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Original Research

The Immediate Effects of Different Types of Augmented Feedback on Fast Walking Speed Performance and Intrinsic Motivation After Stroke

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KEYWORDS
Feedback;
Motivation;
Rehabilitation;
Stroke;
Walking speed

Abstract *Objective:* To examine the immediate effects of different types of augmented feedback on walking speed and intrinsic motivation post-stroke.
Design: A within-subjects repeated-measures design.
Setting: A university rehabilitation center.
Participants: Eighteen individuals with chronic stroke hemiparesis with a mean age of 55.67± 13.63 years and median stroke onset of 36 (24, 81) months (N=18).

List of abbreviations: ABC, Activities Specific Balance Confidence; AES, Apathy Evaluation Scale; ANOVA, analysis of variance; IMI, Intrinsic Motivation Inventory; IQR, interquartile range; KA, KineAssist; SFS, Short Flow Scale; VR, virtual reality.

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Clinical Trial Registration Number: NCT04740060.

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Interventions: Not applicable.
Primary outcome: Fast walking speed measured on a robotic treadmill for 13 meters without feedback and 13 meters with augmented feedback on each of the 3 experimental conditions: (1) without virtual reality (VR), (2) with a simple VR interface, and (3) with VR-exergame. 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 without VR (0.86±0.44 m/s); simple VR interface (0.87±0.41 m/s); VR-exergame (0.87±0.44 m/s) conditions than in the fast-walking speed without feedback (0.81±0.40 m/s) condition. The type of feedback had a significant effect on intrinsic motivation (P=.04). The post hoc analysis revealed borderline significance on IMI-interest and enjoyment between the VR-exergame condition and the without-VR condition (P=.091).
Conclusion: Augmenting feedback affected the intrinsic motivation and enjoyment of adults with stroke asked to walk fast on a robotic treadmill. Additional studies with larger samples are warranted to examine the relations among these aspects of motivation and ambulation training outcomes.

Stroke is the second leading cause of death and the third leading cause of disabilities worldwide.[1] Many individuals are left with physical and psychological issues after a stroke, 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 restrict participation in social roles related to responsibilities, employment, community life, and recreation.[6]

In addition to slow walking speed, apathy is 1 of the psychological issues after a stroke, described by loss of interest and lack of motivation in a third of stroke survivors.[4] Lack of motivation due to apathy might negatively affect activities of daily living and functional recovery after stroke.[7,8] Self-determination theory conceptualized intrinsic motivation as the engagement in an activity to enjoy it rather than to seek external rewards or avoid punishments.[9] In contrast, extrinsic motivation is more focused on external rewards or avoidance of punishments. Hence, intrinsic motivation is a facilitator that enhances walking recovery during rehabilitation sessions after stroke.[10] Therefore, providing motivational strategies during gait training sessions might help improve adherence and improve walking outcomes (ie, walking speed) in stroke survivors.[11]

Augmented feedback as extra information provided during training sessions is essential for enhancing walking outcomes and motivation for individuals after stroke.[12] Augmented feedback enhances motivation and performance by directing performers' attention toward the movement goal and providing information about errors and corrective actions.[13] Clinical practice guidelines suggest providing augmented feedback using virtual reality (VR) to enhance walking after 6 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 to mimic the conventional gait training sessions in the VR environment (ie, hallway walking, street crossing, and park walking).[20] On the other hand, the game-based VR applications are called exergames or a combination of exertion and video games used to add more engagement, enjoyment, and challenges to the training tasks.[21] These exergames make motor tasks more play-like by simulating a task goal into gaming scenarios.[22] It is unknown if these game-based VR applications would add extra benefits to walking speed and intrinsic motivation in individuals with post-stroke.

The Enhanced OPTIMAL framework combines OPTIMAL theory[23] and a Theory of Work Gamification[24] to provide all possible pathways to provide performance and motivation changes. The Enhanced OPTIMAL framework details 4 pathways (ie, motivation, attention, information, and affective) that can affect motor performance (fig 1).[25] Both motivation and attention pathways affect motor performance via goal-action coupling by increasing focus on task goals (ie, an external aspect) and minimizing self-focus. Motivation, however, can be affected by the information pathway (ie, augmented feedback) and affective pathway as task enjoyment (ie, VR and exergames).[25] 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.

Methods

Participants

Eighteen adults with chronic stroke hemiparesis (ie, stroke onset of more than 6 months that resulted in muscle weakness in 1 side of the body) participated in the within-subjects repeated-measures study at a university rehabilitation center. Table 1 describes the participants' characteristics. Participants were included if they had a stroke onset more than 6 months, had a Mini-Mental State Examination score

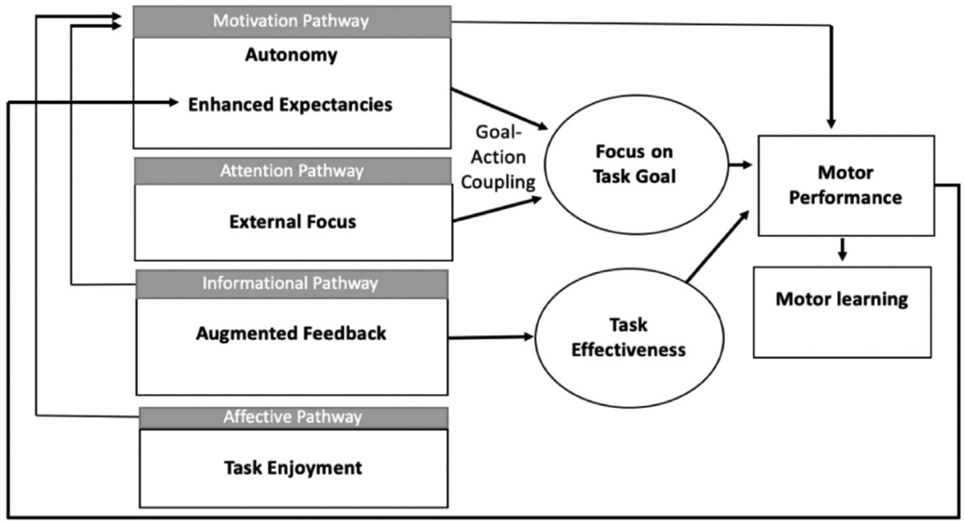

Fig 1 The Enhanced OPTIMAL Theory with several pathways and constructs to induce motivation and motor performance.[25] It depicts 4 pathways, and within each pathway, 1 or 2 constructs can be manipulated to enhance motor performance.[25] Both motivation and attention pathways affect motor performance via goal-action coupling by increasing focus on task goals (ie, an external aspect) and minimizing self-focus. Motivation, however, can be affected by the information pathway (ie, augmented feedback) and affective pathway as task enjoyment (ie, VR and exergames).[25]

higher than 24 (ie, no cognitive impairment),[26,27] and could walk independently for at least 3 minutes without physical assistance. Participants were excluded if they had coronary heart disease, other neurologic or musculoskeletal diseases known to affect balance and walking, or significant visual impairment. During the recruitment process, we administered the Cerebral Vision Screening Questionnaire (CVSQ) over the telephone to screen for visual impairments.[28] A university institutional review board approved the study protocol, and all participants signed informed consent before data collection began.

KineAssist-MX and VR game

KineAssist (KA)-MX Robotic Treadmill was used to allow for self-drive of the treadmill belt, complete freedom of pelvic movement, and a 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.[29,30] In addition, we used a custom-made partial immersion VR exergame (ie, The Racing Game) designed for individuals after a stroke to enhance their walking speed. The Racing Game was developed using Unreal Engine 4 (UE4), an advanced real-time 3D creation tool Epic Games developed using the C++ programming language.[31] The game was connected to the KA-MX treadmill via an ethernet connection cable and displayed on a large TV screen (ie, VIZIO-75 Class V-Series, LED 4K UHD, Smart cast TV) placed in front of the treadmill.

The Racing Game (fig 2) provides a real-time measure of walking speed and gamifies the walking task by including avatar competitors (ie, racers) with different speeds higher and lower than a participant's pre-captured baseline fast walking speed (ie, a participant's average fast baseline speed±0.1, 0.2, 0.3 m/s).

Table 1 Participants' characteristics (n=18)

Sex, N (%)	Women	4 (22.2)
	Men	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)
AES	Mean ± SD	58.89 (5.36)
ABC	Mean ± SD	66.15 (15.97)
Comfortable walking speed (m/s)	Mean ± SD	0.48 (0.23)

NOTE. 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.

Experimental procedures

Study protocol

After consenting participants, we measured their blood pressure and administered several questionnaires, including demographics, Apathy Evaluation Scale (AES),[32] and Activity Specific Balance Confidence Scale (ABC).[33,34] The AES contains eighteen items rating from 1 (Not at all) to 4 (A lot) with total scores ranging from 18 to 78 (ie, a low score indicating more apathy).[32] The ABC contains 16 items rating from 0% (No confidence) to 100% (Complete confidence).[34] In post-stroke, a cutoff score of 81.1% on ABC designates relative certainty in the absence of a history of falls.[35]

Participants were helped to get into the KA-MX motorized treadmill and given walking and setting practices (ie, not recorded) to be familiar with the device. Ten Meters Walking Test (10 MWT) was performed 3 times, with participants self-selected comfortable walking speeds. Cutoff scores

Fig 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 Racing Game was used in 3 experimental conditions by masking some of its components (ie, we stuck crafted cardboard pieces on the TV screen to cover some of the game components). Experimental conditions include **1**. Fast walking without VR: In this condition, participants were asked to walk for 13 meters while showing a real-time measure of their walking speed and distance (A). **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 (A and B). **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.

were used to classify individuals to household and community ambulators (ie, walking speed <0.4 m/s are more likely to be household ambulators, 0.4-0.8 m/s are limited community ambulators, >0.8 m/s are community ambulators).[36] Participants then were asked to walk at their self-selected fast walking speeds for 13 meters before each of the following 3 experimental conditions in which we used the same VR-exergame (ie, Racing Game) with masking some of its components (ie, we stuck crafted cardboard pieces on the TV screen to cover some of the game components). The 13 meters of the walkway was determined based on the software, which was designed to measure walking speed in 17 meters without capturing the first and last 2 meters (ie, acceleration and deceleration phases).

Experimental conditions

1. Fast walking without VR: In this condition, participants were asked to walk for 13 meters while showing a real-time measure of their walking speed and distance (fig 2A). The instruction was, "Look at the screen and keep your 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 (fig 2A and B). The instruction was, "Look at the screen and make the avatar walker representative walk 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. The instruction was, "Look at the screen and make the avatar walker representative walk ahead of the other avatar racers."

The order of the 3 experimental conditions was counterbalanced for 6 possible orders; participants were randomly assigned to these orders. After each experimental condition, participants were given a seat for at least 2 minutes as a resting period.

Outcome measurements

Primary outcome measures

Fast walking speed without feedback and within each experimental condition was measured on the KA-MX Robotic treadmill as the covered distance in meters (13 m) 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.[37] 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 4 subscales (ie, interest and enjoyment, perceived Choice, perceived competence, and pressure and tension).[37] The IMI has been widely used to evaluate intrinsic motivation in post-stroke studies,[38–40] and its psychometric properties have been extensively studied.[41,42]

Secondary outcome measures

After conducting the IMI, participants were asked to complete the Short Flow Scale (SFS).[43] Flow states are the optimal experience of fully engaging in an activity and have been used as a theoretical framework for intrinsic enjoyment.[44] The SFS contains 9 items rating from 1 (Completely disagree) to 5 (Completely agree).[43]

Statistical analysis

Descriptive statistics were used to summarize participants' characteristics, including age, sex, race, stroke onset, affected side, AES, Balance Confidence (ABC), and comfortable walking speed. Spearman's rho Correlation with a two-tailed significance test was performed to determine the relations between participants' comfortable walking speed, AES, and Activities Specific Balance Confidence (ABC).

Fast walking speed without feedback was calculated as the average of the 3 fast speeds performed before each experimental condition. To determine statistically significant increases in walking speed among fast walking without feedback (ie, performed before each experimental condition) and fast walking with feedback in each experimental condition, a 1-way repeated-measures analysis of variance (ANOVA) was used. As assessed by Shapiro-Wilk's test, walking speed data were normally distributed ($P>.05$). The assumption of sphericity was met, as assessed by Mauchly's test of sphericity, chi-square=8.65, $P=.125$.

A non-parametric Friedman test with a 2-tailed significance test 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 3 experimental conditions. Median and interquartile range (IQR) were used as descriptive statistics for a Friedman test analysis. The relations between IMI-subscales and SFS in each experimental condition were examined using Spearman's rho Correlation with a 2-tailed significance test. Correlation coefficient *r* which ranges from -1.00 to 1.00 was used to interpret the correlation magnitude. The higher correlation coefficient value indicates the more substantial magnitude of the relation and vice versa.[45] 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 a mean age of 55.67±13.63 years and median stroke onset of 36 (24, 81) months. Most of the participants were men (77.8%), and participants were able to walk at an average comfortable speed while on the KineAsist-MX of 0.48 m/s± 0.23. Of the 18 participants in this study, 8 were household ambulators, 9 were limited community ambulators, and 1 was a community ambulator. Participants' average apathy score (AES) was 58.89±5.36, and their average balance confidence (ABC) was 66.15%±15.97. Table 1 describes the participants' characteristics.

There was a statistically significant positive correlation between apathy and balance confidence *r* (16)=0.490, *P*=.03, indicating that participants with high scores on the AES (ie, less or absence of apathy) had high balance confidence scores in ABC Scale. Balance confidence was also positively correlated with comfortable walking speed, *r* (16) =0.479, *P*=.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*=.25.

Fast walking speed performance

Participants were able to perform fast-walking speed without feedback (0.81±0.40 m/s), augmented feedback without VR (0.86±0.44 m/s), with simple VR interface (0.87± 0.41 m/s), and with VR-exergame (0.87±0.44 m/s). Participants' increase and decrease in walking speed performance from fast walking without feedback to fast walking with augmented feedback on each experimental condition are described in Table 2.

A 1-way repeated-measures ANOVA was conducted to evaluate the null hypothesis that there is no change in the participant's fast walking speed when measured without feedback and with each of the experimental conditions (ie, without VR, simple VR interface, VR-exergame) with a group of patients with chronic stroke (n=18). The results of the ANOVA indicated an approached significant experimental effect, Wilk's Lambda=0.996, *F* (3, 15)=.890, *P*=.070, Eta Squared=0.366.

Table 2 Changes in experimental conditions fast walking speed from fast walking speed without feedback (n=18)

Experimental Conditions	Change From Fast Walking Speed Without Feedback	N (%)	Mean ± SD
Without-VR	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)

Intrinsic motivation

Table 3 describes IMI subscales and SFS results for each experimental condition.

Friedman test results revealed a significant effect of feedback types on participants' intrinsic motivation based on their scores on IMI-Interest and Enjoyment subscale chi-square =6.426, *P*=.04. Post hoc analysis revealed significance on IMI-interest and enjoyment between VR-exergame and without-VR (*P*=.03). However, adjusted *P* values with Bonferroni correction for multiple tests revealed non-significance on IMI-interest and enjoyment between VR-exergame and without VR (*P*=.091). The medians of IMI-Interest and Enjoyment scores among the 3 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 without-VR (Median=5.86, IQR=6.50-5.00).

IMI Subscales and SFS

Table 4 shows Spearman's rho correlation matrix between the Intrinsic Motivation Inventory (IMI) subscale and 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: without-VR *r* (16)=.824, *P*=.01; with simple VR interface *r* (16)=.597, *P*=.01; with VR-exergame *r* (16)=.486, *P*=.04. IMI-Interest and Enjoyment subscale was positively correlated with SFS only with the VR-exergame condition *r* (16)=.680, *P*=.01.

Discussion

Our objective was to test the immediate effects of 3 different types of augmented feedback (ie, without VR, simple VR interface, and VR-exergame) on inducing fast walking speed performance and intrinsic motivation. Participants showed slight increases in their fast-walking speed with all types of feedback (ie, 0.1 m/s) faster than their fast-walking speed without feedback. The observed slight increases in walking speed align with clinical practice guidelines suggestion to provide augmented feedback with VR to enhance walking outcomes after 6 months of stroke onset.[14] VR-exergame

Table 3 Median and IQR of IMI-Subscales and SFS in each experimental condition (n=18)

Condition	IMI-Interest and Enjoyment Subscale Median (IQR)	IMI-Perceived Competence Subscale Median (IQR)	IMI-Perceived Choice Subscale Median (IQR)	IMI-Tension and Pressure Subscale Median (IQR)	SFS Median (IQR)
Without-VR	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)

NOTE. IMI scores rating from 1=not at all true to 7=very much true; higher scores represent higher concepts described in the subscale name. SFS scores rating from 1=completely disagree to agree 5=completely; higher scores represent a higher flow state.

induced the highest motivation level, followed by a simple VR interface and without VR. The highest intrinsic motivation with the VR-exergame condition is in line with existing research findings suggesting that feedback with VR games has higher intrinsic motivation and acceptance by individuals after a stroke than without VR games.[46] Another study results with healthy individuals also suggested that exercising with the therapeutic exergaming system result in a high level of interest and enjoyment.[47]

Participants with low balance confidence had slow walking speeds, and those with high balance confidence had high walking speeds at baseline. The positive correlation between balance confidence and walking performance was illustrated as individuals with low confidence demonstrate impaired control of quiet standing and walking characteristics associated with cautious gait strategies.[5] Also, Kongsuk et al found a positive correlation between balance confidence and fast walking speed on the treadmill with older adults.[48] Interestingly, individuals with less or no apathy had high balance confidence and vice versa. Hence, after 12 months of a stroke, high apathy negatively affected overall physical function.[7]

Additionally, individuals with high motivation levels also had high perceived competence and vice versa. The perceived competence was theorized to be a positive predictor of intrinsic motivation.[9] Navarro et al suggested that competition may improve the effectiveness and enjoyment of rehabilitation therapies and address post-stroke attention problems.[49] It was observed but not measured that our participants paid more attention to the VR-exergame condition, which was later found to have the highest interest and enjoyment level.

Based on the Enhanced OPTIMAL framework, motivation is directly affected by the information pathway (ie, augmented feedback) and affective pathway (ie, task enjoyment).[25] Our results revealed an agreement with the framework that the highest motivation was observed with VR-exergame (ie, more enjoyment elements were displayed), followed by a simple VR interface (ie, fewer enjoyment elements were displayed), followed by without-VR (ie, no enjoyment elements were displayed).

Table 4 Spearman's Rho Correlation matrix between IMI subscales and SFS in experimental conditions (n=18)

Without-VR Condition	1	2	3	4	5
1. IMI-Interest and Enjoyment	-				
2. IMI-Perceived Competence	.82*	-			
3. IMI-Perceived 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-Perceived 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-Perceived Choice	.40	-.14	-		
4. IMI-Pressure and Tension	-.36	-.34	-.11	-	
5. Short Flow Scale	.68*	.44	.19	-.26	-

* Correlation is significant at the .01 level (2-tailed).

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 1 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 short periods, which was considered a limitation of this study.

Conclusions

Augmented feedback, in general, shows an approached significant immediate effect on inducing fast walking speed after a stroke. However, individuals after a stroke could walk slightly faster with all types of augmented feedback than their fast-walking speed without feedback. Different types of augmented feedback revealed a significant effect on intrinsic motivation, and VR-exergame induced the highest motivation level. The positive relation between enjoyment and perceived competence among the experimental conditions suggests that augmented feedback may enhance perceived competence, enhancing fast walking speed after stroke. Additional studies with larger samples are warranted to examine the relations among these aspects of motivation and ambulation training outcomes.

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