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ORIGINAL RESEARCH

Immediate Effects of Immersive Biofeedback on Gait in Children With Cerebral Palsy

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Abstract

Objective: To investigate the immediate response to avatar-based biofeedback on 3 clinically important gait parameters: step length, knee extension, and ankle power in children with cerebral palsy (CP).

Design: Repeated measures design.

Setting: Rehabilitation clinic.

Participants: Children with spastic paresis (N=22; 10.5±3.1y), able to walk without assistive devices.

Intervention: Children walked on a treadmill with a virtual reality environment. Following baseline gait analysis, they were challenged to improve aspects of gait. Children visualized themselves as an avatar, representing movement in real time. They underwent a series of 2-minute trials receiving avatar-based biofeedback on step length, knee extension, and ankle power. To investigate optimization of biofeedback visualization, additional trials in which knee extension was visualized as a simple bar with no avatar; and avatar alone with no specific biofeedback were carried out.

Main Outcome Measures: Gait pattern, as measured by joint angles, powers, and spatiotemporal parameters, were compared between baseline and biofeedback trials.

Results: Participants were able to adapt gait pattern with biofeedback, in an immediate response, reaching large increases in ankle power generation at push-off (37.7%) and clinically important improvements in knee extension (7.4°) and step length (12.7%). Biofeedback on one parameter had indirect influence on other aspects of gait.

Conclusion: Children with CP show capacity in motor function to achieve improvements in clinically important aspects of gait. Visualizing biofeedback with an avatar was subjectively preferential compared to a simplified bar presentation of knee angle. Future studies are required to investigate if observed transient effects of biofeedback can be retained with prolonged training to test whether biofeedback-based gait training may be implemented as a therapy tool.

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Walking is an important activity in daily life, not only for general health[1] but as a facilitator for social inclusion.[2] As a complex motor task, gait is often impaired in patients with neurologic disorders and is considered a common treatment target. Gait training can be effective in improving functional outcomes in stroke[3] and in populations with cerebral palsy (CP).[4] Gait training allows for repetition of motor task to drive skill acquisition[5,6] and can be beneficial to restructuring motor pathways.[7,8]

Recent studies suggest improved gait-related outcomes when gait training is enhanced with virtual reality (VR) and biofeedback.[9,10] Rehabilitation usually involves repetition; this can become tedious for patients, particularly in difficult tasks where little short-term reward is perceived. This may lead to a lack of motivation, which can be an important factor driving effort and intensity. VR allows the patient to experience stimulating environments, providing challenging tasks in controlled, safe settings.

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An additional benefit of VR is that it allows for manipulation of multiple forms of augmented feedback; visual, auditory, and haptic. This can help focus attention and provide feedback on performance of task, important in effective motor learning.[8] Gamification of feedback in rehabilitation may be particularly important in pediatric populations, such as children with CP. However, the games themselves must be therapeutically principled and encourage movement or motor control strategies that offer sound rehabilitation benefit.[11]

There is no established protocol for gait training in CP and there remain many unexplored areas in the developing use of biofeedback-based rehabilitation. Therapists often treat gait with a functional goal to increase walking speed, linked to quality of life.[12] VR and biofeedback may be applied to support this therapeutic goal. Faster walking speed can be achieved by increasing step length, however, in CP, increased speed is often the consequence of increased cadence.[13,14] Step length in CP is frequently considered to be a biomechanical limitation, associated with spasticity and shortened muscles. However, stride length can be improved with simple auditory and visual cues.[15] Spatiotemporal parameters are influenced by kinematics; one common gait limitation reducing step length is diminished knee extension in late swing, which has an important influence on function.[16] The cause of this is complex but may be related to selective motor control, short hamstring length, and knee joint contractures.[16] With biofeedback on joint angle, children are able to improve hip and knee extension in stance,[17] but it is unknown if they can achieve increased extension during late swing. Ankle power is important in providing energy efficient transfer of center of mass from step-to-step and contributes to leg-swing acceleration.[18] Adequate ankle power requires force generation of the plantar flexors at precise timing. If ankle power is diminished, this must be compensated for by greater work in the hip joint, leading to increased energy cost.[19] Therefore, it is key in maintaining walking speed and step length.[20] While plantar flexor muscle activation can be increased with EMG biofeedback,[21] it is not known if children can improve power generation and the full extent of adaptability in gait of children with CP; this requires further exploration. While functional goals like walking speed, endurance, and stability are improved, we can postulate step length, knee extension, and ankle power are likely to influence functional performance. Therefore, providing biofeedback on these may ultimately lead to functional benefits. These gait parameters have a complex dynamic interaction during gait and the optimal target for gait-related therapy is unknown.

The delivery of biofeedback is critical to its success as a treatment. A recent review suggested that while biofeedback interventions can improve motor outcomes, evidence is limited due to wide heterogeneity in both intervention and measures reported.[22] Immersive biofeedback, with multiple modalities, were most often associated with positive outcomes.[22] The use of an avatar to visualize biomechanical feedback in rehabilitation has shown promise in providing whole body awareness of movement in stroke patients and improving communication with therapists.[23] It is not known if an avatar representing a child's movement has any influence on self-perception of walking in children with pathologic gait. By visualizing biofeedback attached to the avatar in immersive VR, this may be an intuitive and effective method of biofeedback.

The aim of this study was to explore the extent of adaptability of gait in children with CP, providing biofeedback on 3 related clinically relevant gait parameters: step length, knee extension in late swing, and ankle power generation. A secondary aim was to investigate optimized visualization of biofeedback using an avatar, comparing this to a more simplified visual representation.

List of abbreviations:

CP **cerebral palsy**
GPS **gait profile score**
VR **virtual reality**

Methodology

Participants

Twenty-five children with CP and related (hereditary) forms of spastic paresis were recruited for this study; demographics are presented in table 1. Children were included under the following criteria: (1) diagnosis of spastic paresis (both unilateral and bilateral); (2) gross motor classification system level I-II (walking without aids); and (3) aged between 5 and 16 years old. Children were excluded if they had severe cognitive impairment; received botulinum toxin-A treatment within 6 months; or had orthopedic surgery, intrathecal baclofen treatment, or selective dorsal rhizotomy within 12 months prior to measurement date. Children were recruited from the VU University Medical Center, Amsterdam and Revant Rehabilitation Center, Breda. All parents and children aged 12 years and older were provided written informed consent prior to participation. The protocol was approved by the medical ethics committee of the VU University Medical Center.

Study design

All participants walked on a dual-belt instrumented treadmill with immersive VR environment[a] (fig 1). A 10-camera 3D motion capture system[b] was used with 26 retroreflective markers placed on anatomical landmarks. This allowed for real-time gait analysis using the Human Body Model software.[24,25] A safety harness that was not otherwise weight bearing was worn in all conditions to prevent injury in case of an accidental trip.

A period of at least 6 minutes of habituation to walking on the treadmill environment was carried out to establish stable gait.[26-28] After this, a self-selected, fixed, comfortable walking speed was set, and this speed was maintained throughout the session. The study followed a repeated measures design to explore the effect of biofeedback on gait (see fig 1). Participants initially carried out 1 minute of comfortable walking to assess the individual's baseline walking parameters. Here only the

Table 1 Participant demographics (N=22)

Characteristic	Mean ± SD or n	Range
Age (y)	10.5±3.1	6-16
Height (m)	1.51±0.20	1.27-1.9
Body mass (kg)	41.32±18	26.1-89
Walking speed (m/s)	0.65±0.18	0.35-1.1
GMFCS	I: 10, II: 12	
Localization	Unilateral: 6, Bilateral: 16	
Sex, male/female	15/7	

Abbreviation: GMFCS, gross motor function classification system.

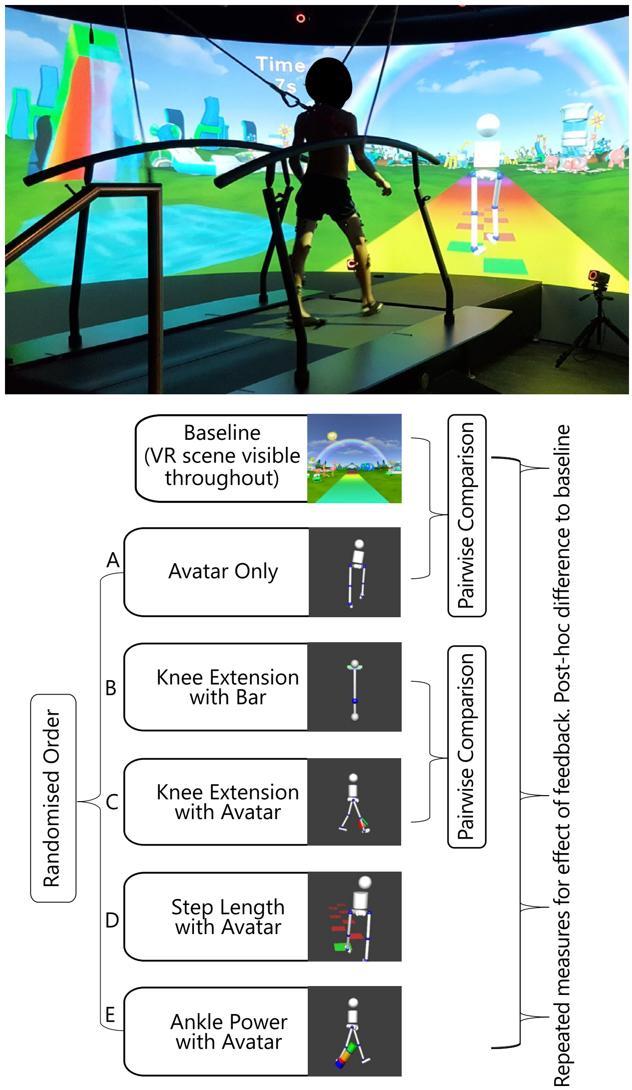

Fig 1 *Above*: Experimental setup with instrumented treadmill and VR screen. Picture shows participant walking while visualizing own movement with avatar and receiving visual biofeedback on step length. *Below*: Experimental design and visual scene across trials. VR background scene removed from biofeedback examples in figure only for clarity. (A) Avatar only, in which only real-time movement of participant with no direct biofeedback is visualized. The following trials provided color-coded biofeedback (green is target, blue is real-time performance). (B) Knee extension visualization with bar, ball moves up and down with extension of knee in swing (no avatar visible). (C) Knee extension with avatar, target is presented as a fan, showing angle of extension at the knee during swing. (D) Step length, task was to step on the blocks with avatar (turn green when target is hit). (E) Ankle power, power bar at ankle increases blue portion with increasing power (visualization from mid-stance until toe-off).

VR environment, with optic flow, was visualized. This environment was visible throughout the session. Baseline gait function was then used to set patient-specific targets for subsequent biofeedback trials. Participants performed a series of trials, in a randomized order, lasting 2 minutes. Children visualized themselves in the third person by a simplified avatar, representing their movements in real time. They were challenged to improve gait with additional visualization of biofeedback cues, on increased step length, knee extension during late swing, and ankle power generation (see fig 1). To test if simply visualizing themselves as an avatar in real time had any effect on gait, a walking trial with the avatar alone and no specific additional biofeedback was carried out. To further test the optimization of visualization of biofeedback, a trial in which a simplified bar chart was used to give biofeedback on knee extension in late swing, with no avatar visible, was performed (see fig 1). Feedback on knee extension and ankle power was provided on the most affected side only. While the target was initially set relative to the individuals' baseline performance, this was adjusted manually by the researcher to obtain maximum improvement and motivation if the task became too easy or too difficult. Visual and auditory rewards were given when the target was reached. Following the biofeedback trials, children were asked subjective questions: (1) Did you understand the task? and (2) Could you accomplish the task? Answers were scored on an ordinal scale from 1 (not at all) to 5 (absolutely). Preference for biofeedback on knee extension visualized by bar or avatar was also recorded.

Data analysis

Kinematic and kinetic data from the entirety of each trial were analyzed. Initial contact and toe-off were based on vertical ground reaction forces (25 N threshold). Gait data were time-normalized to gait cycle. Only the most affected leg that feedback was provided on was included in the analysis. All strides collected throughout the trial were included, however, strides in which data deviated excessively (±3 SD) from the median were excluded from further analysis. Descriptive gait outcomes for a set of clinically relevant outcome parameters (table 2) were calculated for each gait cycle and averaged for an individual, then a group mean was established for each trial. As a measure of overall gait performance, the gait profile score (GPS) was used.[29]

Prior to statistical analysis, outcome measures were assessed for normality with Shapiro-Wilk tests. To explore the main research question of the effect of biofeedback, between-condition (baseline, step length with avatar, knee extension with avatar, and ankle power with avatar biofeedback) differences in clinically relevant outcome parameters were evaluated using repeated measures analysis of variance with Greenhouse-Geisser correction applied as required. Post hoc tests were conducted to establish a change from baseline to biofeedback trials with Bonferroni adjustment for multiple comparisons. To explore the effect of self-perception of gait, differences in clinically relevant outcome parameters between baseline and avatar-only condition were assessed using paired *t* tests. To further investigate optimization of visualization, a pairwise comparison of clinically relevant outcome parameters between knee extension with avatar and knee extension with bar was carried out (see fig 1). Data with a non-normal distribution were tested using the Friedman test or Wilcoxon signed-rank test as appropriate. All analyses were performed using SPSS software[c] with $\alpha=0.05$ and $\alpha=0.01$ when adjusted for multiple post hoc testing.

Results

Two children did not complete the trial with biofeedback on step length and 1 child did not complete the trial with biofeedback on knee extension with bar visualization due to technical issues, as

Table 2 Changes in clinically relevant outcome parameters across walking trials

Clinically Relevant Outcome Parameters (Group Mean ± SD)	Baseline	Avatar Only	P*	Knee Extension With Bar	Knee Extension With Avatar	P†	Step Length With Avatar	Ankle Power With Avatar	P‡
Max hip ext (deg)[NP]	5.9±9.4	5.1±9.0	.006	4.4±9.8	5.3±10.2	.131	5.0±9.0	4.8±9.7	.563
ROM hip sagittal (deg)	40.5±9.7	41.3±9.9	.011	43.5±12.5	41.7±11.9	.116	43.6±10.5[§]	46.6±11.2[§]	<.001
Max hip abd swing (deg)	14.9±3.4	16.2±3.4	<.001	17.3±4.0	16.6±4.2	.072	16.4±4.4[§]	17.2±4.4[§]	.005
Mean hip rot stance (deg)	8.6±10.5	8.1±10.5	.195	8.2±11.2	7.8±12.1	.403	8.2±11.0	8.8±10.4	.633
ROM knee sagittal (deg)[NP]	46.9±12.9	49.9±13.8	.003	55.5±16.2	55.6±16.2[§]	.987	50.9±15.7[§]	57.2±18.9[§]	<.001
Max knee flex (deg)	62.4±6.8	62.5±7.3	.756	64.1±10.0	63.9±8.9	.894	64.5±9.7	69.1±12.7[§]	.013
Max knee ext IC (deg)	27.0±9.8	25.0±9.7	.001	20.9±10.4	19.6±10.4[§]	.139	25.4±11.0	28.1±10.1	<.001
Max knee ext stance(deg)	15.7±11.5	12.8±11.7	<.001	8.8±11.6	8.7±12.2[§]	.925	14.0±12.7	12.2±13.7[§]	<.001
Max ankle dorsiflexion stance (deg)	16. ±7.4	16.8±6.9	.084	15.9±7.0	16.2±7.0	.552	15.9±6.4	17.1±6.9	.317
Max ankle dorsiflexion swing (deg)[NP]	-4.5±11.2	-4.3±11.1	.884	-5.8±11.3	-4.2±9.5	.144	-6.1±10.7	-7.4±9.9	.152
Max ankle plantar flex (deg)[NP]	-4.7±11.2	-4.6±10.9	.858	-7.2±10.5	-5.8±9.0	.291	-7.0±10.5	-8.5±9.7	.215
Mean FP stance (deg)	-1.3±11.9	-2.3±10.1	.131	-2.0±9.9	-2.5±9.5	.391	-1.4±9.9	-0.7±11.5	.439
A2 (W/kg)[NP]	0.81±0.40	0.84±0.40	.072	0.83±0.43	0.86±0.52	.408	0.93±0.40[§]	1.12±0.69[§]	<.001
Timing A2 (% gait cycle)	60±4	59±5	.225	58±5	58±5	.700	58±3	56±6[§]	.006
H3 (W/kg)[NP]	0.66±0.38	0.69±0.38	.211	0.86±0.42	0.93±0.45[§]	.046	0.74±0.49	0.86±0.51[§]	<.001
Timing H3 (% gait cycle)[NP]	61±11	62±10	.560	65±12	63±11	.115	61±13	65±9	.230
Step length (m)	0.36±0.09	0.37±0.09	<.001	0.42±0.11	0.42±0.10[§]	.856	0.40±0.11[§]	0.38±0.10	<.001
Step width (m)	0.26±0.05	0.25±0.05	.370	0.25±0.06	0.27±0.06	<.001	0.30±0.07[§]	0.26±0.05	<.001
% stance	64±4	65±4	.498	64±5	65±6	.243	63±3	62±5	.055
GPS[NP]	10.3±2.5	10.2±2.6	.645	10.7±2.6	11.0±3.0	.935	10.5±2.8	11.8±4.1	.179

NOTE. Nonparametric testing was performed using Friedman/Wilcoxon testing ($\alpha_{critical} = .05$, $\alpha_{\_Bonferroni\ adjusted} = .01$).

Abbreviations: A2, peak ankle power around toe-off; abd, abduction; ext, extension; flex, flexion; FP, foot progression angle; H3, peak hip power around toe-off; IC, initial contact; max, maximum; NP, nonparametric testing; ROM, range of motion; rot, rotation.

* Pairwise comparison of clinically relevant outcome parameters between baseline vs avatar-only trials.

† Pairwise comparison of clinically relevant outcome parameters between knee extension feedback visualized with bar versus knee extension visualized with avatar.

§ Indicates significant difference in clinically relevant outcome parameter pairwise comparison from baseline measure in post hoc analysis with Bonferroni adjustment.

‡ Repeated measures analysis of variance for the effect of biofeedback between baseline, knee extension with avatar, step length with avatar, and ankle power with avatar.

Fig 2 Frequency of subjective response to feedback.

such they were excluded from further analysis. All other trials were completed and no adverse events were reported. In response to biofeedback children were able to attain immediate improvements in aspects of gait.

The effect of only avatar visualization had small, yet statistically significant, effects on gait (see table 2). Increased hip abduction during swing, maximal hip extension, hip and knee range of motion, and knee extension in stance phase and at initial contact was shown, with a small increase in step length.

With step length biofeedback, children were able to reach an increase in step length of 12.7% (P<.001) (see table 2). A significantly wider step width was also found. The increase in step length was coupled with a significant increase in range of motion at the hip and knee, with increased hip abduction during the swing phase. Ankle power was found to increase by 19.7% (P<.001) with timing occurring slightly earlier in the gait cycle. Step length feedback was considered to be the most intuitive and favorable for children in subjective response (fig 2).

With biofeedback on knee extension during late swing, children reached an increase in knee extension of 7.4° around initial contact (P<.001) (see table 2). While not a direct target, there was also an increase in knee extension during the stance phase (P<.001), leading to a greater range of motion at the knee (fig 3). A large increase in step length (19.2%) as a result of knee extension feedback was also observed. Subjective responses from children suggested that the majority children found the avatar preferential for visualization of biofeedback, with 19 out of 22 children preferring this over bar-based biofeedback on knee extension. In comparison of avatar vs bar biofeedback on knee angle, both methods were effective in increasing knee extension, and resulted in comparable clinically relevant outcome parameters (see table 2).

With biofeedback on ankle power, peak ankle power generation increased by 37.7% (P=.001) (see table 2). Timing of peak activation occurred significantly earlier in the gait cycle than during baseline (P<.001) (fig 4). Peak hip power around push-off was also significantly increased. Increased ankle power at push-off coincided with increased peak knee flexion in swing (P=.001), peak knee extension in stance (P=.003), knee range of motion (P<.001), and increased hip abduction during the swing phase. As a group, children were able to increase peak ankle push-off power, however, they found this task difficult and three children were unable to improve ankle power. Subjective responses confirmed this, as ankle power feedback scored the lowest score (see fig 2). Providing direct biofeedback on one biomechanical parameter had indirect action on the other targets of biofeedback. The dynamic interaction between the biofeedback conditions and effect on gait is shown in table 3.

While sagittal gait kinematics did show improvement, as a group, overall gait performance as measured by GPS did not show significant improvement or worsening in any feedback condition (see table 2).

Discussion

This study investigated the immediate effect of biofeedback on gait during treadmill walking in a VR environment. While it is often considered that children with CP show a relatively rigid gait pattern, we found a remarkable capacity to adapt and improve gait parameters with acute biofeedback; reaching clinically important improvements in step length,[30] knee extension,[31] and large increases in ankle power generation at push-off.

The results of this study confirm and exceed previous findings on the potential adaptability of spatiotemporal and kinematic motion in children with CP,[17] showing that increased knee extension can be observed at specific timing during late swing. Additionally, while not a direct target of feedback, knee extension was found to improve across stance. We showed that step length can be selectively increased with biofeedback both directly and indirectly. This is in line with previous findings, showing an 8.72% improvement in stride length when given direct visual feedback[15] and 6.5% increase in step length with indirect biofeedback on knee angle extension at any time in the gait cycle.[17] In contrast we found a large (19.2%) increase in step length when the focus is on extending the leg in late swing. Feedback on kinematic and spatiotemporal parameters also influenced kinetic outcomes, with large increases (19.7%) in peak ankle power observed when challenged to increase step length. Children with CP showed the capability to adapt both peak and timing of ankle power generation at push-off (37.7%) with direct biofeedback. To our knowledge, this is the first study to show this level of immediate adaptability of power generation during gait in CP. Despite this large increase, children found ankle power biofeedback most challenging. Negative effects of feedback were also observed with small, yet significant, compensational movements, such as

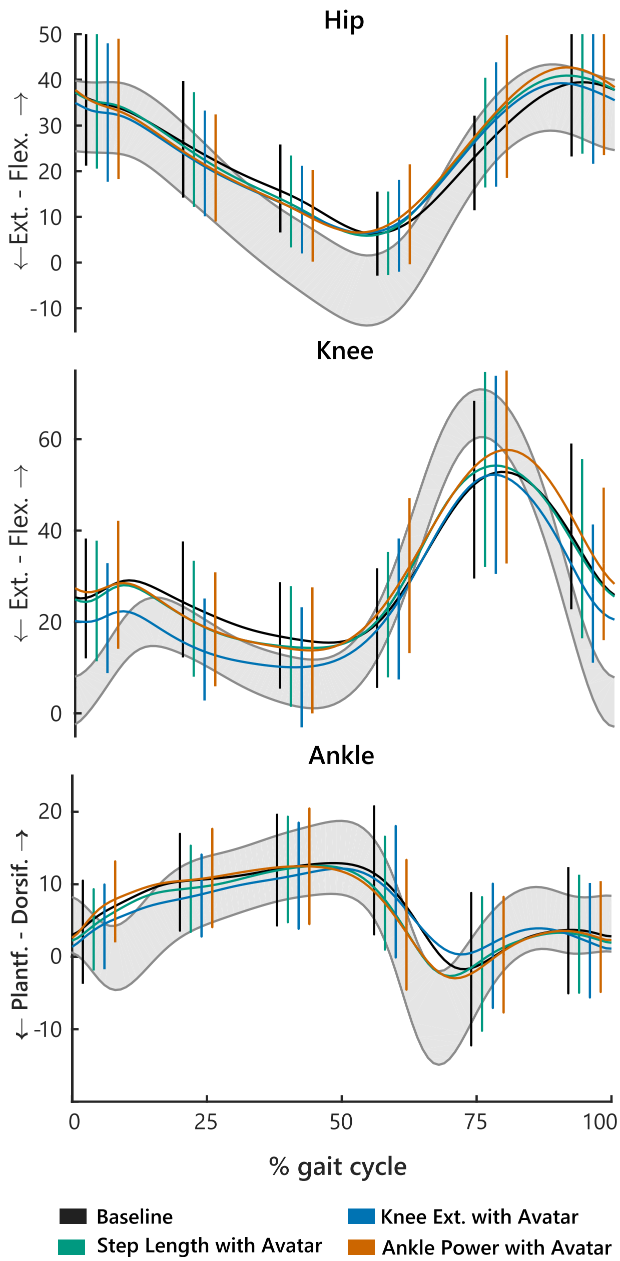

Fig 3 Sagittal plane joint kinematics during each walking trial, normalized to 1 full gait cycle. Vertical lines represent 1 SD across group mean. Gray-shaded area represents normative data for age-matched children walking on a treadmill (n=41).

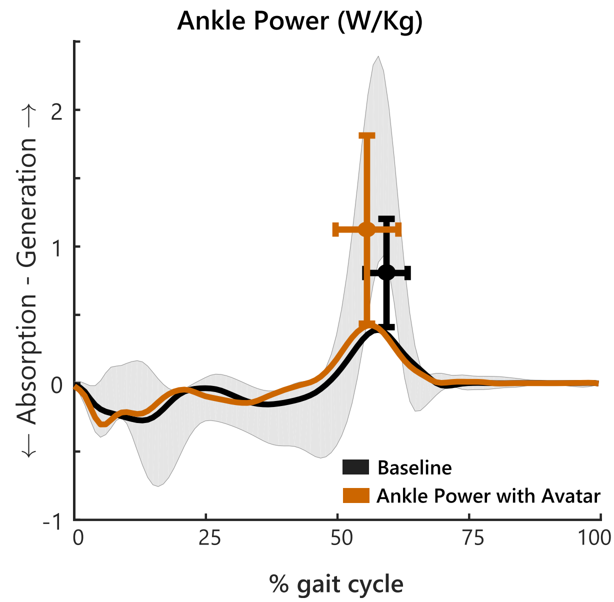

Fig 4 Ankle power generation during baseline walking and feedback on ankle power trials. As the peaks average out over subjects in the overall mean curves, points represent actual peak ankle power and timing with 1 SD represented vertically and horizontally, respectively. Gray-shaded area represents normative data for age-matched children walking on a treadmill (n=41).

increased maximal hip abduction during swing and increased step width. These individual compensations contributed to the lack of change in GPS observed across the group. This response may be a compensation to increase stability during the acute learning stage of a novel motor task. Timing of ankle power generation with direct feedback was significantly earlier. Timing of push-off is important and this early activation may explain the increase in knee extension during terminal stance due to the plantar flexion knee extensor couple.

The optimal gait parameter for biofeedback may depend on the individual patient and primary gait limitation. Direct feedback on step length was considered to be the most intuitive and achievable by the group. Providing feedback on this simple, global measure of gait allows autonomy for patients to choose their own optimal method, with larger range of motion at the hip and knee observed. In addition, a large increase in ankle power generation was observed (19.2%), with an increased ankle power to hip power ratio, that is, the generation of power was shifted toward the ankle, which is closer to that in typical gait.[19] While direct ankle power biofeedback also resulted in an improved power ratio, it was considered to be most challenging as a group and 3 patients were unable to improve ankle power with others showing distinct compensation movements. This highlights that patient-specific targets should be identified and may need to be adapted depending on the cognitive level and ability of the patient. This would also follow with recommendations for client-directed biofeedback based on goals and priorities.[22]

Subjective responses from children suggest that the majority found biofeedback with the avatar preferential for intuitive visualization of the task and increased knee extension, while the bar style was considered by some to be easier to visualize their real-time performance. In comparison of the 2 trials, clinically relevant outcome parameters were very similar, suggesting that adaptions to gait can be achieved with either method of biofeedback. The avatar, however, may improve motivation and understanding of task. When children visualized their movements with the avatar alone, and no specific biofeedback, small yet significant improvements in gait were noted, however, this was variable between participants. It is not clear if these improvements are related to any self-perception of walking. This was perhaps related to cognitive ability or previous experience with therapists. Indeed, the avatar paradigm may be most effective when used together with additional verbal feedback from a therapist, that is, "make the avatar walk more upright." This would follow with motor learning principles, moving toward an external focus of attention. Focusing attention on the effect of movement on the environment, rather

Table 3 Dynamic interaction of biofeedback on gait (change relative to baseline walking)

	Change in Gait Parameter		
	Knee Extension IC (deg)	Step Length (%)	A2 (%)
Feedback Trial			
Knee extension with avatar	+7.4±7.1*	+19.2±16.0	+4.5±23.4
Step length with avatar	+1.6±4.4	+12.7±11.3*	+19.7±21.3
Ankle power with avatar	-1.0±3.8	+6.8±18.5	+37.7±36.1*

NOTE. Values are mean ± SD.
Abbreviations: A2, peak ankle power around toe-off; IC, initial contact.
* Direct effect of biofeedback on target gait parameter.

than how to achieve the movement itself, is thought to encourage faster automation in learning novel motor skills.[32]

Study limitations

The long-term adaptability of gait in children with CP is yet unknown. In this study, only the immediate response to biofeedback was tested. The refined control of this novel gait pattern is not possible in only 2 minutes and it was not predicted that any gait improvements persist following cessation of biofeedback. Following the 3 stage model of motor learning,[33] we could imply participants are in the first cognitive stage of learning and able to achieve the task with the addition of feedback. Further long-term training is essential to establish if gait adaptions in CP can progress to the associative phase and, with sufficient practice time, the autonomous phase where improvement may be retained in over-ground walking. These interventions should incorporate motor learning principles and recommendations by MacIntosh et al.[22] This may include a faded feedback approach,[34] with elements of autonomy, where feedback can be presented only when requested by the patient.[22] Intensity of training is important, in a 6-week biofeedback gait retraining program of patients with osteoarthritis, gait was adapted, however, it was considered patients remained in the associative phase of learning.[35] This follows with the findings of MacIntosh,[22] who report studies with positive outcomes from biofeedback training lasting 8 weeks on average, with 172 minutes per week. Addition of VR and gamification may assist to maintain engagement through prolonged training. Lastly, outcomes should include measures of gait in the context of activities and participation, following the International Classification of Functioning, Disability and Health—Children and Youth Version framework, such as energy expenditure, walking speed, and endurance.[36] This will allow for assessment of biofeedback-based gait training as a tool to improve function in relation to everyday activities.

Conclusions

This study demonstrates that immersive real-time biofeedback can result in large, immediate improvements in a range of related and clinically important gait parameters. Visualizing biofeedback with an avatar was subjectively preferential to visualization with a simple bar, with small yet significant gait improvements observed when presented with a simplified avatar, showing their movement in real time. Our results clearly suggest that biofeedback-based gait training may be trialed as a therapy tool, with the goal of improved walking function. These studies are required to establish if observed transient effects of biofeedback can be retained with prolonged training.

Suppliers

a. Gait Real-time Analysis Interactive Lab (GRAIL) system; Motek.
b. Bonita 10; Vicon.
c. SPSS Statistics for Windows, v23; IBM Corp.

Keywords

Biofeedback, psychology; Cerebral palsy; Rehabilitation; Virtual reality; Walking

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