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ORIGINAL RESEARCH ARTICLE

# Effect of Whole-Body Vibration Training on Standing Balance and Muscle Strength in Children with Down Syndrome

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**ABSTRACT**

Eid MAM: Effect of whole-body vibration training on standing balance and muscle strength in children with down syndrome. *Am J Phys Med Rehabil* 2014;00:00–00.

**Objective:** The purpose of this study was to determine whether whole-body vibration training could improve standing balance and muscle strength in children with Down syndrome.

**Design:** This study was a randomized controlled trial studying 30 children (8–10 yrs old) with Down syndrome. They were assigned randomly using sealed envelopes, with 15 children allocated to the control group (9 boys, 6 girls) and another 15 children allocated to the study group (8 boys, 7 girls). The control group received a designed physical therapy program, whereas the study group received the same program given to the control group in addition to whole-body vibration training. Both groups received the treatment sessions three times per week for 6 successive months. Measurement of stability indices by using the Biodex Stability System as well as muscle strength of the knee flexors and extensors by using a handheld dynamometer was done before and after the 6 mos of the treatment program.

**Results:** Each group demonstrated significant improvements in stability indices and muscle strength after treatment ( $P < 0.05$ ), with significantly greater improvements seen in the study group when compared with the control group ( $P < 0.05$ ).

**Conclusions:** Whole-body vibration may be a useful intervention modality to improve balance and muscle strength in children with Down syndrome.

**Key Words:** Down Syndrome, Balance, Biodex Stability System, Muscle Strength, Whole-Body Vibration

**D**own syndrome (DS) is a genetic disorder attributed to a chromosomal abnormality (trisomy 21) and is the most common genetic form of mental retardation.<sup>1</sup> Children with DS are characterized by clinical symptoms, including orthopedic, cardiovascular, musculoskeletal, and respiratory problems as well as perceptual impairments.<sup>2</sup> It was noted that children with DS, when compared with their healthy peers, have decreased ability to adapt their motor action to the circumstances and to generate greater strength when necessary.<sup>3</sup> Postural deficits and balance problems have been identified in children with DS. Shumway-Cook and Woollacott<sup>4</sup> found that young children with DS have deficits in the postural control system that may result in functional balance problems; they concluded that postural responses to loss of balance were slow and insufficient for maintaining stability. They also suggested that balance problems in these children occur from defects within higher-level postural mechanisms and are not caused by hypotonia.

Postural dysfunctions are the most common problems found in children with DS and are associated with impaired proprioception, impaired motor coordination, sensory-motor integration problems, and decreased reaction time for anticipatory postural adjustments.<sup>5</sup> Although adolescents with DS have postural control strategies similar to adolescents without DS, they may demonstrate precarious balance and show quantitative differences in the integration of sensory input to control stance.<sup>6</sup> Postural control deficits in children with DS leads them to be more inactive, which contributes to functional balance problems.<sup>7</sup> Muscle strength is considered one of the essential abilities to achieve effective and functional movements. Children with DS demonstrated decreased levels of muscle strength when compared with healthy individuals. Particularly, the lower extremity muscle strength is more important to overall physical health and performance of daily activities.<sup>8</sup>

Children with DS had reduced muscle strength of the hip abductors and the knee extensors when compared with children without DS.<sup>9</sup> Cioni et al.<sup>10</sup> reported that children and adolescents with DS also have reduced quadriceps strength when compared with children without mental retardation and with mental retardation without DS. They also stated that adolescents with DS did not demonstrate the physiologic increase in muscle strength that occurs in typically developing adolescents by 14 yrs of age. There is a direct relation between maintaining balance and sensory information, range of motion, coordination, and muscle strength.<sup>11</sup> Pitetti et al.<sup>12</sup> reported that children and adolescents with DS have

low peak aerobic capacity, physical activity, and muscular strength compared with individuals without disabilities. They suggested that exercise training with endurance and/or resistance exercise seems beneficial for youth with DS.

Because children with DS have sensory problems and impaired proprioception, whole-body vibration (WBV) is now considered one of the popular training methods that use high-frequency mechanical stimuli generated by a vibrating platform and transmitted through the body, leading to bone loading and sensory receptor stimulation.<sup>13</sup> WBV is considered a light-resistance exercise modality that depends on automatic body responses to repeated and rapid mechanical oscillations of a vibrating platform.<sup>14</sup> These mechanical oscillations induce continuous eccentric-concentric muscular work and increased oxygen consumption.<sup>15</sup> Therefore, WBV might be a good substitution or complementary method of aerobic and resistance exercises. Because children with DS generally show deficits in somatosensory input and poor motor control, WBV is considered one of the somatosensory stimulations that have great importance in the rehabilitation process.<sup>16</sup> O'Keefe et al.<sup>17</sup> examined the effect of 12-wk WBV exposure in children and adolescents (8–15 yrs old) with cystic fibrosis and found a significant increase in leg strength and power. In addition, Roelants et al.<sup>18</sup> examined the effects of a 24-wk WBV training in older women (58–74 yrs old) and reported improvements in knee extension strength and speed of movement. Verschueren et al.<sup>19</sup> investigated the effects of 6-mo WBV in postmenopausal women (58–74 yrs old) and reported improvements in muscle strength, balance, and bone density. Moreover, the effects of a single session of WBV in patients with neuropathy was examined and reported improved balance and muscle strength.<sup>20</sup>

WBV training has demonstrated improvements in balance and muscle strength in postmenopausal women,<sup>19</sup> in peripheral neuropathy,<sup>20</sup> and in muscle strength in children with cystic fibrosis.<sup>17</sup> The purpose of this study was to determine whether WBV will improve balance and muscle strength in children with DS.

## **MATERIALS AND METHODS**

### **Subjects**


Thirty children with DS with ages ranging from 8 to 10 yrs were enrolled in this study. Selection of this age may be attributed to the fact that children and adolescents with DS between 7 and 14 yrs

AQ4

had greater sway in static balance.<sup>21</sup> To avoid a type II error, a preliminary power analysis (power, 0.86;  $\alpha = 0.05$ ; effect sizes [ESs]  $\geq 0.8$ ) determined a sample size of 30 for this study. They were recruited from the outpatient clinic of Faculty of Physical Therapy, Cairo University, Cairo, Egypt, and assigned randomly into two equal intervention groups (a control and a study group). Children in both groups were selected with inclusion criteria, including children with DS with mild hypotonia, children who can stand and walk independently with balance problems as revealed from physical examination, the absence of gross visual and hearing impairments, as well as children with mild intellectual disabilities and sufficient cognition to understand commands given to them. Exclusion criteria were children who were on medical treatment that restricted their participation in the study and who had musculoskeletal or cardiac problems. This work is carried out in accordance with the code of ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans. Parents of the children signed a consent form before participation. In addition, approval of the ethical committee of the Faculty of Physical Therapy, Cairo University, was taken.

### Randomization

In the present study, 37 children were assessed for eligibility. Five children were excluded because they did not meet the inclusion criteria, and two children were excluded because their parents refused to participate in the study. After the baseline measurements, randomization process was performed using closed envelopes. The investigator prepared 30 closed envelopes, with each envelope containing a card labeled with either control or study. Finally, each child was asked to draw a closed envelope that contains whether he/she was allocated to the control group (physical therapy program) or the study group (physical therapy program and WBV). The experimental design is shown as a flow diagram in Figure 1.

 The experimental design is shown as a flow diagram in Figure 1.

### AQ5 Control Group

The control group consisted of 15 children with DS (9 boys and 6 girls), with a mean (SD) age of 9.26 (0.79) yrs and a mean (SD) height of 119.06 (2.81) cm, and received a designed physical therapy program for 1 hr, three times per week, for 6 successive months.

### Study Group

The study group consisted of 15 children with DS (8 boys and 7 girls), with a mean (SD) age of 8.93 (0.7) yrs and a mean (SD) height of 118.2 (2.27) cm, and received the same program as the control group

for 1 hr in addition to WBV training for 5–10 mins, three times per week, for 6 successive months.

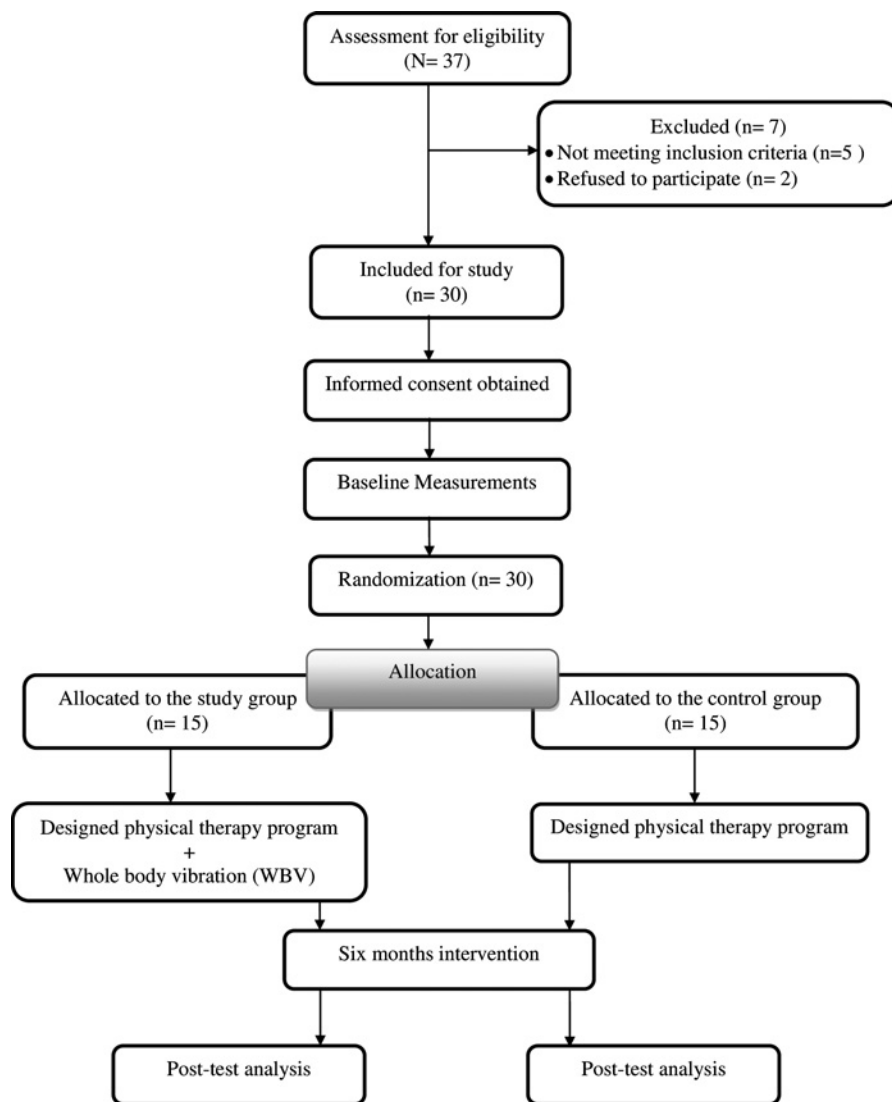
### Procedures

All procedures for evaluation were explained to all children and their parents. Weight and height were recorded using an electronic weighing and measuring station with automatic body mass index calculation (Seca 763). The IQ level was determined using the Wechsler Intelligence Scale for Children, Third Edition (Chinese version),<sup>22</sup> administered by a clinical psychologist. It is a standardized test of intellectual aptitude for children and adolescents between the ages of 6 and 16 yrs and has been used in DS.<sup>23</sup> Each child was evaluated for balance and muscle strength of the knee flexors and extensors, before and after 6 mos of treatment, by the same examiner who was blinded regarding the group to which each child was assigned.

### Balance

Balance assessment was carried out using the Biodex Stability System (BSS; Biodex, Inc, Shirley, NY), which enables objective assessment of balance.<sup>24</sup> The BSS consists of a display screen that the child looks at and can be adjusted according to the height of each child. The screen provides visual feedback for the child about the degree of tilting, that the child should maintain the cursor in the center of the screen to obtain a good score of balance. It also consists of a dynamic balance platform that allows movements around the anterior-posterior and medial-lateral axes simultaneously. The BSS measures the degree of tilting for each axis during dynamic conditions and calculates a medial-lateral stability index (MLSI); an anterior-posterior stability index (APSI); and an overall stability index (OSI), which is a composite of the MLSI and the APSI.<sup>25</sup> The BSS calculates the mean position for the child during all motions throughout the test. Higher scores in all these outcomes indicate poorer balance. The BSS has eight levels of stability, extending from the least stable level (level 1) to the most stable level (level 8). In the present study, to determine the appropriate level of stability, familiarity sessions were conducted before the main clinical testing. During the sessions, the children expressed difficulty maintaining their balance and slight muscle discomfort at stability levels lower than 8; consequently, all measurements were performed at the level (8) of stability. In addition, level 8 represents the most stable and high resistance level of the platform because high test-retest reliability for the BSS was reported when using high resistance levels.<sup>26</sup> The

AQ6



**FIGURE 1** Flow chart showing the experimental design of the study.

intratester reliability of the BSS has been reported as 0.43 for MLSI, 0.80 for APSI, and 0.82 for OSI.<sup>27</sup>

Each child was allowed to stand in the center of the locked platform of the BSS for 1 min with the two-leg stance. Certain parameters such as the child's age, weight, height, and stability level (platform firmness) were obtained to be fed to the device. During the assessment period, the platform began to freely move and simultaneously calculate the degree of tilt for both axes (AP and ML). A printout was obtained at the end of each test, including OSI, APSI, and MLSI. The balance measurement test was repeated three times, and the mean was obtained for data analysis.

### AQ7 Muscle Strength

Muscle strength of the knee flexors and extensors of the dominant side was measured in pounds

using a handheld dynamometer (Nicholas Manual Muscle Test system, Model 01163; Lafayette Instrument Company, Lafayette, IN). The handheld dynamometer has been shown to be reliable in measuring isometric muscle strength in children with DS, with intraclass coefficients ranging from 0.89 to 0.95.<sup>9</sup>

To measure muscle strength of the knee flexors, from prone lying position, the trunk and the non-dominant limb were stabilized. The child was asked to perform maximal isometric contraction of the knee flexors against dynamometer resistance while the examiner was holding it at the posterior lower third of the tibia.

To measure muscle strength of the knee extensors, from a comfortable sitting position, the knees flexed at 90 degrees with the pelvis and the nondominant limb were stabilized. The child was asked to perform maximal isometric contraction of

the knee extensors against dynamometer resistance while the examiner was holding it at the anterior lower third of the tibia just above the ankle joint.

Three attempts at each muscle group were recorded. The first attempt was used for familiarization, and a score was obtained by averaging the second and third attempts.

## TREATMENT

### Physical Therapy Program

The children in both groups received a designed physical therapy program in the form of the following:

- A. Gentle stretching exercises for the hip flexors, the hip adductors, the knee flexors, and the ankle plantar flexors bilaterally. Twenty seconds of stretching was followed by 20 secs of relaxation, repeated five times per session for each muscle, for 15 mins.
- B. Static muscle contraction for the hip extensors, the quadriceps, the hamstrings, the anterior tibial group, and the calf muscles for 15 mins. It was performed five times initially, building up to ten repetitions as tolerated, two to three times per day.<sup>28</sup> Each contraction was maintained for five counts, then relaxation for another five counts.
- C. Balance and postural control exercises for 30 mins, including the following:
  - (1) Standing with both feet together while the therapist sits behind the child and applies manual locking of both knees and then slowly tilts him/her to each side, forward and backward.
  - (2) Standing with step forward and shifts his/her weight forward then backward alternately.
  - (3) High step standing and tries to keep balanced
  - (4) Standing with manual locking of both knees then tries actively to stoop and recover
  - (5) Equilibrium, righting, and protective reactions training
  - (6) Gait training

The total program lasted for 1 hr, three times per week, for 6 successive months.

### Whole-Body Vibration

The children in the study group received WBV training, with 5 mins of rest after completing the physical therapy program. A commercial device for WBV was used (Vibraflex Home Edition II; Orthometrix Inc, White Plains, NY; outside North America, the brand name is Galileo Basic). This device has a motorized board that generates side-to-side alternating vertical sinusoidal vibrations around a fulcrum in the midsection of the plate. The frequency of the vibrations can be selected by the user. The device generates vibration by allowing separate and unsynchronized multidimensional oscillations along the sagittal axis. In the present study, the device was set to produce a peak-to-peak sinusoidal vibration with an amplitude of 2 mm, and the vibration frequency was set at 25–30 Hz because these stimuli cannot generate resonance catastrophes or kinesthetic illusions.<sup>29</sup>

The children in the study group were asked to stand with slightly flexed knees (30 degrees of knee flexion), and both feet were placed at an equal distance from the center of the platform to achieve an equal distribution of body weight over both feet. All children were asked to contract the muscles of the lower limbs during exposure to WBV. In addition, all the children used gymnastic shoes to standardize the damping effect of the vibration caused by footwear. During WBV training sessions, the therapist always accompanied the child performing the training to ensure safety, to supervise a correct knee angle, and to apply commands to contract lower limb muscles during vibration, immediately stopping the vibration session if the child complained of pain, fainting, or fatigue.

The treatment schedule for WBV as detailed in Table 1 was adopted from Gonzalez-Aguero et al.,<sup>30</sup> who applied WBV to adolescents with DS to measure

AQ8

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**TABLE 1** Exercise protocol for the WBV training

Month	Sessions	Frequency, Hz	Amplitude, mm	Duration, secs	Rest, secs	Repetition	Vibration Total Time, mins	Training Total Time, mins
Month 1	12	25	2	30	60	10	5	15
Month 2	12	25	2	30	60	10	5	15
Month 3	12	28	2	45	60	10	7.5	17.5
Month 4	12	28	2	45	60	10	7.5	17.5
Month 5	12	30	2	60	60	10	10	20
Month 6	12	30	2	60	60	10	10	20



body composition. The treatment program extended for 6 successive months, with an amplitude of 2 mm and a frequency that ranged from 25 to 30 Hz. In the first 2 mos, WBV was applied for 30 secs followed by 1 min of rest and repeated ten times per session, so the vibration time was 5 mins and the total training time was 15 mins. In the second 2 mos, WBV was applied for 45 secs followed by 1 min of rest and repeated ten times per session, so the vibration time was 7.5 mins and the total training time was 17.5 mins. In the last 2 mos, WBV was applied for 60 secs followed by 1 min of rest and repeated ten times per session, so the vibration time was 10 mins and the total training time was 20 mins. The total program for the children in the study group lasted for 1 hr for the designed physical therapy program in addition to 5–10 mins for WBV training, three times per week, for 6 successive months.

### Statistical Analysis

The normality of data was tested by using the Shapiro-Wilk test. The age, weight, height, and body mass index were expressed as mean (standard deviation). Repeated-measures multivariate analysis of variance was conducted to compare between the pretreatment and posttreatment measurements of stability indices and knee strength in each group; it was also used to compare these variables between the study and control groups. The level of significance for all statistical tests was set at  $P < 0.05$ . The sample size was determined by using the Slovin formula ( $n = N/1 + Ne^2$ ), where  $N$  represents the population size and  $e$  represents the margin of error. ESs were calculated according to Cohen<sup>31</sup> as  $d = (\text{study mean} - \text{control mean}) / \text{SD}$  to quantify the magnitude of the postintervention difference between the study and control groups. ESs are considered “small” if  $ES \geq 0.2 < 0.5$ , “moderate” if  $ES \geq 0.5 < 0.8$ , or “large” if  $ES \geq 0.8$ . All statistical

measures were performed through the Statistical Package for the Social Sciences (SPSS) version 20 for Windows.

## RESULTS

### Mean Training Attendance

The mean (SD) training attendance was 88.03% (6.57%). There were no withdrawals in the study group or the control group.

### Testing the Normal Distribution of Data

The Shapiro-Wilk test was conducted to test the normal distribution of data for each dependent variable. The results revealed no significant deviation from normal distribution for all variables in both groups ( $P > 0.05$ ).

### Subject Characteristics

Thirty children (17 boys and 13 girls) with DS completed 6 mos of WBV training and were included in the statistical analysis. The baseline measurements indicated that there was no significant difference between both groups in mean age ( $P = 0.23$ ), sex ( $P = 0.71$ ), weight ( $P = 0.78$ ), height ( $P = 0.36$ ), and body mass index ( $P = 0.92$ ). In addition, the mean (SD) IQ level was 57.6 (3.08) and 57.06 (2.98) for the control and study groups, respectively. There was no statistically significant difference ( $P = 0.63$ ) in IQ level between both groups. The anthropometric details of the children in both groups are described in Table 2. These data indicated that both groups were homogeneous and had the same demographic characteristics.

### Balance (Stability Indices)

The pretest mean (SD) MLSI was 1.37 (0.15) and 1.38 (0.16) for the control and study groups, respectively, with no significant difference observed

**TABLE 2** Sample demographics

Demographic	Study ( $n = 15$ )		Control ( $n = 15$ )		$P$
	Mean	SD	Mean	SD	
Age, yrs	8.93	0.7	9.26	0.79	0.23
Weight, kg	29.2	3.4	29.53	3.22	0.78
Height, cm	118.	2.27	119.06	2.81	0.36
BMI, kg/cm <sup>2</sup>	20.	1.89	20.79	1.74	0.92
IQ	57.06	2.98	57.6	3.08	0.63
Sex, $n$ (%)					0.71
Female	7 (47)		6 (40)		
Male	8 (53)		9 (60)		

BMI, body mass index.

( $P = 0.91$ ). In addition, the pretest mean (SD) APSI was 1.14 (0.13) and 1.14 (0.12) for the control and study groups, respectively, with no significant difference observed ( $P = 0.76$ ). In addition, no significant difference was observed in OSI ( $P = 0.74$ ), with a pretest mean (SD) of 1.42 (0.09) and 1.4 (0.11) for the control and study groups, respectively.

Because higher scores in the stability indices indicate poor balance, the reduction in the pretest mean values represents balance improvement.

AQ13

A significant reduction was observed in the mean values in both groups when comparing their pretreatment and posttreatment measurements; the posttest mean (SD) values were 1.24 (0.09) and 1.09 (0.15) for the MLSI, 1.05 (0.08) and 0.92 (0.8) for the APSI, and 1.37 (0.12) and 1.19 (0.14) for the OSI, for the control and study groups, respectively ( $P < 0.05$ ).

After intervention, analysis between the groups revealed a statistically significant improvement in favor of the study group in terms of MLSI ( $P = 0.001$ ,  $d = 1.66$ ), APSI ( $P = 0.0001$ ,  $d = 1.62$ ), and OSI ( $P = 0.004$ ,  $d = 1.5$ ). Large ESs ( $d$ ) were obtained for all stability indices as  $d \geq 0.8$ .

13 The obtained results, as presented in Table 3, indicated that the children in the study group showed remarkable improvement when compared with the children in the control group.

### Muscle Strength

There was no significant difference in the pretreatment mean values of the knee flexors ( $P = 0.76$ ); the pretest mean (SD) was 13.92 (1.72) and 13.71 (2.06) for the control and study groups, respectively. Similarly, the pretest mean (SD) of the knee extensors was 13.94 (0.83) and 14.04 (1.31) for the control and study groups, respectively ( $P = 0.8$ ).

A significant increase was observed in the mean values in both groups when comparing their pretreatment and posttreatment measurements; the posttest mean (SD) of the knee flexors was 14.3 (1.66) and 15.65 (1.78) for the control and study groups, respectively. In addition, the posttest mean (SD) of the knee extensors was 14.76 (0.91) and 16.04 (1.6) for the control and study groups, respectively.

After the intervention, comparing the post-treatment mean values of the two groups revealed a statistically significant improvement in favor of the study group in terms of strength of the following muscle groups: knee flexors ( $P = 0.04$ ,  $d = 0.81$ ) and knee extensors ( $P = 0.01$ ,  $d = 0.8$ ). Large ESs ( $d$ ) were obtained for muscle strength of the knee flexors and extensors as  $d \geq 0.8$  (Table 3).

### DISCUSSION

The present study investigated the effect of WBV training on balance and muscle strength in children with DS. The main finding of this study is that, after 6 mos of WBV training combined with a physical therapy program, the children with DS were able to improve balance and muscle strength of the knee flexors and extensors compared with 6 mos of a physical therapy program alone.

The baseline measurements of the stability indices and muscle strength of the knee flexors and extensors showed that the children with DS in both groups had balance problems and muscular weakness. These results were consistent with the study of Rigoldi et al.,<sup>32</sup> who reported that children with DS had specific impairments in muscle strength and posture.

Significant improvement in both groups in the mean values of the stability indices and muscle

**TABLE 3** Stability indices and muscle strength of the knee flexors and extensors before and after treatment in the control and study groups

	Pretest				$P$	Posttest				$P^a$	Repeated Measures (Study)	Repeated Measures (Control)	ES "d"
	Study (n = 15)		Control (n = 15)			Study (n = 15)		Control (n = 15)					
	Mean	SD	Mean	SD		Mean	SD	Mean	SD				
Stability index													
Mediolateral	1.38	0.16	1.37	0.15	0.91	1.09	0.15	1.24	0.09	0.001	0.0001	0.02	1.66
Anteroposterior	1.14	0.12	1.14	0.13	0.76	0.92	0.8	1.05	0.08	0.0001	0.0001	0.001	1.62
Overall	1.4	0.11	1.42	0.09	0.74	1.19	0.14	1.37	0.12	0.004	0.0001	0.15	1.5
Muscle strength													
Knee flexors	13.71	2.06	13.92	1.72	0.76	15.65	1.78	14.3	1.66	0.04	0.0001	0.01	0.81
Knee extensors	14.04	1.31	13.94	0.83	0.8	16.04	1.6	14.76	0.91	0.01	0.0001	0.0001	0.80

$P$  indicates significance level between groups before treatment.

$^aP$  indicates significance level between groups after treatment.



strength of the knee flexors and extensors was reported. However, higher improvement was fulfilled by the children in the study group in all measuring variables.

In the control group, the improvement might be attributed to the effect of the physical therapy program, which consisted of balance and postural training exercises with static strengthening muscle contraction. These results were consistent with the study of Gupta et al.,<sup>8</sup> who studied the effects of resistance and balance exercises on strength and balance in children with DS. They reported improvement in strength and balance after a specific exercise program. These results are also consistent with the study of Ching and Wuang,<sup>23</sup> who found a significant improvement in lower extremity muscle strength and agility performance in adolescents with DS after a 6-wk exercise program; this improvement was high especially in the knee extensors and flexors.

The results of the study group revealed significant improvement in balance in children with DS after WBV training. These results come in agreement with those of Villarroja et al.,<sup>33</sup> who first studied the effect of a 20-wk WBV training program on static standing balance in adolescents (11–20 yrs) with and without DS under four conditions (C1, open eyes/fixed foot support; C2, closed eyes/fixed foot support; C3, open eyes/compliant foot support; and C4, closed eyes/compliant foot support). They found positive effects of WBV training on balance of adolescents with DS but only under specific conditions, when vision and somatosensory input were altered.

The effective mechanisms underlying the improvements in balance control after WBV training are hardly understood.<sup>34</sup> However, it is well documented that WBV training causes rapid vertical and horizontal displacements with particularly high levels of acceleration,<sup>35</sup> classified as perturbations.<sup>14</sup> These perturbations are known to be an appropriate training stimulus regarding balance control. After perturbation training, postural control was improved to a similar extent as in response to balance training.<sup>36</sup> Moreover, vibration-induced changes in joint stiffness, which are accompanied by an improvement in ankle and knee joint stabilization,<sup>37</sup> also might have contributed to the improvement in balance control.<sup>34</sup>

The vibratory load is dependent on four variables: frequency, amplitude, acceleration, and duration.<sup>38</sup> In the present study, WBV was applied with gradually increasing frequency and duration, aiming to gain accommodation of the child to the gradually increasing load to stimulate mechanoreceptors. Thus, improving balance in children with DS

could be attributed to its influence on joint proprioceptors because vibration has been identified as one of the strongest methods for stimulating proprioception.<sup>39</sup> These results come in agreement with those of Gusi et al.,<sup>40</sup> who reported balance improvement with WBV intervention in women with fibromyalgia, which may indicate a relatively quick and positive influence on the proprioceptive system.

Significant improvement in muscle strength of the knee flexors and extensors after WBV exposure was also observed, and this comes in agreement with the study of Gonzalez-Aguero et al.,<sup>30</sup> who examined the effects of a 20-wk WBV training in adolescents (12–18 yrs) with DS and reported that it might be helpful for improving body composition and lean muscle mass in the body. The results of the present study also come in agreement with those of Mahieu et al.,<sup>41</sup> who studied the effects of a 6-wk WBV training in young, healthy competitive skiers (9–15 yrs) and found greater improvement in the isokinetic strength of the ankle and the knee flexors as well as extensor peak torque.

WBV training stimulates the muscle spindles and alpha motor neurons, which initiates a muscle contraction, according to the tonic vibration reflex.<sup>42</sup> In the present study, the child was asked to perform voluntary muscle contraction of the lower limbs during vibration because the reflex muscle contraction has been suggested to increase the synchronization of the motor units when combined with a voluntary contraction.<sup>41</sup>

The gain in knee flexor and extensor muscle strength in the present study also comes in agreement with previous reports of Torvinen et al.,<sup>43</sup> who showed that WBV induces a tonic excitatory effect on the stimulated muscles; it has been shown to elicit a response called *tonic vibration reflex*. They reported that tonic vibration reflex involves the activation of muscle spindles, mediation of the neural signal by Ia afferents, and activation of muscle fibers through large alpha motor neurons. It may also enhance recruitment of motor units via activation of muscle spindles and polysynaptic pathways, the effect of temporary increase in muscle force.

The results of the present study come in agreement with those of Delecluse et al.,<sup>44</sup> who compared WBV training with resistance training in a placebo-controlled study in young healthy women and found that WBV training could increase muscle strength to the same extent as resistance training. Lee and Chon<sup>45</sup> also studied the effect of 8 wks of WBV on 30 children with cerebral palsy with a mean (SD) age of 10 (2.26) yrs. The experimental group received WBV training combined with conventional physical

AQ14

therapy training, and the control group received conventional physical therapy training for 3 days a week. They suggested that WBV may improve mobility, ambulatory function, and leg muscle thickness in these children.

The present study suggests that WBV training can be considered as a light-resistance exercise modality that may be easily performed indoors and can be used in conjunction with active and resisted exercises in improving muscle strength. These results were consistent with those of Figueroa et al.,<sup>46</sup> who reported that WBV training could significantly improve the dynamic strength of the lower limbs. They explained the physiologic mechanism involved in such effect that the addition of WBV to static and dynamic exercises increases oxygen uptake as well as improves arterial function and muscle strength. The increase in muscle strength after WBV training may be attributed to increased muscle blood flow as reported by Kersch-Schindl et al.,<sup>47</sup> who showed a significant increase in muscle blood volume in the calf and thigh muscles with a significant increase in mean blood flow velocity in the popliteal artery after WBV exercise on a vibrating plate (26 Hz, 3-mm amplitude).

It was thought that WBV causes rapidly repeating eccentric-concentric muscular work because enhancement of muscle strength can be attributed to postactivation potentiation, which is defined as an increase in the contractile ability of the muscles after a bout of contractions.<sup>48</sup> Wang and Chen<sup>49</sup> confirmed that muscle strength is an important variable that predicts dynamic balance, in which the musculature of the thighs, the legs, the feet, and the trunk allows the individual to stand erect against forces of gravity.

The present study has some clinical implications. First, the findings from this study suggest that, to achieve better balance performance and muscle strength in children and adolescents with DS, a combination program of WBV and conventional physical therapy might be more effective. Second, because children and adolescents with DS are at higher risk for chronic diseases that are worsened by obesity, muscle weakness, balance deficits, and decreased fitness, physical activity needs to be part of their lifestyle.

The present study also has some limitations. First, few studies are investigating the effects of WBV training in children with DS, with only two studies available. One of these studies is the study of Gonzalez-Aguero et al.,<sup>30</sup> who studied the effects of WBV training on body composition in adolescents with DS. The other study is the study of Villarroya et al.,<sup>33</sup> who studied the effects of a WBV training

program on static standing balance in adolescents with and without DS. Second, the underlying mechanisms of WBV are still ambiguous. Finally, the results could potentially differ if the various parameters of WBV exposure are different: frequency, amplitude, direction, and duration. Therefore, there is a potential for future studies to investigate these parameters either alone or in a combination.

## CONCLUSIONS

WBV training combined with proper physical therapy program could improve balance and muscle strength in children with DS.

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