user categories (users, experts), and they clarified the requirements of the game (operational objectives and restrictions). These identifications were based upon prior experience and literature review. [2,17,18] The identified need was to improve motivation and feedback during gait training. Operational objectives included: to be safe and adaptable to the motor capabilities of the diverse patient; to provide efficient gait training in line with motor learning theory; to provide high-quality feedback on WS; to contain gamified content to motivate the patient to achieve the rehabilitation goals; to be fun. Additionally, the team identified crucial technical requirements: people must be free to walk without the restriction of movement (e.g., wireless, low-weight/comfortable, secure), and they must be able to use their usual walking aids (crutches, posterior walker). It should be a “ready-to-use” application for patients and clinicians to avoid wasting valuable clinical time.

E. *Statistical analysis*

After checking the stochastic assumptions, within-subjects ANOVA for repeated measures and the Dunnett test for multiple comparisons were performed to compare experimental values (i.e., during each mini-game) and a single control value. Descriptive statistics were reported to describe participant feedback collected via questionnaires.

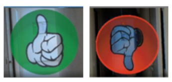
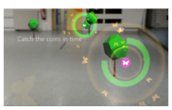
Mini Game	Capture	Focus of attention		Spatial representation		Method of presentation	
		Knowledge of performance	Knowledge of Results	World-locked	Body-locked	Rich holographic content	Simpler holographic content
MG1 SpeedNumber		Number indicates the current speed			Always 3m in front of the user's head orientation		One color, no animation, no sound
MG2 Speedometer		Needle indicates the current speed			Always 3m in front of the user's head orientation		Three colours, animation of the needle, no sound
MG3 SpeedThumb			Success or failure to reach the target speed changes the holographic colour and image		Always 3m in front of the user's head orientation		Two colors, two orientations, no animation, no sound
MG4 RocketButterfly			Success or failure to reach the target speed changes the holographic colour and distance	Hologram follows a trajectory in the world independently to the head orientation		Animation (flapping wing), colour changes (green or red), no sound	
MG5 TokenTime			Success or failure to reach the target speed changes the holographic content	Each holographic target is placed at 3 m from each other		Animation (mini butterflies moving around trees), positive sound when a token is catched in time	

Figure 2. Characteristics of the five mini-games: the focus of attention, spatial representation, and method of presentation.

III. Results

A. Walking speed

The mean WS during each mini-game and the control scene and target speed were not statistically different ($F (5,76) = 2.31$, $p = 0.052$) (Figure 3). These results are close to being significant (mean WS during MG are higher than the target speed). More participants are required to confirm the trend observed. The Dunnett test revealed that the mean WS during MG4 was significantly higher than the target WS.

There was a significant difference in the speed variability for each candidate (measured by the standard deviation of WS) during each mini-game and the control scene ($F (5,76) = 9.39$, $p < 0.001$) (Figure 3). Dunnett test revealed that MG4 and MG5 resulted in high variability in WS compared to the control scene (respectively 0.26 m/s, 0.33 m/s, and 0.13 m/s).

B. User questionnaire

Each participant successfully understood the instructions during mini-games (median 5/5, IQR 0). None had previous experience with AR. Participants reported high satisfaction with the game session (5/5, IQR 1). They rated the mini-games sufficiently efficient to reach the target speed (4/5, IQR 1). About the Hololens HMD, they did not report any limitations

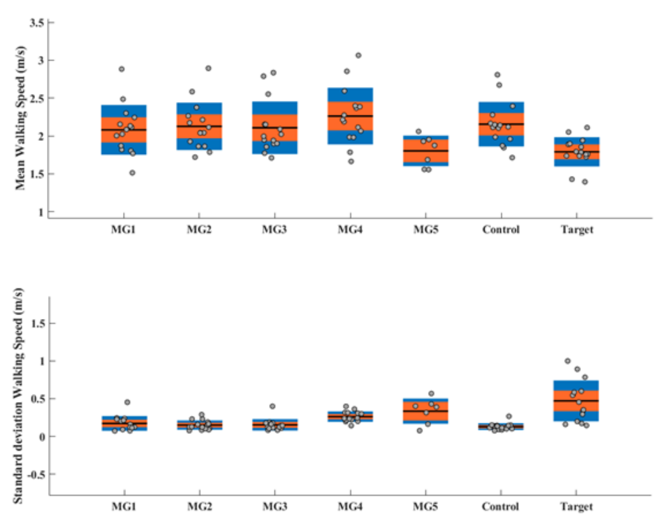


Figure 3. Mean walking speed (m/s) and variability of walking speed (m/s) during the five mini-games

for walking (5/5, IQR 0), but they highlighted discomfort due to the weight (579g) bearing on the nose. Participants also reported some confusion about the MG5. Some participants hesitated to catch the token, mainly when it appeared in virtual trees. For participants, the ranking of the best mini-games was MG2, MG4, and MG3 in a tie, MG1, and last MG5.

IV. Discussion

This first pilot study investigated the impact of different forms of visual AR feedback on gait in typically developing adults. This study was part of a larger-scale project, ARRoW-CP, which aims to create an active video game (AVG) for gait rehabilitation for children with ND. This first study established the effectiveness of augmented reality feedback in healthy adults as a foundational step prior to including people with disabilities. We asked two main research questions: Can AR feedback be used to help individuals achieve or exceed a target WS? Does AR feedback result in increased variability in WS? We hypothesized that a game with AR feedback could help individuals to maintain or exceed a target WS without significantly affecting WS variability.

Feedback is based on the conversion, the supplementation and augmentation of sensory informations that are usually accessible only by an internal focus of attention, to accessible information. In this paradigm, augmented feedback is defined as augmented sensory information (visual, auditory, haptic, proprioceptive) provided by an external resource (therapist or device) to the patient [6,15].

Our results showed that all mini games helped the participant to reach the target WS. Moreover, some feedback modalities helped exceed a target WS better. Participants achieved their maximum walking speed over the length of the sprint in the MG4 condition where the focus of attention was on “knowledge of result” (i.e., focusing on the outcome of a movement) and a richer effect (animation) was experienced.

Gait variability during gait was also impacted by the specific feedback modalities presented, particularly during MG4 and MG5, compared to the control scene. These mini-games had different visual characteristics and could be described by the Macintosh model [15]: the focus of attention (KR or KP), spatial representation, and method of presentation. Of note, the frame of reference of feedback in MG4 and MG5 was world-locked as opposed to being presented relative to the user’s head orientation. Due to the field of view (30°), some participants may have turned their heads to follow holograms. This might have influenced speed variability. Another potential factor in movement variability could be the objective/aim of the mini-game. In MG4, some participants wanted to race with the butterfly, which lead to greater variability in speed as when they reached it, they often slowed down. Changing the spatial representation of MG4 from world-locked to body-locked could be one potential strategy to decrease movement variability (not to subject the person to sudden or insufficient starts).

Today, VR/AR games are increasingly popular, but designing efficient rehabilitation video games remains a challenge [19]. Even if the literature converges on the positive impact of visual feedback on stability, asymmetry, and balance, the precise feedback modalities are not detailed [20]. Recently, Liu et al. classified patient profiles according to their results in front of feedback experience: “nonresponders” and ”responders” to the feedback [21]. In another study with children with CP using VR games, Booth et al. found that self-perception of walking, preference, cognitive ability, and previous experience with feedback could be other factors that influenced the responses [22]. This suggests that even if a general conclusion is drawn, individual reactions to feedback may still vary. This information must be considered when designing an active video game.

To summarize, the potential benefits of AVG are essential, but motor learning ingredients should not be ignored in motor rehabilitation using AVG in AR/VR [23]. The game interest, which raises the child’s level of motivation for rehabilitation, is not sufficient to improve motor skills. To be efficient, game-based interventions should integrate motor learning ingredients such as appropriate dosage (high intensity), variable practice, difficulty progression, task-specific exercises, feedback in real-time and with delay, motivation of the patient, context-focused and goal-directed therapy. These recommendations were not always integrated into virtual reality interventions, as we have seen previously and as confirmed by Demers et al. in 2020 [19].

These preliminary results on healthy participants enhanced our understanding of how different feedback characteristics affect WS. This understanding will inform the future design of the ARRoW-CP active video game.

Moreover, the acceptability of an AR HMD was excellent, participants did not report any limitations for walking, which was a crucial condition for developing an active video game to enhance gait. Even if some reported discomfort due to the headset bearing on the nose, it was not related to virtual reality sickness symptoms (nausea, oculomotor discomfort, and disorientation).[24]

V. Conclusions

This paper presented the collaborative design and evaluation of AR mini-games with visual feedback for gait training. This investigation demonstrated that gait parameters and user experience could vary depending on the type of AR feedback presented. Some feedback modalities increased WS, whereas others had a more significant impact on speed variability. Specific recommendations based on learnings in this study include using knowledge of results feedback to create a more challenging task that motivates participants to excel. These body-locked holograms are easier to track and clarify the game presentation. A new version of the game based on the MG4 but with body-locked characteristics is being developed that will be tested with people with ND.

Supplementary Materials

Video S1: https://youtu.be/P_fwBqIbqZU).

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