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Effects of virtual reality training in the postural control of children with Down syndrome: A case series

Andrea Leiton-Muñoz[a], Ricardo Cartes-Velásquez[b] and Valeska Gatica-Rojas[c,*]
[a]*School of Kinesiology, Faculty of Health Sciences, Universidad de Talca, Talca, Chile*
[b]*Fundación Kimntrum, Concepción, Chile*
[c]*Tele-Rehabilitation Technology Center and Neurosciences in Human Movement, Faculty of Health Sciences, Universidad de Talca, Talca, Chile*

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Abstract.
BACKGROUND: Children with Down syndrome (DS) may struggle adjusting their posture during gait or standing and tend to adapt slower to demanding motor tasks and environmental changes. The functionality in their daily activities is frequently diminished or they are slower, with poor postural control and balance as possible reasons. There is limited research on exercise programmes to improve postural control in children with DS.
OBJECTIVE: To determine the effectivenes of an exercise programm with the Nintendo Wii Balance Board (NWBB) interface o postural control and functional balance of children with DS.
METHODS: Participants were five children age 6–9 years belonging to the legal organization *Espacio Down* (in Talca, Chile), who underwen an exercise programm with the NWBB. The duration of the intervention wa 9 weeks, with two 25-minute sessions per week and a total intervention timeof 7.5 hours for each subject. Postural control pre-/postintervention was evaluated at a functional level with clinical tests: Timed Up and Go (TUG), One-Leg Standing (TOLS) and posturographic measures using centre of pressure (CoP) variables Descriptive statistics and the Wilcoxon test were applied, with $p < 0.05$ considered to be significant.
RESULTS: Th NWBB programme showed a significant decrease in the CoP total velocity, mean velocity and displacements in themediolateral and anteroposterior directions ($p = 0.021$) for the closed-eyes condition and a decrease in the time of the TUG test ($p = 0.021$).
CONCLUSIONS: This pilot study provides initial evidence for the effectiveness of the NWBB programme in children with DS. A 9-week NWBB programme improves the postural control and functional balanceof children with DS.

Keywords: Down syndrome, postural control, balance, center of pressure

1. Introduction

Down syndrome (DS) has an incidence rate of 1/700–800 live births [1]; in Latin America there is an increased rate of 2.4–2.9 per 1000 live births [2] whereas in the USA it is 10 per 10,000 live births [3]. Persons with DS have several comorbid medical problems and reduced life expectancy [4].

Common anomalies include diminished muscle strength, abnormal body composition and decreased physical fitness, including reduced aerobic capacity or cardiorespiratory fitness [5]. This may lead to low levels of resting energy expenditure and physical activity, which can result in a sedentary lifestyle [5]. Individuals with DS also display generalized muscle hypotonia, lig-

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[*] Corresponding author: Valeska Gatica-Rojas, Tele-Rehabilitation Technology Center and Neurosciences in Human Movement, Faculty of Health Sciences, Universidad de Talca, Av. Lircay S/N, Talca, Chile. Tel.: +56 71 2418859; E-mail: valeskagaticar@gmail.com.

amentous laxity, articular hypermobility and difficulties in agonist–antagonist muscle co-contraction [6].

It is known that poor postural control, balance, coordination and agility often leads to a higher incidence of accidents, such as falls, and other associated injuries [7]. A recent systematic review found that children and adolescents with DS showed delays and dysfunction in performing various daily life activities, using compensatory mechanisms to maintain their postural control [8]. Therefore, it is necessary to address the therapeutic needs at the sensorimotor level of individuals with DS in the early stages due to the associated brain plasticity.

Postural control is directed by at least three sensory systems: proprioceptive, visual and vestibular. Therefore, its plasticity depends on the neural maturity of these three systems: the proprioceptive system reaches maturity at age 3.5 years, the visual system at 12 years and the vestibular system at 15 years of age [9]. In this regard, virtual reality (VR) appears to be a promising option for improving functional performance in daily activities and the postural control key for improving the quality of life in people with DS. However, few studies have evaluated the effect of a VR-based intervention on functionality and postural control in children with DS [7].

A recent systematic review found that VR training improves sensorimotor functions used as a main or complementary therapy in the rehabilitation of people with DS or cerebral palsy [10]. Low-cost VR exergames are well-accepted by children and adolescents due to their playful, motivating and engaging features [11]. Game consoles, especially Nintendo Wii, have been used in VR-based rehabilitation therapies for several conditions and diseases with good results [12]. Moreover, in some conditions such as Parkinson's disease, Nintendo Wii have provided better results than other game consoles [13]. In the case of patients with DS, VR-based therapies have shown good results also in terms of motor proficiency [7]. However, there are only a few studies on this topic, particularly for children with DS

This study aims to determine the effect of a VR training protocol using the Nintendo Wii Balance Board (NWBB) interface in the postural control and functional balance of children aged 6–9 years with DS.

2. Methods

2.1. Design and setting

This is a case series that includes 6–9-year-old children with DS affiliated to the organization *Espacio Down* in Talca (Chile). *Espacio Down* is a legal organization that welcomes families of those diagnosed with DS.

2.2. Sample and recruitment

The inclusion criteria of the sample were that the subjects: are 6–9 years old; have a diagnosis of DS; have mild to moderate intellectual impairment reported by a psychologist; have vision and hearing that is normal or corrected to normal; have no history of seizures or controlled seizures; and can independently achieve the bipedal position. Subjects were excluded if they had severe cognitive impairment, physical injuries or surgeries in the past year and were unable to provide parental consent or participant opinion. Subjects were not allowed to perform other parallel training during the study period.

Two meetings were held in the offices of *Espacio Down*, aimed to provide information about the project and to attract interested subjects. The intervention sample of five children was a convenience sample, not randomized, comprising one 8-year-old girl and four 7–9-year-old boys.

2.3. Intervention

The intervention used a protocol of training with the NWBB (Wii Fit Plus, Nintendo Co., Japan) for a period of nine consecutive weeks at a frequency of twice a week, 25 minutes per session, delivering a total of 7.5 hours of training to each subject. The protocol was carried out in the Tele-rehabilitation Technology Center and Neurosciences in Human Movement of the University of Talca. The 2 × 1.5 metre VR image was projected onto a white wall 2 metres away from the subject, as has been established in other two-dimensional VR environment protocols [14–16].

The protocol includes three categories of exercises, with manual and verbal guidance during the intervention that was controlled by a physical therapist trained in the NWBB protocol. The games in order of execution were chosen to practice balance in three planes of movement – Snowboard (sagittal plane), Penguin Slide (mediolateral plane) and Super Hula Hoop (transverse plane) – and were made in two series. The first series of three games was executed with the arms in a comfortable position for the subject and the second series with the hands on the waist. Relative rest periods of 2 minutes were given between each series of exercises,

Table 1
Characterization of the sample

Subject	Age	Sex	Weight (kg)		Height (m)		BMI		Intellectual disability
			Pre	Post	Pre	Post	Pre	Post	
1	7y 4m	M	22.5	23.5	1.13,5	1.15,5	17.47	16.87	Moderate
2	8y 9m	F	36	37.5	1.20	1.23	25	24.7	Moderate
3	8y 6m	M	31	29.5	1.17	1.19	22.65	20.83	Moderate
4	9y 3m	M	35.5	36	1.23	1.24	23.46	23.41	Moderate
5	8y 11m	M	29.5	27.5	1.16	1.18	21.9	19.75	Moderate

according to the needs of each child. The third series of exercises was yoga, where the subject must maintain a relaxed bipedal posture on the platform for 30 seconds, with their eyes open and then with their eyes closed, as has been used in previous protocols [14–16].

Each participant was asked to stand on the NWBB (20 × 40 cm) comfortably, with their feet in the area recommended by Nintendo, and to maintain their position throughout execution of the protocol. It was standardized that the position of the feet should not exceed the width of the shoulders and be arranged in parallel [17].

2.4. Data collection

Before and after the intervention, participants were scheduled to be evaluated in the motor control laboratory individually, always by the same evaluator – a physical therapist specialist in neurological rehabilitation with 6 years of experience in VR. Characteristics of the subjects such as weight, height and body mass index (BMI) were evaluated, followed by two functional tests for which the execution time of each was noted. The instructions for both tests were given verbally and using body language.

Functional testing started with the Timed Up and Go (TUG) test, where the subject is asked to: sit in a chair of his or her height (hips and knees at a 90° angle); stand up and walk as fast as possible 3 metres towards the evaluator; and walk around a cone, passing outside of it and returning to sit in the chair again. The one-leg standing (TOLS) test is performed on each leg sequentially because when trying to discriminate the dominant leg for unipodal support (defined as the one that kicks the ball) it is not possible to differentiate laterality. The subject is asked to raise one leg to approximately 90° hip flexion for as long as possible. The record time of two attempts on each leg is recorded, using the quickest of the times. The test stops at a maximum time of 30 seconds if the foot touches the floor or, if immediately given the instruction, the leg falls under 45° of flexion.

Table 2
Functional tests, pre-post changes

Subject	TUG	TOLS right leg	TOLS left leg
1	3%	−6%	4%
2	21%	−48%	15%
3	21%	Not maked	Not maked
4	22%	0%	−24%
5	15%	83%	75%

The table expresses the differences between pre and post for each clinical measurement.

After the functional tests and a resting pause (less than 10 minutes), posturographic measures were evaluated using a force platform (Model AMTI OR6-7; Watertown, MA, USA) at 200 Hz. The performance of each participant was measured in bipedal position on the platform under two visual conditions: open eyes and closed eyes. The participants were instructed to maintain an upright standing position for 30 seconds with their arms relaxed at the side of the body and their feet placed parallel in a comfortable position not exceeding the width of their shoulders.

Data were collected in two consecutive trials. In the first, they are asked to keep their eyes straight ahead while maintaining the standing position. In the second trial, due to the difficulties of the participants in keeping their eyes closed throughout the test, it was decided to use a black mask to subtract the vision. Participants were asked to sit down after each trial to rest, for as long as necessary, for a maximum of 2 minutes.

2.5. Statistical analysis

To process and calculate the variables delivered by the force plate, MATLAB R2012 software (MathWorks Inc., Natinck, MA, USA) was used. First, a descriptive analysis was used to evaluate the effects of the intervention individually. Second, the assumptions of normality were confirmed using the Shapiro–Wilk test and, to analyse the behaviour of the entire sample, the Wilcoxon signed-rank test was performed. Statistical analyses were performed using IBM-SPSS 20.00 (SPSS Inc., Armonk, NY, USA), with a level of significance established at $p < 0.05$.

Table 3
Center-of-pressure pre-post measurements

Open eyes	Median pre	Median post	p-value
TV ML	0.0359 (0.018; 0.037)	0.0251 (0.018; 0.030)	0.07
TV AP	0.0276 (0.019; 0.033)	0.0276 (0.020; 0.028)	0.34
MV ML	0.0598 (0.031; 0.062)	0.0419 (0.031; 0.051)	0.07
MV AP	0.0460 (0.031; 0.056)	0.0460 (0.034; 0.047)	0.34
DML	1.795 (0.936; 1.88)	1.256 (0.942; 1.53)	0.07
DAP	1.795 (0.936; 1.88)	1.256 (0.942; 1.53)	0.07
DSML	0.0123 (0.003; 0.026)	0.0086 (0.005; 0.021)	0.45
DSAP	0.0081 (0.005; 0.016)	0.0073 (0.004; 0.012)	0.25
CoPSway	0.0023 (0.000; 0.003)	0.0009 (0.000; 0.003)	0.45
Closed eyes	**Median pre**	**Median post**	**p-value**
TV ML	0.0277 (0.021; 0.037)	0.0237 (0.016; 0.025)	0.02
TV AP	0.0311 (0.021; 0.034)	0.0245 (0.020; 0.028)	0.17
MV ML	0.0462 (0.035; 0.061)	0.0395 (0.028; 0.041)	0.02
MV AP	0.0518 (0.035; 0.057)	0.0408 (0.034; 0.047)	0.17
DML	1.385 (1.05 ; 1.84)	1.185 (0.839; 1.25)	0.02
DAP	1.385 (1.05 ; 1.84)	1.185 (0.839; 1.25)	0.02
DSML	0.0054 (0.003; 0.013)	0.0068 (0.003; 0.014)	0.45
DSAP	0.0061 (0.001; 0.009)	0.0056 (0.003; 0.008)	0.34
CoPSway	0.0004 (0.000; 0.001)	0.0005 (0.000; 0.001)	0.45

TV: total velocity; MV: mean velocity; D: Displacement; ML: mediolateral; AP: anteroposterior. CoPSWay: area.

Table 4
Center-of-pressure pre-post measurements for each patient

Subject open eyes	TV ML	TV AP	MV ML	MV AP	DML	DAP	DSML	DSAP	CoPSway
1	25%	16%	25%	16%	25%	25%	21%	74%	62%
2	2%	−13%	2%	−13%	2%	2%	14%	−7%	−14%
3	4%	19%	4%	19%	4%	4%	−162%	6%	−126%
4	−3%	−8%	−3%	−8%	−3%	−3%	−78%	−30%	−132%
5	12%	9%	12%	9%	12%	12%	42%	30%	59%
Subject closed eyes	**TV ML**	**TV AP**	**MV ML**	**MV AP**	**DML**	**DAP**	**DSML**	**DSAP**	**CoPSway**
1	13%	16%	13%	16%	13%	13%	32%	44%	61%
2	6%	−16%	6%	−16%	6%	6%	−60%	−25%	−98%
3	14%	21%	14%	21%	14%	14%	−278%	−13%	−336%
4	60%	40%	60%	40%	60%	60%	58%	31%	71%
5	1%	−20%	1%	−20%	1%	1%	11%	−4%	12%

TV: total velocity; MV: mean velocity; D: Displacement; ML: mediolateral; AP: anteroposterior. CoPSWay: area.

2.6. *Ethics*

The study was approved by the ethics committee of the institution. Written informed consent was obtained by the parents and, when applicable, by the patients.

3. Results

The characteristics of the five participants are shown in Table 1. No adverse effects were reported in any of the subjects.

Functional tests revealed a small improvement for almost the entire sample. In the case of the TUG, improvement was statistically significant, with the median value reduced from 8.77 s (interquartile range [IQR] 8.19–8.99) to 7.28 s (IQR 6.82–7.73; $p = 0.02$). In the case of the TOLS, there were no statistically significant changes: the median value for the right foot was reduced from 1.40 s (IQR 0.85–1.73) to 1.30 s (1.01–1.36) ($p = 0.30$) and for the left foot it was reduced from 2.16 s (IQR 1.08–3.15) to 1.27 s (IQR 0.89–3.03; $p = 0.36$). The values for individualized patients are shown in Table 2.

In the case of posturographic measures, median values for all the centre of pressure (CoP) variables in the closed-eyes and open-eyes conditions are shown in Table 3 and for individualized patients are shown in Table 4.

4. Discussion

There is scant research on exercise programmes to improve postural control in children with DS [7,8]. The data obtained in this study suggest that the effects of training with the NWBB programme improve the static and functional balance variables of children aged 6–9 years with DS. This programme is 7.5 hours long over a 9-week period, with 25-minute sessions held twice a week. This result is probably related to the exceptional adaptability of the central nervous system (neuronal plasticity) in an environment with stimuli that promote motor learning Regrettably, children and adolescents with DS receive few physiotherapy sessions, which is a lost opportunity to improve the functionality and quality of life of these patients during a critical period of their lives. It is important to note that the neural maturity of sensory systems responsible for the control of postural balance is sequential and dependent on age, reaching full maturity at 15–16 years [18,19]. Therefore, providing as much rehabilitation time as possible during this age period is essential to generate motor function improvements that will profoundly impact their quality of life during adulthood.

VR has been strongly incorporated in the area of neurological rehabilitation, the Nintendo Wii being one of the most used devices due to its economic accessibility and ease of use. An NWBB exercise protocol, as part of therapeutic interventions, has been documented to improve the static and functional balance of children with cerebral palsy, who have sensorimotor similarities with children with DS to a variable degree [9,14,20]. All of this is supported because VR provides an artificial environment with multisensory interaction (visual, somatosensory, vestibular and auditory systems) contributing to postural control.

The post-intervention changes could be explained by the VR environment, which fosters the phenomenon of neuronal plasticity [21]. It provides abundant multisensory stimuli (directly associated with postural control) that provide us with sensory feedback, which is one of the foundations of VR effects, plus motivation and repetition. Sensory feedback is delivered, for example, through the visual system in a constant way by achieving reproduction of the avatar's movement with the body movements of the subject; it also promotes major activation of proprioceptors in the different joints and in the vestibular system, which maintains the eyes, head and neck oriented in space according to body movements.

Neural activation is based on mirror neurons that are stimulated by observing the execution of a motor task of another person, as in a mirror, a situation created by the VR environment [9]. Moreover, the motivation is intrinsically given to us by VR games because they are attractive and interesting for the subjects.

In 2012, Berg et al. [22] proved that the Nintendo Wii was useful for improving the postural stability, limits of stability, upper-limb coordination, manual dexterity, running speed and agility standard scores in a 12-year-old adolescent. Recently, Stander et al. [8] found that the Nintendo Wii may be beneficial when used in addition to standard physiotherapy or occupational therapy interventions for improving motor proficiency in individuals with DS. However, studies on the child population are lacking and the evidence available is limited in quantity as well as quality (level of evidence).

NWBB therapy is a dosed VR environment tool that allows interaction between avatars and children through movement guided by a therapist. The therapist facilitates and integrates the three planes of movement, and for children with DS the anteroposterior movements are difficult and unusual to perform. In this case, NWBB therapy improved postural control, modulating the anteroposterior shift both in the open-eyes and closed-eyes conditions Commonly, children with DS have large oscillations in postural control in the mediolateral plane and this axis of movement is greatly accentuated during movements and daily functionality, such as walking, going up and down stairs and during play among their peers. NWBB therapy improved mediolateral postural control, with a significant decrease in all mediolateral CoP variables, both in the open-eyes and closed-eyes conditions Similar findings were found by Berg [22] in a 12-year-old patient with DS, who was treated with the Nintendo Wii at home four times a week for 20 minutes each session for 8 weeks.

The verbal instructions used to guide and understand how the user should perform movement in any physical therapy and even in various situations, such as in the classroom, were largely omitted during NWBB therapy. The two-dimensional VR environments dosed in the NWBB therapy generated an excellent sequential organization for each movement without the need for verbal instructions from the therapists towards the children with DS [23–25].

The changes in postural control were evident and the parents of the children with DS described that they could move better, with greater speed and better control of their body during a race for example. The parents also noticed that all the children grew, and some had a loss of weight. These variables are important because children with DS have a slower metabolism and are usually overweight or obese [26]. Moreover, the NWBB protocol provides the opportunity to implement rehabilitation of children with DS at home, which is an advantage in the current COVID-19 pandemic [27].

As summary, this pilot study provides initial evidence towards the effects of the NWBB program in children with DS. A 9-weeks NWBB program improves the postural control and functional balance of children with DS.

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Author contributions

CONCEPTION: Andrea Leiton-Muñoz and Valeska Gatica-Rojas.
PERFORMANCE OF WORK: Andrea Leiton-Muñoz.
INTERPRETATION OR ANALYSIS OF DATA: Andrea Leiton-Muñoz and Valeska Gatica-Rojas.
PREPARATION OF THE MANUSCRIPT: Ricardo Cartes-Velásquez and Valeska Gatica-Rojas.
REVISION FOR IMPORTANT INTELLECTUAL CONTENT: Ricardo Cartes-Velásquez and Valeska Gatica-Rojas.
SUPERVISION: Valeska Gatica-Rojas.

Ethical considerations

This study adheres to the Declaration of Helsinki and the Chilean laws of rights and duties of the patient and research in humans. Ethical approval was obtained from the Ethics Committee of the University of Talca (Ref. No. 21-2019).

Conflict of interest

The authors have no conflicts of interest to report.

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