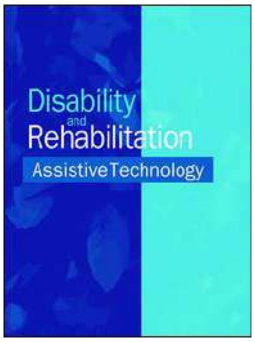

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CASE REPORT

The impact of exergames on the functional balance of a teenager with cerebral palsy – a case report

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ABSTRACT

Purpose: To understand the impact of an intensive rehabilitation program based on exergames in balance and lower limb function in a teenager with cerebral palsy.
Methods: The rehabilitation program comprised different customised exergames and was delivered in 5 weekly sessions of 30 min for 4 weeks. Pre-, post-, and 1-month Follow-up assessments included the following metrics: Berg Balance Scale (BBS), Dynamic Gait Index (DGI), Gross Motor Function Measure (GMFM), Posturography, and Gait analysis.
Results: We observed increased scores after the intervention of 9/72 points in GMF – Module E (Walk, Run and Jump) and of 9/56 points in BBS, sustained at Follow-up. Changes in function, specifically in the quality and independence of the performance of specific movements such as turning 360°, increased distance reaching forward, walk behind, step over obstacles, and step stairs up and down were also observed. Gait kinematics and Spatio-temporal parameters tended to get closer to the 50th percentile.
Conclusions: We observed positive changes in motor function of a teenager with cerebral palsy, with sustained increased scores at a 1-month Follow-up. Findings are suggestive that intensive rehabilitation programs using exergames with high customisation features are a potentially valuable rehabilitation tool for training balance in teenagers with Cerebral Palsy.

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KEYWORDS
Exergames; cerebral palsy; virtual reality; balance; rehabilitation

➤ IMPLICATIONS FOR REHABILITATION

- Exergames may be a useful for providing balance training for teenagers who have a mixed form of cerebral palsy.
- Exergames that require body displacement may be suitable for modulating gait kinematics and spatio-temporal parameters.
- The customisation of virtual rehabilitation tools seems to impact the motivation and effort of the user positively.

Introduction

Cerebral Palsy (CP) is a non-progressive neurodevelopmental condition. It mainly affects movement and posture but can also disturb perception, cognition, and communication [1]. Movement and posture relate to balance, which involves maintaining the centre of body mass within the limits of the base of support during static or dynamic activities [2–4]. To that end, the central nervous system coordinates the activation of postural muscles, agonists, and antagonists in the proper sequence and intensity [5], while integrating visual, vestibular, and proprioceptive sensory input to produce these (corrective) motor commands [6]. Maintaining a stable posture during daily functional activities is challenging, as it demands complex interactions between the sensory and the motor systems [2,7]. These systems are known to be affected in CP, which may explain the deficits in postural control and balance [8], leading to important functional constraints [9]. The consequent reduction in physical activity in CP also affects fitness negatively, impacting strength, endurance, and cardiopulmonary function [10], increasing the risk of secondary psychological problems such as pain, depression, and fatigue [11].

The rehabilitation of balance in CP patients typically involves exercises for gross motor task training such as sit to stand, stepping up, reaching limits of stability, or walking on different surfaces with or without obstacles to transpose [12]. Other methods are also used, such as hippotherapy, neurodevelopmental therapy, and reactive balance training [12]. Alternative approaches such as Virtual Reality (VR) started to be widely used with children with CP when low-cost commercial solutions such as the Nintendo Wii Fit became available. Research studies have reported promising results in using these systems in addition to conventional therapy, with particular benefits for static balance [13] and trunk control [14]. VR for children with CP has also shown positive results on the development of gross motor skills such as balance, strength, and coordination [15]. While showing positive results, commercial low-cost VR solutions are targeted at the general population and do not allow for satisfactory customisation to users with motor deficits. For example, individuals with low motor control or poor balance, which is a characteristic of CP [1], have a bigger chance

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Supplemental data for this article can be accessed here.

of getting frustrated by not succeeding. Moreover, conventional gaming technologies that require motor skills such as coordination, bilateral coordination, or balance, are not designed to develop or rehabilitate those domains, but just to promote cognitive and motor engagement while playing [16]. However, within the computer gaming community, individuals usually are intrinsically motivated in playing, as they have a conscious and prior willingness to engage in a specific ludic task. This is not necessarily the case in rehabilitation. Hence, to sustain the engagement and to guarantee involvement with the activity, other factors need to be considered, such as the patients' interests, values, affect, and ability [17]. It is expectable that motivations and interests are specific according to each individual's characteristics. This is specifically important when games are designed for rehabilitation, as these individuals tend to have motor and cognitive specificities, and social and life experiences that differentiate them.

In this paper, we present a case report of a teenager with CP who underwent a 1-month intervention on balance based on customised exergames. Our goal was to report the impact that an exergame designed for rehabilitation purposes could have on a patient for whom traditional approaches did not improve function anymore. A case report methodology allows us to identify the different relationships between the user and the exergame itself and how they can potentially contribute to motor and functional improvements. Specifically, we aim to understand which variables are relevant to maintaining motivation along with the intervention, and how we can tune them to promote improvements in balance.

Methods

Participant's profile and clinical history

Harry (pseudonym for the participant), a 17 years old male, is diagnosed with CP. According to his family, he had a healthy psychomotor development until he was three years old, when he suffered a near-drowning episode that resulted on brain damage and the CP diagnosis. He has a mixed form of quadriplegia with spastic and non-spastic characteristics (dystonia and ataxia). After the accident, he underwent early intervention services until age 8, at which period he was integrated into a regular school with the support of special education, speech therapy, and physiotherapy. At the age of 12, he got implanted with a deep brain stimulator, which improved upper body movement control and speech but led to more difficulties with lower limbs motor control. This regression negatively impacted his mobility and he was admitted to a rehabilitation hospital to engage in an intensive rehabilitation program. When he was 13 years old, he did surgery to elongate the Achilles tendon. After he finished this rehabilitation program, he was able to ambulate with an anterior walker for short distances and showed signs of more independence in Activities of Daily Living (ADL), except for putting on shoes.

At the moment of the report, Harry's gross motor ability was at level II, according to the Gross Motor Function Classification System [18], which means he could walk in most settings and transpose stairs if there was a rail. However, environmental factors such as uneven terrain, inclinations, and long distances were limitations to his mobility. In some contexts, a hand-held mobility device was needed (standard anterior walker) for safety. Falls were persistent and dangerous, as he triggered a protective extension reflex for anterior falls only. He was not able to protect himself when falls were posterior. His standing posture was marked by hyper trunk extension and mild scoliosis, which contributed to difficulties with balance. He also presented a global posterior posture, with a forwarded centre of mass, possibly due to the shortening of the Achilles tendon. Regarding gait, it was influenced by the exhibited spastic pattern, with external rotation on the left hip and flat foot (*pes planus*) and varus foot on the right.

Harry's family approached our research group looking for new therapeutic approaches that could enhance his skills and improve his functionality. Associated with this motivation for new rehabilitation methods, Harry had an intrinsic interest in technology. He was enrolled in a regular school, studying informatics, with an educational program adapted to his needs. At the time of this report, Harry was not enrolled in any rehabilitation program. However, he had swimming classes twice a week and Pilates classes three times per week. Both activities started approximately five months before enrolment in the report and continued after the intervention.

Experimental setup

The intervention took place at the facilities of the Madeira Interactive Technologies Institute in Funchal. For the setup, we used a white projection canvas of 1.8×3.0 metres and an Optoma GT1080 DLP Projector. A Kinect V2 sensor was used to track the user's movements. A PC (ADDOS: Windows 8.1, CPU: i7-4790 at 3.60 GHz, RAM: 8 Gb, Graphics: GeForce GTX1060 6GB SPECS) was used to run the exergames. Harry interacted with the projection moving along the largest extremity of the canvas, moving left and right, and never over it (Figure 1). Addittionaly, as we knew there was a high risk of falls, we equipped him with a protective helmet and the therapist was always positioned to anticipate his falls (mainly behind).

Exergames

The three exergames used in this report, Exerfado, Rabelos VR and Exerpong (Supplementary video), were chosen among a list of five, four of them developed to promote exercise with the elderly [19,20] and one designed for exploring changes in physiological responses caused by the gaming and exercising components of an Exergame [21]. These games were chosen according to their potential to train balance skills. As these games are custom-made, designed initially to promote exercise among the elderly, they were adapted explicitly for this intervention to fit Harry's age and condition. Therefore, games were slightly changed to promote the use of arms and centre of mass variations and sudden velocity and direction changes, thus enabling improved postural control strategies (Table 1, Figure 2).

Report design

The report followed established international ethical guidelines regarding research with human participants, and signed informed consent was provided by the participant and his legal representative. The intervention was delivered by the occupational therapist of the research team, which has 6 years of experience. He was also responsible for the assessments. The intervention comprised 20 sessions for 4 weeks (5 sessions per week during workdays). If, for any reason, a session was missed, it was compensated in the following Saturday. In every session, each game was played for 10 min with a break of 2–3 min to rest and drink some water, resulting in a total session time of approximately 40 min. The order of the games in each session was randomised using *random.org*. At the end of each game, the participant was asked how exhaustive and how easy the game was on a scale from 0–10.

Figure 1. Experimental setup. The user interacts with a floor projection while his movements are being tracked by a Kinect sensor.

Table 1. Description of each game used with the goal, way of interaction and how games can be customised.

Name	Goal	Interaction	Motivation related mechanics	Customisation
Exerfado	Catch falling music notes	- Each foot can virtually press a piano key by positioning the foot in front of the key - Upper limbs are used to clear black notes that interrupt the music by swiping them	- Points for each caught note - Not clearing a black note, the music is interrupted with an uncomfortable sound	- Upper limbs range of movement required for pushing the black note to the correct key - Frequency of black notes - The time that a note takes to disappear - Choosing music
Rabelos VR	Control a boat, avoiding obstacles (rocks) and collect wine barrels	- Displace the body right/left to control the boat - Twist the trunk in the barrel's direction, grab it with both arms (like a hug) and move in the boat direction	- Number of barrels collected - Number of rocks avoided	- Frequency of rocks - Distance between docks
Exerpong	Control a paddle to collide with a constantly moving ball to destroy targets	- Displace the body right/left to control the paddle	- Points for each destroyed object - Levels cleared	- Paddle size - Ball velocity - Ball size

Figure 2. Screenshot of Exerfado, Rabelos VR and Exerpong.

The therapist defined each game's level of difficulty by manipulating specific game parameters such as the speed of the game, the frequency of obstacles, and the size of the controller that could impact difficulty and/or exertion (see Table 1). The manipulation of the parameters was done to guarantee an optimal game challenge for Harry, considering the perceived exertion and difficulty reported by Harry in the previous training session. For difficulty, the parameters were increased if Harry reported a value equal/lower than 6, and lowered if a 9/10 was reported. The same rule was applied for exertion, following the recommendations of the American College of Sports Medicine (ACSM) for an individual that does not exercise regularly [22]. For the first session, we used a training trial with Harry before the 1st assessment to set the initial parameters. Assessments were performed at 6-time points: before the intervention (Baseline), intermediate assessments after the 5th, 10th, and 15th sessions, Post-intervention, and 1-month Follow-up.

Outcome measures

The outcome measures in this report aimed to assess balance, gait, gross motor functions, and the self-reported changes after the exergame intervention. At Baseline, Post-intervention, and Follow-up phases, data were collected using the Gross Motor Function Measure (GMFM) (Dimensions D and E), Berg Balance Scale (BBS), and Dynamic Gait Index (DGI). Posturography, and Gait analyses were also done after the 5th, 10th, and 15th sessions. A brief description of each measure follows:

- The BBS [23] is a 5 point ordinal scale, ranging from 0–4. It is a clinical scale that measures static and dynamic balance. Although it is designed for an elderly population, several studies have acknowledged that it is reliable and valid for cerebral palsy [24–26]. Therefore, we chose this measure as it can provide us with information about changes in the participant balance skills.
- The DGI [27] is a 4 point ordinal scale, ranging from 0–3. It measures the capacity of the individual to adapt the gait to complex tasks, such as transposing obstacles. As gait is nearly related to balance, this measure was selected to detect changes in gait after the intervention.
- The GMFM [28] is a standardised observational instrument aimed to measure changes in gross motor function in children with cerebral palsy, widely used and considered the standard outcome assessment tool for functional intervention with CP [28]. It can offer information about changes in participants' more complex gross motor movements such as walking, running, and jumping. It is a 4-point ordinal scale, ranging from 0–3, with higher scores relating to higher levels of function. The first dimensions of the instrument are directed to the first stages of motor development; for this reason only Dimension D (Standing) and E (Walk, Run, and Jump) were used. Dimension D has a global score of 39 points and Dimension E of 72 points.
- Nintendo® Wii Balance Board™ - Based Posturography System [29] consists of three measures: Romberg's test, limits of stability, and ability to rhythmically shift weight in two directions (medial-lateral and anterior-posterior). With Romberg's test, the software required 3 repetitions to present a score (average). In contrast, only one repetition was required for limits of stability (on eight different directions) and rhythmic weight shift (medial-lateral and anterior-posterior). However, we repeated these last two twice, and then we kept the best value, which for some parameters could be the maximum (e.g., Directional control) and for others the minimum (e.g., Reaction time) [30]. This test complements the previous ones with objective data about participants' performance while performing balance tasks.
- Gait analysis software [31] consists of software that analyses Spatio-temporal gait data and kinematics retrieved through Kinect v2 (Microsoft, Redmond, WA). A normative study with 355 healthy individuals and 82 individuals with stroke demonstrated excellent reliability and variable sensitivity [31]. Similar to the Based Posturography System, with this measure, we can collect objective metrics about gait patterns.
- Perceived exertion was measured while performing the task using the Modified Borg Scale [32] to understand how physically challenging games were for the participant. This scale ranges from 0 to 10 points, where "0" corresponded to 'Nothing' and "10" corresponded to 'Maximal Exertion'.
- To measure the difficulty while performing the tasks, we used a Likert scale that ranged from 0 to 10, where "0" corresponded to 'Nothing' and "10" corresponded to 'A lot'. Thus, we could understand how difficult Harry perceived the games to be.

Results

Harry increased his scores at the BBS, DGI, and Module E of Gross Motor Function Measure at the end of the intervention, with sustained increased scores at Follow-up except for Module E of Gross Motor Function Measure (Table 2).

Berg balance scale

Regarding the results on the BBS, Harry had a Baseline score of 39/56. In this test, he was unable to stand in one leg for 3 s. Additionally, he revealed a need for assistance to:

- Turn 360° in a counterclockwise direction;
- Place left foot on a stool while standing unsupported without falling;
- Stand with one foot in front of the other.

Additionally, he could reach 15 cm forward with outstretched arms while standing (maximum score requires at least 25.4 cm). Regarding transfers, he needed to use his hands to transfer between two chairs safely.

After the intervention, he increased his score by 9 points (48/56) and sustained it at Follow-up. The main changes detected were:

- Better performance turning 360°, from needing assistance to turn 360° safely for one side only;
- Improved balance while alternately placing foot on a step, completing more than 2 steps with minimal assistance;
- Improved balance on standing with one foot in front of others, being able to place foot ahead independently for 30 seconds;
- Increased reaching forward with outstretched arms while standing from 15cm towards 32cm;

Table 2. Scores for Berg Balance Scale (BBS), Gross Motor Function Measure (GMFM) Component D and E, and Dynamic Gait Index (DGI), at Baseline, Post Intervention, and Follow-up.

Scales	Baseline	Post-intervention	Follow-up
BBS (0-56)	39	48	48
GMFM – D (0-39)	26 (67%)	26 (67%)	26 (67%)
GMFM – E (0-72)	41 (57%)	50 (69%)	47 (65%)
DGI (0-24)	17	18	18

- Improved transference from chair to chair. He passed from needing to use hands to transfer safely to needing just a minor use of the hands.

Gross motor function measure

On what concerns the GMFM, Harry got a Baseline score of 26/39 in Module D (Standing) and 41/72 in Module E (Walking, Running & Jumping). As major difficulties in Module D, we highlight:

- With hands-free, he could lift the right foot for some seconds and could initiate the movement with the left foot;
- Sited on a small bench, he could not reach the standing position without using his arms. From knees position, he could initiate the standing movement if on the left knee, but not with the right one;
- He could not sit on the floor from a standing position without using the arms but could initiate the movement.

Concerning Module E, Harry could not:

- Walk-behind;
- Walk 10 consecutive steps on a line;
- Transpose an obstacle at knees height with the left foot, but initiated with the right foot;
- Jump.

In Module E, Harry was able to partially:

- Go up 4 stairs alternating feet (needed to be near a rail), and initiated the movement to go down;
- Run 4.5 metres, stop and return;
- Kick a ball using the right foot.

Overall, the difficulties were accentuated when the use of the left leg was required.

In Dimension E of GMFM, we verified an increased score from 41/72 to 50/72, while in Dimension D, there were no changes. At Follow-up, Dimension E decreased 3 points (47/72), and Dimension D was unchanged. The main changes detected in this measure after the intervention were:

- Improved from unable to perform to partially completing 10 steps backward;
- Improved the ability to step over a stick at knee level both with right and leg fet, more evident with the left foot, from not being able to initiate it before the intervention to being able to complete it after the intervention;
- Improved performance stepping up and down 4 steps alternating feet, from partially completing stepping up and initiating stepping down to completing both. At Follow-up, the stepping down worsened to partially completing.

Dynamic gait index

In the DGI, Harry achieved a Baseline result of 17/24. While performing the test, he revealed signs of moderate gait impairment such as slow gait speed, an abnormal pattern, and evidence for imbalance. Harry demonstrated to be able to change gait speed but could not achieve a substantial change. He showed difficulties stepping over an obstacle, slowing down, and adjusting steps to clear the box safely.

After the experiment, the final score increased 1 point to 18/24, which was maintained at Follow-up. The only change detected with this measure was to turn 180° after a prompt while walking. Before the intervention, he was able to turn slowly with small steps to keep balance. After the intervention, he could turn safely (but slowly) and stop without losing balance.

Posturography

For Posturography, we applied Romberg's test and assessed the limits of stability and reaction time. Regarding Romberg's test, the most important difference between Baseline and Post-intervention was the higher scores in stability with eyes closed, either with or without foam. Without foam, Harry had a value of maximum excursion in the anterior-posterior axis of 6.27 cm at Baseline and 5.64 cm at the end of the intervention. He registered a value of 8.01 cm at Baseline and 4.28 cm at the end of the intervention in the medial-lateral axis. Harry had a maximum excursion with foam in the anterior-posterior axis of 15.48 cm at Baseline and 9.16 cm after the intervention. In the medial-lateral axis, we measured 15.59 cm at Baseline and 10.16 cm after the intervention. Follow-up scores were very close to those observed at Baseline.

In limits of stability, we collected data concerning reaction time, maximum excursion, and directional control (Figure 3). We observed a reduction of variability on the three measures, mainly between Baseline and Post-intervention. For the reaction time, we observed an important reduction of the variability in the Post-intervention measurement. After the intervention, there was less dispersion, and the median was slightly higher compared to Baseline. At follow-up, the maximum value was the same, and the dispersion was higher but distributed over lower reaction time values. On what concerns maximum excursion, the median was slightly better at Post-intervention, with similar values at Follow-

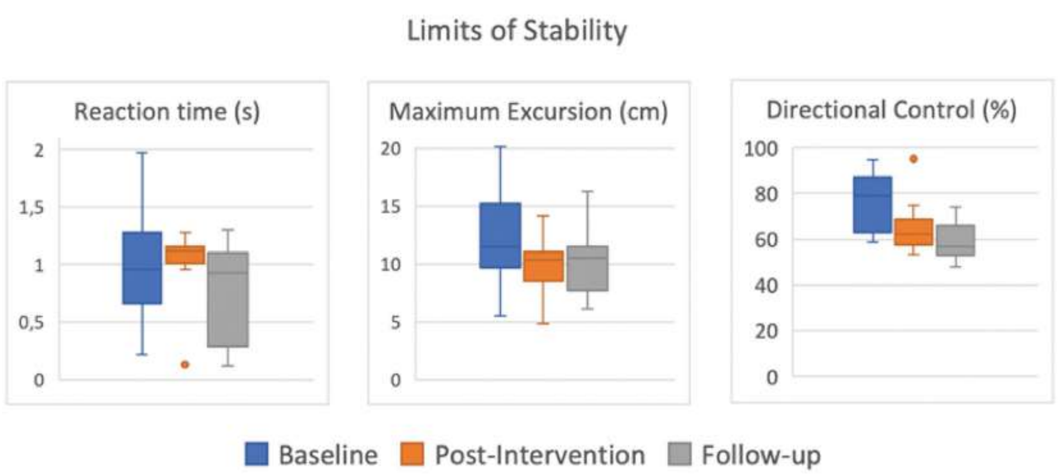

Figure 3. Boxplots for reaction time, maximum excursion and directional control for Baseline, Post-intervention and Follow-up for limits of stability.

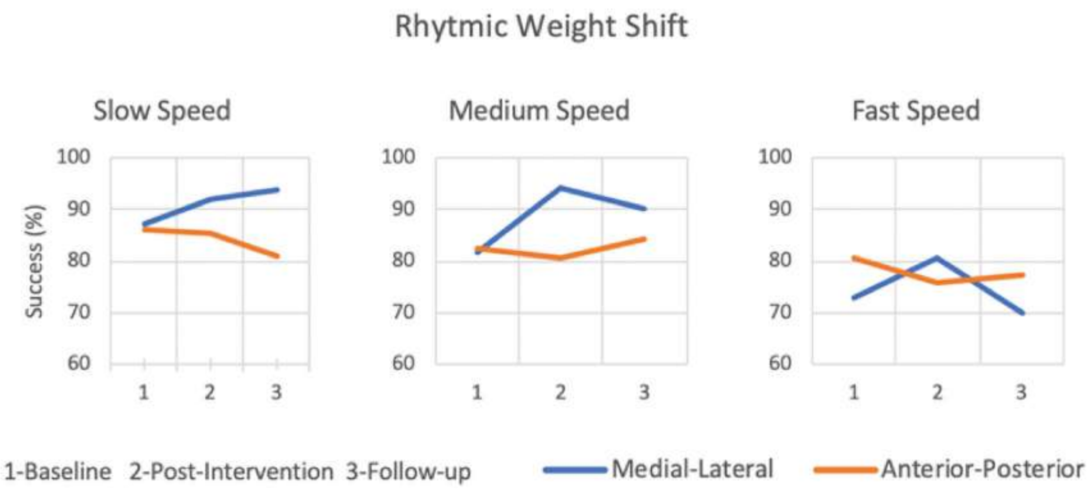

Figure 4. Rhythmic weight shift with slow, medium and fast speed at Baseline, Post-intervention and Follow-up.

Table 3. Comparison of gait Spatio-temporal parameters between Baseline and Post-intervention on the left leg and right leg.

	Left leg		Right leg	
Spatio-temporal parameters	Baseline	Post-intervention	Baseline	Post-intervention
Step length (m)	0.32 (16th percentile)	0.65 (71th percentile)	0.51 (73th percentile)	0.73 (73th percentile)
Step time (s)	0.71 (80th percentile)	0.96 (80th percentile)	0.98 (80th percentile)	1.03 (80th percentile)
Swing time (s)	0.54 (92th percentile)	0.51 (92th percentile)	0.49 (16th percentile)	0.51 (92th percentile)
Swing phase (%)	21.74 (35th percentile)	33.34 (46th percentile)	39.13 (53th percentile)	32.80 (47th percentile)

up. Directional control decreased in both extent and variability over time. We also observed a better percentage of directional control on medial-lateral shift and worse on anterior-posterior between Baseline and Post-intervention (Figure 4). It can be noted that when the Medial-Lateral weight shift improved, the Anterior-Posterior got worst, and vice-versa, for all speeds.

Gait

Regarding gait analysis, several metrics changed their score towards higher normative percentiles between Baseline and Post-intervention. These were mainly verified in the left leg (which was the less functional side), namely on step length, from 0.32 metres (16th percentile) to 0.65 metres (71st percentile) and on swing phase from 21.74% (35th percentile) to 33.34% (46th percentile). Cadence got closer to normality going from 73.26 steps/minute (36th percentile) to 81.71 steps/minute (40th percentile). However, the double support phase decreased from 39.13% (67th percentile) to 33.87 (60th percentile). Overall, there was a tendency to increased symmetry in several Spatio-temporal parameters (Table 3).

We also verified in some kinematic gait features (measured through angle or distance), that the anatomic segments (trunk, hip, knee, or ankle) revealed a trend towards standard patterns expected for healthy individuals of Harry's age group (depicted as a green region in Figure 5). Specifically, trunk tilt, hip abduction-adduction, hip flexion-extension, and knee valgus-varus (Figure 5).

Exergames – difficulty and exertion

We systematically collected data about Harry's perceived exertion and difficulty after each game (Table 4). All games required lateral displacement from the user, i.e., to move laterally (perpendicularly to the projection). What differentiated them, besides the game theme and different arms gestures for interaction, was the intensity and the frequency of lateral displacement. In Exerfado, Harry reported a median perceived exertion of 5.0 ± 3.0. This game required coordination of both legs, as each leg could press different piano keys simultaneously. The distribution of the falling notes across the piano keys did not always promote lateral displacements. Sometimes, moving one leg was enough; other times, he had to displace to catch a falling note. In Rabelos VR, Harry had to avoid stones. In this game, the minimum distance between obstacles was achieved on session 3 (rocks distance); however, he never ended a session without hitting any stone. At the end of the 20 sessions, Harry reported a median perceived exertion of 5.0 ± 3.5, confirming that it was not too intense. Exerpong showed to be the one that required more physical effort, with a median of 7.0 ± 1.0. This was the only game that we did not reach the maximum difficulty level. In this game, Harry was constantly displacing himself to catch the ball in different positions. Consistent with this, Exerpong was also reported as the most difficult game (5.0 ± 2.5).

Discussion

Here we studied the use of a set of customised exergames for functional balance training of a teenager with cerebral palsy. After an intensive rehabilitation month with 5 weekly sessions, Harry showed increased scores with related functional diferences between Baseline and the end of the treatment, with retention of gains 1 month after the treatment. Precisely, an increase of 9 points in the BBS was measured at Post-intervention. Although few studies use this scale with children with CP, it is considered a reliable measure to help understand functional impairment in postural control in CP [9]. Moreover, most of the studies that use VR for addressing balance in CP focussed their programs on children and used the Paediatric Balance Scale (PBS) [33,34], which is

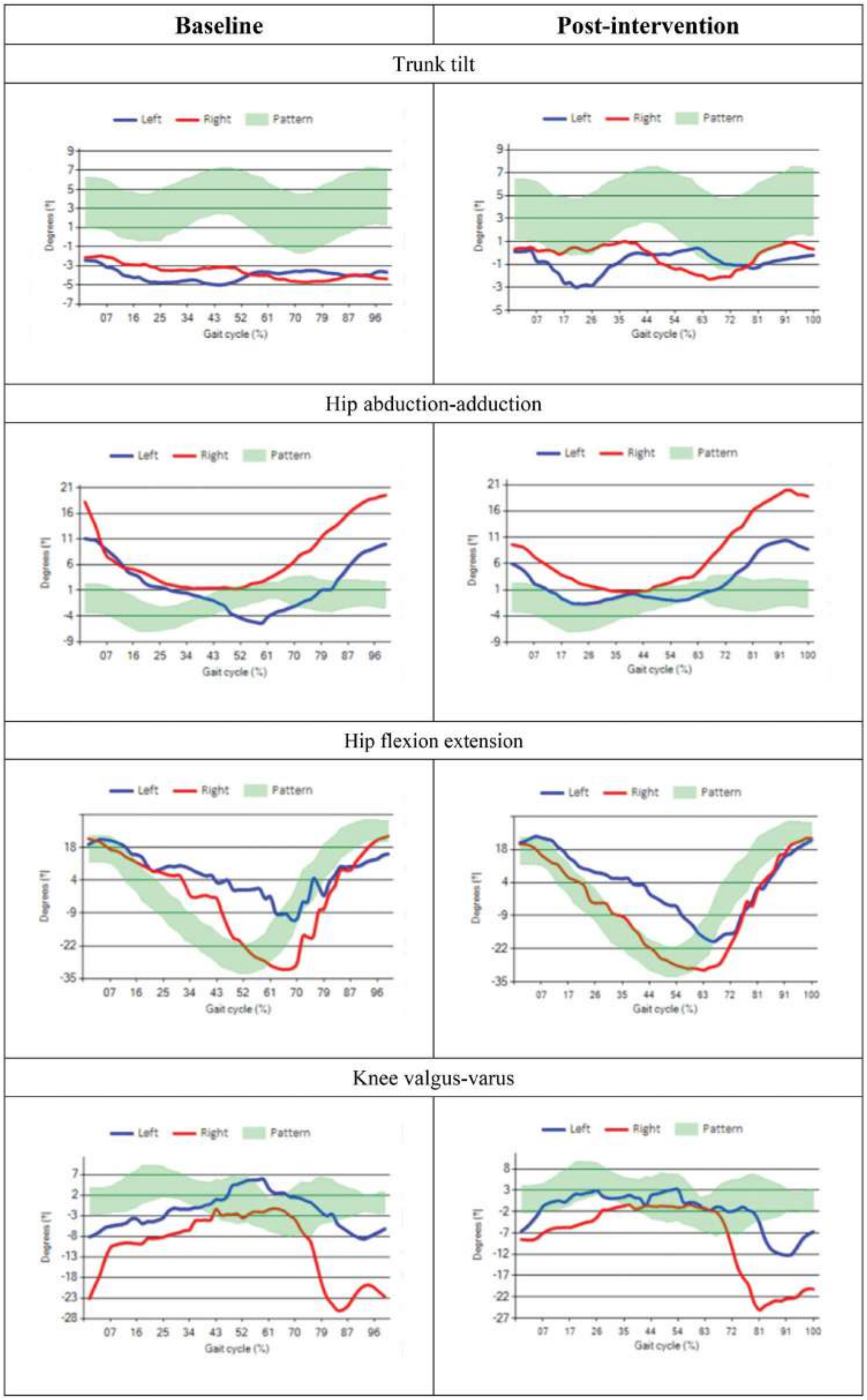

Figure 5. Comparison of different kinematics (trunk tilt, hip abduction-adduction, hip flexion-extension, knee valgus-varus, and ankle height variation, between Baseline and Post-intervention.

Table 4. Median and interquartile range regarding perceived exertion and difficulty felt by Harry on Exerfado, Rabelos VR, and Exerpong.

Descriptive statistic	Exerfado Difficulty	Exerfado Exertion	Rabelos VR Difficulty	Rabelos VR Exertion	Exerpong Difficulty	Exerpong Exertion
Median	4.0	5.0	5.0	5.0	5.0	7.0
Standard Deviation	2.0	3.0	1.5	3.5	2.5	1.0

a modified version of BBS appliable to children [35]. For example, Kozyavkin *et al.* [33] studied the impact of games for balance rehabilitation in children with CP and reported an average improvement of only 1 point over 56 in the PBS. We observed an increase of 9 points on BBS, which can be related to the balance demands from our exergames, by providing opportunities to engage in challenging motor behaviours, translating into better motor performance [36].

Regarding Module E of the GMFM, we verified an increase of 9 points at the end of the intervention. The Minimally Clinically Important Difference (MCID) for a person with a level II in the Gross Motor Function Classification System is 4.5 (Effect Size 0.8) [37]. The differences observed at Post-intervention are relevant from the functional point of view. He gained the ability to face stairs independently and walk backward and showed a higher ability to raise one leg at a time while keeping balance. These improvements in functional mobility, which is considered an activity of daily living, is important as functional ambulation is crucial to enrol on other significant activities of life such as going to a supermarket or going for a walk [38]. Interestingly, these skills were not explicitly trained with our games. The importance of training real-life skills may explain this result as ours contrast with the results of other studies [39–41]. For example, a study that used games aimed to improve standing balance resulted in improvements just in standing balance, without any transference to dynamic balance, as stair climbing ability did not change or in some cases even deteriorated [39]. Luna-Oliva et al. studied the impact of the Xbox 360 Kinect™ game console as a therapeutic modality for children with CP using the GMFM as an outcome measure [40]. The games aimed at balance and trunk movement, general and visuo-manual coordination and limb tasks. Eleven participants with a mean age of 7.9 years enrolled in sessions twice a week for 30 min for 2 months. Like in our report, they used the Modules D and E of the GMFM with an improvement 7.7% ± 13.0%. In this report, the increase of scores considering just modules D and E was 6%, which is in accordance with our result. In another study, Cho et al. [41] studied the impact of a VR and treadmill program compared to a treadmill-only program. The results showed that the program including VR was more effective, with an average improvement of 9.1% in Module D and 5.2% in Module E. In the same line of results, Urgen et al. [42] reported significant improvements in the GMFM with a group of participants enrolled on a rehabilitation program using Nintendo® Wii Fit compared with a control group. The authors reported improvements of 5.6% in Module D and 2.7% in Module E. In our case, we were not expecting higher scores in Module D (0%), as this module requires less evolved motor development skills, according to developmental milestones, when compared to Module E (12%). The characteristics of the exergames used in this report directly stimulated the skills measured in Module E, which are more related to the displacement of the body in the space compared to Module D, which is standing.

Regarding gait-specific outcomes, we observed a slight increase in the DGI score at Post-intervention, specifically, the ability to turn 180° after a prompt while walking. This observed capability can be related to Harry's movements while playing the games, namely, to turn 180° to change direction, as side walking was difficult for him. The specific gait analysis outcomes allow us to have a qualitative examination of the differences between pre and post intervetion. The main results show better scores in the step and swing phases. In the step phase, Harry increased 23 cm in the left leg and 22 cm in the right leg, with a corresponding increase in step time. The swing phase got more balanced between legs, increasing in the left leg and decreasing in the right one. There was also an approximation of trunk, hip, and knee kinematics to the pattern of people with the same demographic characteristics as Harry [30]. Cho et al. [41] concluded in their study that gait training on a treadmill increased the strength of lower limbs of the participants with CP, resulting in improvement in gait. We believe our intervention contributed to developing postural control with an impact on Harry's gait performance.

Concerning Posturography, Harry revealed better control of the centre of mass after the intervention, with more stability with eyes closed balance. This could mean that the proprioceptive and/or vestibular systems integrated the sensory input more efficiently, resulting in more appropriate answers from the neuromuscular system [43]. However, this was not retained after one month, returning to values close to the initial ones. Additionally, the maximum values of maximum excursion in limits of stability test were lower at Post-intervention. They increased slightly at Follow-up, indicating better control of the centre of mass and better postural control. Taking into account the reported tonus and voluntary contraction difficulties, this is a positive result for Harry. We hypothesise that the need for walking to interact with the game compared to standard static balance tasks can be more effective; however, further studies are needed.

Harry was *a priori* intrinsically motivated for this intervention, as informatics is one of his interests [44]. Additionally, several characteristics on exergames were used to arise his extrinsic motivation, such as the game personalisation of the music and difficulty adjustment, which allowed him to keep a constant challenge during the games [45]. A recent literature review shows that 5 in 9 VR-based studies used commercial solutions to train children's motor skills with CP. These are not as customisable for individuals with motor dysfunction as games specifically designed to that end [46]. The literature recommends adapting the motor skill level and providing meaningful tasks to increase users' motivation [47,48]. For the specific case of Harry, he showed the need to have some targets, which generally were to do better than the last score. Also, the interaction with the therapist played a role, as he enjoyed being challenged with some bets. We also felt that the relationship established with the therapist contributed to his involvement. Indeed, there is evidence that the alliance between therapist and patient can positively affect patients' outcomes in physical rehabilitation settings [49]. Concerning the perceived exertion reported by Harry (5.55 for Exerfado, 5.65 for Rabelos VR and 6.75 for Exerpong), and taking into account the ACSM recommendations [22], we can consider that the level of intensity was appropriate for his condition. The recommendations of ACSM for an individual that does not exercise regularly and does not have symptoms of cardiorespiratory, metabolic, or renal problems are light to moderate exercise intensity. This corresponds to a value of perceived exertion from 2 to 6 in the Modified Borg Scale [50].

This report has some limitations that should be taken into account in the interpretation of results. First, the assessor was not blind to the intervention. Second, Harry has an uncommon form of CP, acquired when he was nearly 3 years old, moment until when he followed the pattern of development of a typically developing child. Hence, it is unclear how the results obtained with Harry can be generalised to individuals with standard CP. Third, our results should be interpreted with caution since the rehabilitation program applied was designed according to Harry's specificities and motivations, as he was already intrinsicly motivated to participate. Finally, because this is a case report, we cannot establish a causal relationship between the intervention and the outcomes.

Conclusion

This case report aimed to explore the impact of an intensive intervention using exergame on the balance of a teenager with CP. After 20 sessions of 30 min for 1 month, we verified increased scores on the outcome measures. After the rehabilitation program, Harry demonstrated to have better control of his centre of gravity when standing. He improved reaching with arms stretched, his ability to walk backward, to step up and downstairs, and became able to raise one leg at a time. The possibility of our exergames being customised to the user's needs allowed us to address tiredness and motivation during the sessions, being fundamental to keep the user engaged. The presence and encouragement of the therapist during the sessions were also crucial for keeping the user involved in the rehabilitation process.

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Disclosure statement

The authors report no conflicts of interest.

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