Running title: Down Syndrome, Exercise, and Balance

Do exercise interventions improve balance for children and adolescents with Down syndrome? A systematic review. Physical Therapy

Christophe Maïano[1,2], Olivier Hue[3], Geneviève Lepage[2], Alexandre J. S. Morin[4], Danielle Tracey[5], Grégory Moullec[2,6,7]

[1] Cyberpsychology Laboratory, Department of Psychoeducation and Psychology, Université du Québec en Outaouais (UQO), Gatineau, Canada.
[2] Department of Psychoeducation and Psychology, Université du Québec en Outaouais (UQO), Saint-Jérôme, Canada.
[3] Department of Physical Activity Sciences, Université du Québec à Trois-Rivières, Trois-Rivières, Canada
[4] Substantive-Methodological Synergy Research Laboratory, Department of Psychology, Concordia University, Montreal, Canada.
[5] School of Education, Western Sydney University, Sydney, Australia
[6] School of Public Health, Department of Social and Preventive Medicine, Université de Montréal, Montréal, Canada
[7] Research Center, Centre intégré universitaire de santé et de services sociaux (CIUSSS) du Nord-de-l'Île-de-Montréal, Montréal, Canada

Acknowledgements: The preparation of this systematic review was supported by grants from the Social Sciences and Humanities Research Council of Canada (430-2012-0091, 435-2014-0909) awarded to the first, second, fourth and fifth authors, and from the Australian Research Council (DP140101559) awarded to the first, fourth and fifth authors.

Corresponding author: Christophe Maïano, Université du Québec en Outaouais, Campus de Saint-Jérôme, Département de Psychoéducation et de Psychologie, 5 rue Saint-Joseph, Saint-Jérôme, Québec, J7Z 0B7, email: christophe.maiano@uqo.ca

This is the prepublication version of the following manuscript:
Maïano, C., Hue, O., Lepage, G., Morin, A. J. S., Tracey, D., & Moullec, G. (Accepted: September 18, 2018). Do exercise interventions improve balance for children and adolescents with Down syndrome? A systematic review. *Physical Therapy.* Doi: 10.1093/ptj/pzz012

Abstract

Background. Youth with Down syndrome are characterized by deficits in balance/postural stability. One way to palliate balance deficits among this population is through exercise interventions. However, to our knowledge, the effects of exercise interventions designed to improve the balance of youth with Down syndrome have never been systematically reviewed.

Purpose. The purpose of the present article was to summarize the findings from studies examining the effects of exercise interventions designed to improve balance in youth with Down syndrome.

Data Sources. A systematic literature search was performed in 10 databases (Academic Search Complete, CINAHL Plus with Full-text, Education Source, ERIC, Medline with Full-text, PsycARTICLES, Psychology and Behavioral Sciences Collection, Scopus, SocINDEX, SPORTDiscus with Full-Text) on June 12th 2017.

Study Selection. Randomized controlled trials and controlled trials examining the effects of exercise interventions designed to improve balance in youth with Down syndrome were included.

Data Extraction. Two authors selected the studies and extracted their characteristics and results. Three authors assessed risk of bias in studies using the Cochrane collaboration's tool.

Data Synthesis. Eleven studies, published between 2010 and 2017, met our inclusion criteria. Findings show that exercise interventions are more effective than control conditions to improve the static balance of children with Down syndrome and static-dynamic balance of children and adolescents with Down syndrome. Nevertheless, findings on dynamic balance in children and static balance in adolescents are inconclusive.

Limitations. With a small number of studies and their high risk of bias, the present findings need to be interpreted with caution.

Conclusions. The reviewed exercise interventions were successful in improving the static balance of children with Down syndrome and static-dynamic balance of children-adolescents with Down syndrome.

Keywords. Down syndrome; intervention; physical activity; clinical tests; posturography; balance; postural control.

In the research literature, it is well-documented that, when compared to typically developing youth, youth with Down syndrome tend to be characterized by deficits in gross or fundamental motor skills[1,2], and in particular poor balance and postural control[3-7]. Balance or posture is the capability to sustain one's body or different body segments in equilibrium (in order to avoid a fall) and requires the integration of several sensory, motor, and biomechanical inputs. This capability can be examined in static (the body remains motionless) or dynamic (the body can react to perturbations or is in movement) conditions, as well as in both conditions[8]. In order to challenge the balance/postural control system in either static or dynamic conditions, youths' ability or strategies to maintain their body in a state of equilibrium is often assessed by disturbing the visual (eyes opened, eyes closed) and/or plantar cutaneous sensitiveness inputs (hard floor, foam floor), as well as the position of the leg and feet (i.e., one leg or double leg: feet apart, feet together, and semi- or full-tandem)[8]. According to Lauteslager, Vermeer, and Helders[9], the postural balance deficit displayed by youth with Down syndrome could be explained by disturbances in the regulation system of balance or postural control. Indeed, youth with Down syndrome tend to exhibit a reduced postural tone (hypotonia) that negatively affects muscular co-activation and balance reactions, and relates to deficits in proprioceptive feedback and to hypermobility or joint laxity[9].

Balance/postural control is fundamental to the ability to safely accomplish movements or motor tasks characterizing daily life[8]. As such, these postural and balance deficits represent a serious functional limitation for this population. Among youth with Down syndrome, these balance/postural deficits may even heighten motor delays or impairments[1,2,10], increase risks of body instability, falls and fall-related injuries[8], and lead to activity limitations or participation restriction. Therefore, the improvement of balance and postural control among youth with Down syndrome represents a key issue.

In youth with a typical development, exercise interventions represent an effective way to improve balance/postural control[11,12]. Such interventions involve activities soliciting the neuromuscular components of the balance/postural control necessary to maintain one's body's in equilibrium in response to external forces or unexpected stimulus or perturbations[13]. It can also take several forms, encompassing balance exercises (i.e., exercises soliciting balance/posture ability while disturbing visual, vestibular and/or somatosensory inputs), virtual reality exercises, computerized balance exercises, "well being" or three-dimensional physical activities (e.g., Tai Chi Chuan, Qigong, yoga), muscle strength activities, vibration platform exercises (i.e., whole-body vibration), domestic and/or general physical activities (e.g., walking, cycling, stair climbing), sport activities, as well as combinations of the above interventions[8,13]. The rationale behind the use of exercise interventions to improve balance/postural control is that these types of activities induce functional and structural adaptations of the balance/postural control system that will increase balance/postural performance and strategies[8]. For example, since lower-limb strength is related to the ability to maintain the balance of the whole body, exercise interventions focusing on ankle strength tend to result in improvements in the standing balance of participants when compared to control groups.[8]

To our knowledge, the effects of exercise interventions designed to improve the balance of children and adolescents with Down syndrome have never been systematically reviewed and summarized. However, such a synthesis is important to inform scholars, physical therapists, and adapted physical educators about evidence-based practices in order to support the design of effective programs aimed at improving balance and postural control among youth with Down syndrome. The purpose of the present article is to systematically review the effects of exercise interventions (controlled trial [CT] or randomized controlled trial [RCT]) specifically designed to improve balance and/or postural stability (i.e., static, dynamic, and/or static-dynamic) in children and adolescents with Down syndrome aged 5 to 22. The effects of these exercise interventions should be compared with control groups comprising youth with Down syndrome.

Method

Data Sources and Search

A systematic electronic search was conducted simultaneously in seven databases provided by EBSCO (Academic Search Complete, CINAHL Plus with Full-Text, Education Source, ERIC, Medline with Full-Text, Psychology and Behavioral Sciences Collection, and SocINDEX) and separately in

PsycARTICLES (including PsycINFO), Scopus, and SPORTDiscus with Full-Text. The electronic search was conducted on June 12th 2017, and no year restriction was imposed.

The identification of studies of interest was performed using four groups (Gr.) of search terms: (Gr. 1) "Down syndrome"; AND (Gr. 2) balance OR "postural control*" OR "postural sway" OR "postural stabili*" OR "postural instabilit*" OR "postural adaptation*" OR "postural performance*" OR "postural perturbation*" OR "postural strateg*" OR posture*; AND (Gr. 3) clinic* OR effect* OR enhanc* OR evaluation OR exercis* OR experiment* OR improv* OR intervention* OR "physical activit*" OR "physical therap*" OR physiotherap* OR pilot OR program* OR psychomot* OR random* OR rehabilitation OR sport* OR therap* OR trainin* OR treatment OR trial*; AND (Gr. 4) child* OR adolescen* OR student* OR youth*. These grouping combinations were researched in the title-abstract-keywords of the studies published by the journals indexed in the databases. Finally, the reference lists of the studies of interest were also examined to find additional relevant studies.

Study Selection

Types of studies. Only studies using a prospective randomized controlled trial (RCT) or a controlled trial (CT) design were included in this review. Case studies and non-original studies (e.g., reviews, theoretical papers) were excluded.

Type of participants. Participants had to exhibit Down syndrome and be of school age, which we defined as 5 to 22 years old. Therefore, samples with a lower (e.g., 2-4.9 years) or higher (> 22 years) age range were excluded. Additionally, studies of mixed-age samples (i.e., adolescents and adults) were considered to be eligible if the sample mean age was lower than 18 with an age range of 5-22 years old or if results were provided separately for participants younger than 22 years old.

Type of interventions. Interventions had to focus on exercise, and be specifically designed to improve balance in youth with Down syndrome. Therefore, studies using exercise interventions not designed to improve balance among youth with Down syndrome were excluded. Finally, these interventions could take place in any environment (i.e., school, home, community, institution, etc.) and their effects should be compared with control groups comprising youth with Down syndrome.

Type of outcomes. The studies had to report intervention effects on outcomes related to balance and/or postural stability (i.e., static, dynamic, and/or static-dynamic) assessed using either a clinical test or by posturography.

Type of publications. Only articles in-press or published in English in a peer-reviewed journal were considered to be relevant. Additionally, when the same sample was used in different publications, only one publication (the first) of an intervention study was included.

The eligibility of studies was assessed by the first two authors following the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Statement (PRISMA)[14]. First, the two authors independently assessed the titles and abstracts of the articles. Second, they independently assessed the full text of the studies retained in the previous step. Finally, their results were discussed to reach a consensus in cases of discrepancies.

Data Extraction and Risk of Bias Assessment

Data Extraction. As illustrated in Tables 1 to 4, the following categories of information were independently extracted by the first two authors for each of the included studies: (a) country and geographic region as defined by the World Health Organization (see http://www.who.int/about/regions/en/); (b) design; (c) recruitment setting; (d) sample age category; (e) intellectual disability level; (f) characteristics of the exercise intervention and control groups; (g) characteristics of the exercise intervention program; (h) description of the control condition; (i) characteristics of balance measures; and (j) within and between-group differences in balance measures.

Risk of Bias Assessment. The first two authors independently assessed the risk of bias in studies using the Cochrane collaboration's tool[15]. This six-item scale measures the following criteria[10]: (1) random sequence generation (selection bias); (2) allocation concealment (selection bias); (3) blinding of participants and personnel (performance bias); (4) blinding of outcome assessment (detection bias); (5) incomplete outcome data (attrition bias); and (6) selective reporting (attrition bias). Each item is graded using the following categories: "low risk of bias", "high risk of bias" and "unclear risk of bias". These

ratings were then reviewed by both authors and discrepancies were resolved by the last author.

Results

Selection of the Studies

As reported in Figure 1, 659 articles were identified, and this number fell to 353 when duplicates were removed. Analysis of titles and abstracts showed that 331 articles did not meet the inclusion criteria, leading to their exclusion. The full text of the 22 remaining articles was screened, leading to the exclusion of 11 publications (see the online supplement for the full references of these studies) that did not meet the inclusion criteria (see Figure 1 for reasons). A total of 11 studies[16-26], published between 2010 and 2017, met our inclusion criteria. Almost three quarters of these studies (8/11) focused on children with Down syndrome. The remaining ones (3/11) focused on adolescents with Down syndrome. These studies are described in Table 1.

Characteristics of the Reviewed Studies

Sample Characteristics and Design. As illustrated in Table 1, eight of the studies (73%) were conducted in the Eastern Mediterranean region, two in Europe and one in South-East Asia. Seven of these studies (64%) were RCT. A total of 281 youth with Down syndrome participated in these studies, including 189 children (M_{total} = 11.8, range = 8 to 16; 75% boys), and 92 adolescents (M_{total} = 15.3, range = 11 to 20; 60.6% boys). Children were mainly recruited in outpatient clinics and schools, whereas adolescents were mainly recruited in schools and institutions. Most studies (4/8 for children and 2/3 for adolescents) reported the intellectual disability level of the participants (Table 1).

Exercise Interventions and Control Condition. As shown in Table 2, studies of children with Down syndrome examined balance[18,21] (backward walking training, Hopscoth local game), computerized balance training using visual feedback[16] (Wii Fit balance game training), strengthening[17,20,22] (core stability exercises, isokinetic training), vibration platform[19] (whole body vibration), or combined[23] (Stretching, strength, and balance exercises) exercise interventions. Studies of adolescents assessed balance[25], vibration platform[26], or combined[24] exercise interventions (Table 3). Exercise interventions lasted between 6 and 24 weeks (M_{weeks} = 10.7, SD_{weeks} = 6). Additionally, only one study of children[15] relied on a follow-up period of 10 weeks. Finally, in studies of children and adolescents, training sessions were held two or three times per week (M_{times} = 2.7, SD_{times} = 0.5), and lasted between 20 and 90 minutes per session. Only two studies[19,26] described who delivered the intervention, and none mentioned the intervention setting, whether the intervention was adapted during trial, or whether strategies were used to ensure the conformity of the intervention. In half of the studies of children (4/8), the control group followed a conventional/designed physical therapy program, whereas in studies of adolescents, the control condition was only detailed in one study[24] (i.e., regular school activities).

Balance Measures. For children (Table 2), five out of the eight studies assessed dynamic balance, one assessed static balance, one assessed both static and dynamic balance, and one assessed static-dynamic balance. For adolescents (Table 3), out of the three studies, two assessed static balance, and one assessed static-dynamic balance.

Studies conducted among children and adolescents with Down syndrome assessed static balance using either posturography apparatus (pressure platform) or clinical tests such as the original or modified version of the Stork Test[27]. Those measuring dynamic balance used either a posturography apparatus (Biodex Balance System) or clinical balance tests, such as the Heel-to-Toe Dynamic Balance Test[28] and the Timed Up and Go Test[29]. Finally, studies examining static-dynamic balance used the balance subscale of the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP)[30].

In studies using posturography, estimates of balance were based on stability index scores (overall, anterior-posterior, and medio-lateral), the path length covered by the vertical projection of the center of gravity, the time spent by the vertical projection of the general center of gravity within a 13 mm radius circle, the velocity of the center of pressure, and the root-mean-square error of the center of pressure. For the clinical tests, estimates of balance were standing time, time taken to perform the test, number of steps, and a score obtained with the BOTMP.

Effects of Exercise Interventions

Children samples. The detailed results from the studies conducted among children are presented in Table 4. All of the studies showed that the exercise intervention groups have significant higher *post-test* static, dynamic and static-dynamic balance values than the control groups (Table 4). Additionally, findings showed that all of these studies reported a statistically significant improvement (from *pre* to *post* test) in static[22,23], dynamic[17,19-21,23], and static-dynamic[16] balance in the exercise intervention groups Finally, three of the eight studies reported a statistically significant improvement (from *pre* to *post* test) in dynamic balance for the control groups as well[17,19,20].

Adolescent Samples. As shown in Table 4, none of the RCT studies found or reported *post-test* differences in static balance[25,26] between groups, but one study reported that the intervention group reported a significantly higher *pre-post* change values in static-dynamic balance than the control group[24]. Additionally, findings showed that two of the studies focusing on adolescents reported a statistically significant improvement (from *pre* to *post* test) in static balance[25,26] in the exercise intervention groups. Finally, none of these studies reported a statistically significant improvement (from *pre* to *post* test) in static balance for the control groups[25,26].

Risk of Bias of the Reviewed Studies

Figure 2 presents the quality assessment of the reviewed studies. This systematic review indicates, for both types of samples (children and adolescent), a high risk of bias related to allocation concealment (selection bias), performance (blinding of participants and personnel) and detection bias (outcome assessment), with unclear risk of bias in random sequence generation, attrition (incomplete outcome data), and reporting bias.

Discussion

The purpose of the present article was to conduct a systematic review of the effects of exercise interventions specifically designed to improve balance in children and adolescents with Down syndrome. All of the reviewed studies focusing on children with Down syndrome showed that the *post*-effects of exercise interventions on static, dynamic and static-dynamic balance were significantly higher than control groups. Additionally, they showed, in contrast to control groups, that exercise interventions with a duration of 6-24 weeks significantly improved (from *pre* to *post* test) the static[22,23] and static-dynamic[16] balance of children with Down syndrome. Despite the exercise intervention groups[17-21,23] being effective in improving dynamic balance from *pre* to *post* test, similar effects were also observed for dynamic balance in the control groups[17,19,20].

None the reviewed studies[25,26] focusing on adolescents with Down syndrome showed or reported that the *post*-effects of exercise interventions on static balance were significantly different from those found with control conditions. Nevertheless, these studies showed, in contrast to control groups, that exercise interventions with a duration of 12-20 weeks significantly improved (from *pre* to *post* test) the static[25,26] balance of adolescents with Down syndrome. Finally, one study reported that *pre-post* change values in static-dynamic balance were significantly higher in the exercise intervention group than in the control group.

From a clinical point of view, both clinical and posturographic tests showed a significant and positive effect of exercise interventions on the balance/posture of youth with Down syndrome. However, only a few studies measured balance/posture changes when visual[16,24-26] and/or plantar cutaneous sensitiveness[26] inputs were disturbed. This represents a gap in research as it is well known that variations of sensory information impact balance/posture capability as the brain must adjust and rearrange the inputs sent by other sources of sensory information.[31] For example, the foam surface disturbs balance/postural control by producing a balance perturbation in multiple directions.[32,33]. When used in a static balance condition, it modifies the biomechanics of the foot, which results in a change in the distribution of the plantar pressure and an augmentation of the ankle muscles' activation linked to the location of the foot's center of pressure[32,34-36]. However, the maturation of the cortical and central processes involved in balance/postural control takes place during childhood. Consequently, the balance/postural control does not reach adult levels until the age of 13-14 years[37]. Similarly, vision plays a predominant role in adolescents' control of orientation and body stabilization. Youth use different balance/postural strategies and are not capable of

reaching postural performance levels comparable to those observed in adults[38]. The explanation is that youth are not yet able to use the available plantar cutaneous sensitiveness information to improve their balance/postural control due to a maturation difference compared to adults. This suggests that the mechanisms underlying balance/postural control are still maturing during adolescence, which might constitute a transient period for pondering and adequately using the proprioceptive inputs in sensory integration of balance control[39]. The observed findings suggest that, after exercise interventions, children and adolescents with Down syndrome were better able to compensate for the insufficiency of visual or plantar cutaneous sensitiveness inputs in balance/postural control. This is a key point since it has been proposed that the proprioception of youth with Down syndrome does not adequately compensate for the lack of visual information in static postural control when compared to typically developing youth, suggesting that there is an important sensorial component in maintaining balance/postural stability[6,40]. Indeed, it is well known that when vision is removed during the maintenance of a normal quiet stance, a sensorial reweighting occurs and somatosensory inputs (proprioception) are tuned up in order to compensate and maintain balance/postural stability[41,42]. Finally, the results of one study[26] also suggest that both the tactile sensitivity and ability to detect plantar pressure distributions can improve for youth with Down syndrome after exercise interventions.

Additionally, even though different types of exercise interventions (i.e., balance, strengthening, vibration platform, or multiple components) and types of balance of measures (clinical test or posturography) were used in these studies, the results appear to hold irrespective of these differences. The findings suggest that, because of the exercise intervention, children and adolescents with Down syndrome experienced an increase in their ability to maintain balance/postural stability under different balance/postural stances challenging their balance/postural control. Interestingly, the results also suggest that a control condition consisting of a conventional physical therapy program also represents an effective means to improve dynamic balance among children with Down syndrome[17,19,20]. These results are consistent with the research literature related to the effects of different types of exercise, physical and sport interventions on the balance/postural function[8]. It has been reported that, compared to other types of exercise, specific balance exercise interventions induce balance/postural adaptations because they are directly related to the neurophysiological organization of balance/postural control[8,43,44]. Strength exercises and techniques that stimulate the neuromuscular system (whole-body vibration training) also improve balance since lower limbs muscles are involved in balance/postural control, with the ankle level explicitly related to the inverted pendulum regulation[8,45,46]. Finally, multicomponent exercises seem to be efficient to improve balance/posture, especially if specific balance exercises are included in the multicomponent training program[8,47].

Directions for Future Studies to Inform Exercise Intervention

Although encouraging, the conclusions from this systematic review should be interpreted with caution given the following limitations.

First, the effects of the exercise interventions on the static and static-dynamic balance of children with Down syndrome were examined in a very limited number of studies. Likewise, only a few studies considered the effects of exercise interventions on any form of balance among adolescents with Down syndrome. In addition, most of the studies assessed balance capacities while adopting a double leg stance with opened eyes. Therefore, it is currently unclear whether the exercise interventions are truly effective at improving (a) the static or static-dynamic balance of children with Down syndrome; (b) the balance of adolescents with Down syndrome; and (c) balance while standing on one leg or when visual cues or plantar cutaneous sensitivity are disturbed.

Second, each study included only one type of exercise intervention. Therefore, the type of exercise intervention that is most effective at improving balance among youth with Down syndrome remains unknown. This issue should be examined more thoroughly in future studies aiming to compare distinct intervention programs so that educators can make informed decisions to expend their limited resources on the most effective types of exercise intervention.

Third, the duration of the exercise interventions was generally short (two-thirds of the studies were of 6 or 8 weeks), and may not have been long enough to induce balance changes in youth with Down

syndrome. Therefore, more research is warranted to clarify the required duration. Furthermore, no study has examined the impact of the frequency and duration of the exercise sessions to identify the most effective combination for the improvement of balance among youth with Down syndrome. Evidence regarding the maintenance of the balance training effects also remains unclear and needs to be more thoroughly examined in future studies.

Fourth, most of the reviewed studies did not report sufficient information about the nature of the exercise interventions, such as their settings, the facilitator (i.e., person who delivers the intervention), the adaptation of the intervention during trial, and the strategies used to maintain intervention conformity. Thus, it is presently impossible to conclude which configurations of exercise intervention characteristics and contextual features are fundamental for successful outcomes. Furthermore, without the publication of such information, educators and therapists are unable to implement the evidence-base into best practice.

Fifth, most of the RCTs suffered from major weaknesses in concealed allocation; blinding of participants, investigators, and assessors; and compliance with assigned intervention. Therefore, future studies examining the effects of exercise interventions on the balance of youth with Down syndrome should improve the quality of their methodology and reporting regarding these specific criteria if the research field is to improve practice, and thus outcomes, for this population.

Sixth, despite the fact that most of the reviewed studies relied on RCT, the total number of studies was limited, which diminish the strength of our conclusions. Furthermore, the fact that most of these studies were conducted in the Eastern Mediterranean region limit the generalizability of our findings to other geographic regions.

Finally, further rigorous studies are required to generate a more complete view on the topic. In particular, the present review remains limited by its focus on a small number of studies characterized by a generally high risk of bias, notably the presence of selective reporting bias (for instance, only one study[24] has provided analyses about the *pre-post* change in balance). As such, the true magnitude and generalizability of the effects of these exercise interventions remain unclear, despite being promising. With additional studies having less risk of bias, and larger samples it will be interesting to update this review and to perform quantitative analyses of effect sizes controlling for risk of biases.

Conclusion

In sum, the present results show that the reviewed exercise interventions are more effective than control conditions to improve static and static-dynamic balance of children with Down syndrome. Additionally, findings among adolescents with Down syndrome suggest that exercise interventions are more effective than control conditions to improve static-dynamic balance. Nevertheless, findings on dynamic balance in children and static balance in adolescents are inconclusive. Given the limited number of studies, and their high risk of bias, the present findings need to be interpreted with caution. Therefore, the effect of exercise interventions on balance outcomes needs to be more rigorously and systematically examined in the future. Finally, our review highlights that more detailed exercise interventions and reporting practices are needed to support professionals in the selection, development, and implementation of interventions to enhance the physical health of youth with Down syndrome.

References

1. Block ME. Motor development in children with Down syndrome: A review of the literature. *Adapt Phys Activ Q.* 1991;8:179-209.

2. Henderson SE. Motor skill development. In: Lane D, Stratford B, editors. Current approaches to Down syndrome. London, United Kingdom: Holt, Rinehart & Winston, 1985;187-218.

3. Capio CM, Mak TCT, Tse MA, Masters RSW. Fundamental movement skills and balance of children with Down syndrome. J Intellect Disabil Res 2018;62(3): 225-236.

4. Guzman-Muñoz EE, Gutierrez-Navarro LB, Miranda-Diaz SE. Postural control in children, adolescents and adults with Down syndrome. *Int Med Rev Down Syndrome* 2017;21:12–6.

5. Rigoldi C, Galli M, Mainardi L, Crivellini M, Albertini G. Postural control in children, teenagers and adults with Down syndrome. *Res Dev Disabil* 2011;32:170–175.

6. Villarroya MA, González-Agüero A, Moros-García T, et al. Static standing balance in adolescents with Down syndrome. *Res Dev Disabil* 2012;33:1294–300.

7. Wang HY, Long IM, Liu MF. Relationships between task-oriented postural control and motor ability in children and adolescents with Down syndrome. *Res Dev Disabil* 2012;33:1792–8.
8. Paillard T. Plasticity of the postural function to sport and/or motor experience. Neurosci Biobehav Rev 2017;72:129-152.
9. Lauteslager PEM, Vermeer A, Helders PJM. Disturbances in the motor behaviour of children with Down's syndrome: The need for a theoretical framework. *Physiother.* 1998;84:5-13.
10. Henderson SE. Some aspects of the development of motor control in Down's syndrome. In: Whiting HTA, Wade MG, editors. Themes in motor development. Dordrecht, Netherlands: Martinus Nijhoff, 1986 ;69-92.
11. Wälchli M, Ruffieux J, Mouthon A, Keller M, Taube W. Is Young Age a Limiting Factor When Training Balance? Effects of child-oriented balance training in children and adolescents. *Pediatr Exerc Sci.* 2018; 30(1):176-184.
12. Ozmen T, Aydogmus M. Effect of core strength training on dynamic balance and agility in adolescent badminton players. *J Body Mov Ther.* 2016 ;20(3):565-70.
13. Howe TE, Rochester L, Neil F, Skelton DA, Ballinger C. Exercise for improving balance in older people. *Cochrane Database Syst Rev* 2011; 11: CD004963.
14. Liberati A, Altman DG, Tetzlaff J et al. The PRISMA statement for reporting systematic reviews and meta-analysis of studies that evaluate health care interventions: explanation and elaboration. *PLoS Med.* 2009;6:1-6.
15. Higgins, Julian PT, et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ* 2011;343:d5928.
16. Abdel Rahman S. Efficacy of virtual reality-based therapy on balance in children with Down syndrome. *World Appl Sci J.* 2010;10:254-261.
17. Aly SM, Abonour AA. Effect of core stability exercise on postural stability in children with Down syndrome. *Health Sci.* 2016;5:213-222.
18. Amini HA, Fazel Kalkhoran J, Salehi M, Jazini F. Effect of backward walking training on improves postural stability in children with Down syndrome. *Int J Pediatr.* 2016;4:2171-2181.
19. Eid MA. Effect of whole-body vibration training on standing balance and muscle strength in children with Down syndrome. *Am J Phys Med Rehabil.* 2015;94:633-643.
20. Eid MA, Aly SM, Huneif MA, Ismail DK. Effect of isokinetic training on muscle strength and postural balance in children with Down's syndrome. *Int J Rehabil Res.* 2017;40:127-133.
21. Fard AN, Tabar HMA, Sheikh M. Effect of a selected local game on dynamic balance of educable students with Down syndrome. *Int J Sport Studies.* 2015;5:1143-1148.
22. Ghaeeni S, Bahari Z, Khazaei AA. Effect of core stability training on static balance of the children with Down syndrome. *Physical Treatments.* 2015;5:49-54.
23. Mehralitabar H, Sheikh M, Hemayat-Talab R. Effect of a selective physical training on balance of children with Down syndrome. *Int J Sport Studies.* 2016;6:147-151.
24. Gupta S, Rao BK, Kumaran SD. Effect of strength and balance training in children with Down's syndrome: A randomized controlled trial. *Clin Rehabil.* 2011;25:425-432.
25. Jankowicz-Szymanska A, Mikolajczyk E, Wojtanowski WThe effect of physical training on static balance in young people with intellectual disability. *Res Dev Disabil.* 2012;33:675-681.
26. Villarroya MA, González-Agüero A, Moros T, Gómez-Trullén E, Casajús JA. Effects of whole body vibration training on balance in adolescents with and without Down syndrome. *Res Dev Disabil.* 2013;34:3057-3065.
27. Peltenburg AL, Erich WBM, Bernink MJE, Huisveid IA. Selection of talented female gymnasts, aged 8 to 11, on the basis of motor abilities with special reference to balance: A retrospective study. *Int J Sports Med.* 1982;3:37-42.
28. Henderson SE, Sugden DA, Barnett AL. Movement assessment battery for children-2. London, United Kingdom: Harcourt Assessment. 2007.
29. Podsiadlo D, Richardson S. The timed "Up & Go": A test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc.* 1991;39:142-148.

30. Bruininks RH. Bruininks Oseretsky Test of Motor Proficiency. American Guidance Service, Circle pines-Minnesota. 1978.
31. Teasdale N, Stelmach GE, Breunig A. Postural sway characteristics of the elderly under normal and altered visual and support surface conditions. *J Gerontol.* 1991;46:B238-B244.
32. Paillard T, Noé F. Techniques and methods for testing the postural function in healthy and pathological subjects. *Biomed Res Int.* 2015;Article ID 891390.
33. Patel M, Fransson PA, Lush D, Petersen H, Magnusson M, Johansson R, Gomez S. The effects of foam surface properties on standing body movement. *Acta Otolaryngol.* 2008;128:952-960.
34. Chiang JH, Wu G. The influence of foam surfaces on biomechanical variables contributing to postural control. *Gait Posture.* 1997;5:239-245
35. Winter DA. Human balance and posture control during standing and walking. *Gait Posture.* 1995;3:193-214.
36. Wu G, Chiang JH. The effects of surface compliance on foot pressure in stance. *Gait Posture.* 1996;4:122-129.
37. Barozzi S, Socci M, Soi D, et al. Reliability of postural control measures in children and young adolescents. *Eur Arch Otorhinolaryngol* 2014; 271: 2069–77.
38. Vaugoyeau M, Viel S, Amblard B, Azulay JP, Assaiante C. Proprioceptive contribution of postural control as assessed from very slow oscillations of the support in healthy humans. *Gait Posture* 2008; 27: 294–302.
39. Viel S, Vaugoyeau M, Assaiante C. Adolescence: A transient period of proprioceptive neglect in sensory integration of postural control. *Motor Control* 2009; 13: 25–42.
40. Vuillerme L, Marin L, Debu B. Assessment of static postural control in teenagers with Down syndrome. *Adap Phys Act Q.* 2001;18:417-433.
41. Peterka RJ. Sensorimotor integration in human postural control. *J Neurophysiol.* 2002;88:1097-118.
42. Teasdale N, Simoneau M. Attentional demands for postural control: the effects of aging and sensory reintegration. *Gait Posture.* 2001;14:203-210.
43. DiStefano LJ, Clark MA, Padua DA. Evidence supporting balance training in healthy individuals: A systemic review. *J Strength Cond Res.* 2009;23:2718-2731.
44. Lesinski M, Hortobágyi T, Muehlbauer T, Gollhofer A, Granacher U. Effects of balance training on balance performance in healthy older adults: A systematic review and meta-analysis. *Sports Med.* 2015;45:1721-1738.
45. Fort A, Romero D, Bagur C, Guerra M. Effects of whole-body vibration training on explosive strength and postural control in young female athletes. *J Strength Cond Res.* 2012;26:926-936.
46. Behm DG, Muehlbauer T, Kibele A, Granacher U. Effects of strength training using unstable surfaces on strength, power and balance performance across the lifespan: A systematic review and meta-analysis. *Sports Med.* 2015;45:1645-1669.
47. Burke TN, Franca FJ, Meneses SR, Pereira RM, Marques AP. Postural control in elderly women with osteoporosis: comparison of balance, strengthening and stretching exercises. A randomized controlled trial. *Clin Rehabil.* 2012;26:1021-1031.

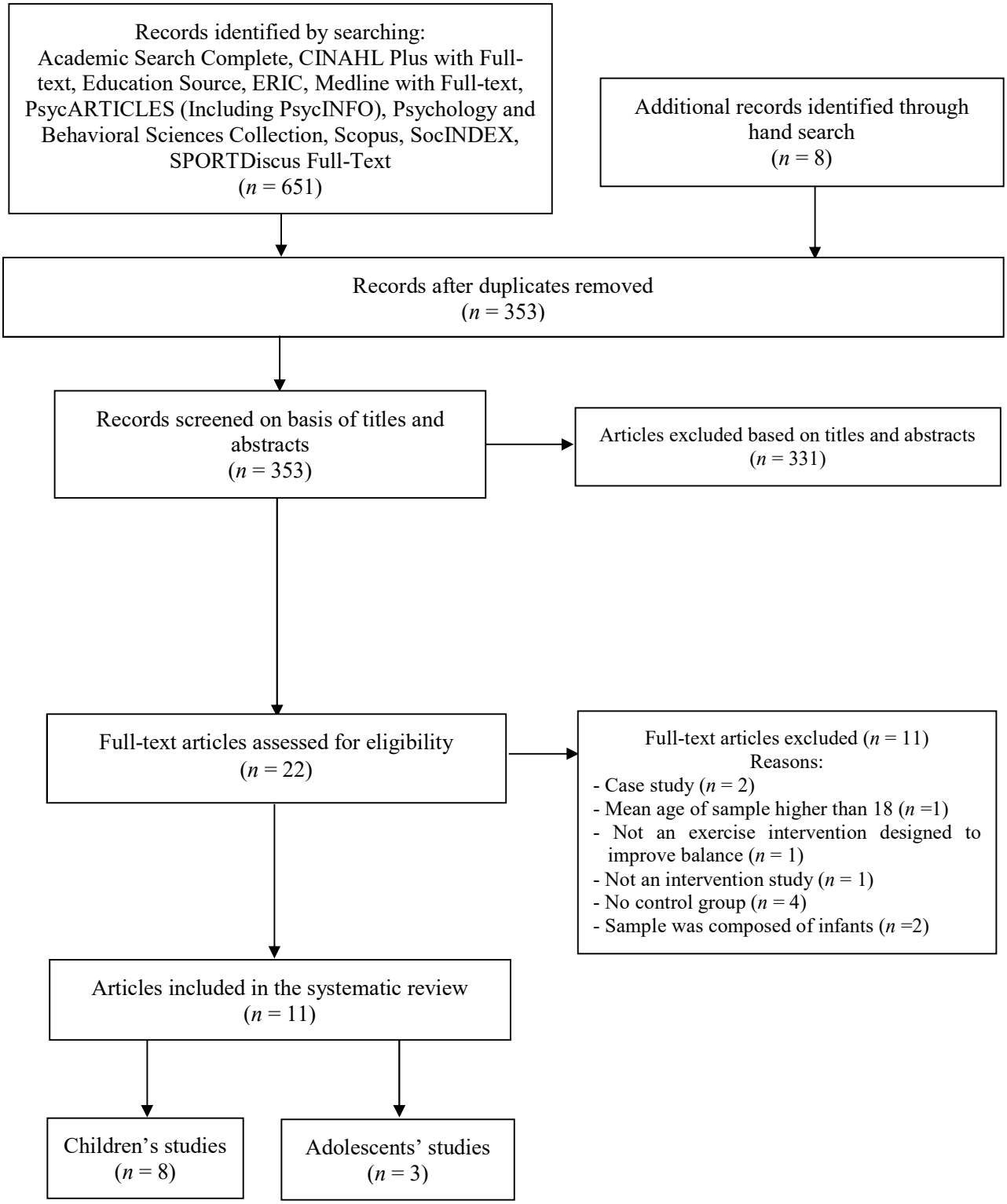

Figure 1. Results of Search Based on the PRISMA Statement.[14]

Studies	Samples	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Masking of participants and personnel (performance bias)	Masking of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)
Abdel Rahman[16]	CHILD	-	-	-	-	?	?
Aly & Abonour[17]	CHILD	+	-	-	-	?	?
Amini et al.[18]	CHILD	-	-	-	-	?	?
Eid[19]	CHILD	+	+	-	+	+	?
Eid et al.[20]	CHILD	+	+	-	+	+	?
Fard et al.[21]	CHILD	-	-	-	-	?	?
Ghaeeni et al.[22]	CHILD	?	-	-	-	?	?
Mehralitabar et al.[23]	CHILD	?	-	-	-	?	?
Gupta et al.[24]	ADOS	+	+	-	-	+	?
Jankowicz-Szymanska et al.[25]	ADOS	?	-	-	-	?	?
Villarroya et al.[26]	ADOS	?	-	-	-	?	?

Note. CHILD = children; ADOS = adolescents + Low risk of bias - High risk of bias ? Unclear risk of bias

Figure 2. Quality Assessment of the Reviewed Studies

Table 1

Characteristics of Children's and Adolescents' Studies Included in the Systematic Review

Study	Country	Design	Recruitment setting	Sample age category	ID level	Intervention group				Control group			
						Sample size (*N*)	% of boys	Age range	Mean age	Sample size (*N*)	% of boys	Age range	Mean age
Abdel Rahman[16]	Egypt	CT	DS charitable association	CHILD	Mild-Mod	15	40	10-12	10.9	15	47	11-13	11.6
Aly & Abonour[17]	Egypt	RCT	Outpatient clinic	CHILD	NM	15	73	6-10	8.1	15	67	6-10	8.3
Amini et al.[18]	Iran	CT	Special school	CHILD	Mild	8	100	8-10	8.6	8	100	8-10	8.9
Eid[19]	Egypt	RCT	Outpatient clinic	CHILD	NM	15	53	8-10	8.9	15	60	8-10	9.3
Eid et al.[20]	Saudi Arabia	RCT	Outpatient clinic	CHILD	Mild	15	53	9-12	10.3	16	56	9-12	10.1
Fard et al.[21]	Iran	CT	Special school	CHILD	NM	8	100	NM	9.4	8	100	NM	9.5
Ghaeeni et al.[22]	Iran	RCT	Rehabilitation center	CHILD	NM	8	NM	8-13	9.6	8	NM	8-13	9.9
Mehralitabar et al.[23]	Iran	CT	Exceptional child care center	CHILD	Mild-Sev	10	100	7-10	NM	10	100	7-10	NM
Gupta et al[24]	India	RCT	Schools	ADOS	Mild-Mod	12	67	11-14	13.5	11	55	10-14	13
Jankowicz-Szymanska et al.[25]	Poland	RCT	Special education and care center	ADOS	Mild	20	NM	16-18	NM	20	NM	16-18	NM
Villaroya et al.[26]	Spain	RCT	Schools and institutions	ADOS	NM	16	NM	11-20	15.9	13	NM	11-20	15.6

Note. ADOS = adolescents; CT = controlled trial; CHILD = children; DS = Down syndrome; ID = intellectual disability; Mod = moderate; NM = not mentioned; RCT = randomized control trial; Sev = severe.

Table 2

Description of Intervention Program, Control Condition, and Balance Measures in Children's Studies

Study	Intervention program						Types of control condition	Balance measures		
	Types	Setting (delivery)	Adaptation (fidelity)	Total duration	Follow-up	Session duration in minutes (frequency per weeks)		Types	Assessment method	Parameters
Abdel Rahman[16]	Wii Fit balance game training	NM(NM)	NM(NM)	6 weeks	-	60(2)	Conventional physical therapy program	Static balance (OLS: EC-EO), dynamic balance	BOTMP (balance subtest)	Static-dynamic balance score
Aly & Abonour[17]	Core stability exercises	NM(NM)	NM(NM)	8 weeks	-	45-60(3)	Conventional physical therapy program	Dynamic balance (DLS: EO)	Biodex Balance System	Overall, A-P, and M-L stability index scores
Amini et al.[18]	Backward walking training	NM(NM)	NM(NM)	8 weeks	10 weeks	35(2)	No participation in regular physical activities	Dynamic balance (DLS: EO)	Biodex Balance System	Overall, A-P, and M-L stability index scores
Eid[19]	Physical therapy + whole-body vibration	NM(PHT)	NM(NM)	24 weeks	-	80-90(3)	Designed physical therapy program	Dynamic balance (DLS: EO)	Biodex Balance System	Overall, A-P, and M-L stability index scores
Eid et al.[20]	Physical therapy + isokinetic training	NM(NM)	NM(NM)	12 weeks	-	60(3)	Conventional physical therapy program	Dynamic balance (DLS: EO)	Biodex Balance System	Overall, A-P, and M-L stability index scores
Fard et al.[21]	Hopscoth local game	NM(NM)	NM(NM)	8 weeks	-	50(3)	Engaged in normal activities	Dynamic balance	Heel-to-Toe Dynamic Balance Test	Number of steps
Ghaeeni et al.[22]	Core stability exercises	NM(NM)	NM(NM)	8 weeks	-	45-60(3)	NM	Static balance (OLS: EO)	Modified Stork Test	STAND-T (in sec)
Mehralitabar et al.[23]	Stretching, strength, and balance exercises	NM(NM)	NM(NM)	6 weeks	-	45(3)	Usual daily activities	Static balance (OLS: EO), dynamic balance	Stork Test, Timed Get Up and Go Test	STAND-T (in sec), time taken to perform the test (in sec)

Note. A-P = anterior-posterior; BOTMP = Bruininks-Oseretsky Test of Motor Proficiency; DLS = double leg stance; EC = eyes closed; EO = eyes open; M-L = medio-lateral; NM = not mentioned; OLS = one leg stance; PHT = physical therapist; STAND-T = stand time.

Table 3

Description of Intervention Program, Control Condition, and Balance Measures in Adolescents' Studies

Study	Intervention program						Types of control condition	Balance measures		
	Types	Setting (delivery)	Adaptation (fidelity)	Total duration	Follow-up	Session duration in minutes (frequency per weeks)		Types	Assessment method	Parameters
Gupta et al.[24]	Strength and balance exercises	NM(NM)	NM(NM)	6 weeks	-	NM(3)	Regular school activities	Static balance (OLS: EC-EO), dynamic balance	BOTMP (balance subtest)	Static-dynamic balance score[a]
Jankowicz-Szymanska et al.[25]	Training program targeting balance capacities	NM(NM)	NM(NM)	12 weeks	-	45(2)	NM	Static balance (OLS: EC-EO)	Pressure platform	PATH-L (OLS, EO-EC; in mm), COG-radius circle (in percentage of time)
Villaroya et al.[26]	Whole-body vibration	NM(RES)	NM(NM)	20 weeks	-	20-30(3)	NM	Static balance (DLS: EO-EC, CFS-FFS)	Pressure platform	COP-RMS (M-L and A-P in mm, EO-EC, FFS-CFS), COP-velocity (in mm, EO-EC, FFS-CFS)

Note. A-P = anterior-posterior; BOTMP = Bruininks-Oseretsky Test of Motor Proficiency; CFS = compliant-foot-support; COG = general center of gravity ; COG-radius circle = time spent by the vertical projection of the general center of gravity within a 13-mm radius circle; COP = center of pressure; COP-RMS = root mean square error of the center of pressure excursion; COP-velocity = mean velocity of the center of pressure; DLS = double leg stance; EC = eyes closed; EO = eyes open; FFS = fixed-foot-support; M-L = medio-lateral; NM = not mentioned; OLS = one leg stance; PATH-L = path length covered by the vertical projection of the COG; RES = researcher; [a] Only the total was considered for the present review.

Table 4

Results from the Children's and Adolescents' Studies

Study	Sample age category	IG (pre- vs. post-test)	CG (pre- vs. post-test)	IG vs. CG (post-test)	IG vs. CG (pre-post change)
Abdel Rahman[16]	CHILD	⬀	NS	IG > CG	NM
Aly & Abonour[17]	CHILD	⬀ (all)	⬀ (all)	IG > CG (all)	NM
Amini et al.[18]	CHILD	NM	NM	IG > CG (all)	NM
Eid[19]	CHILD	⬀ (all)	⬀ only for A-P and M-L stability index scores	IG > CG (all)	NM
Eid et al.[20]	CHILD	⬀ (all)	⬀ (all)	IG > CG (all)	NM
Fard et al.[21]	CHILD	⬀	NM	IG > CG	NM
Ghaeeni et al.[22]	CHILD	⬀	NS	IG > CG	NM
Mehralitabar et al.[23]	CHILD	⬀ (all)	NS (all)	IG > CG (all)	NM
Gupta et al.[24]	ADOS	NM	NM	NM	IG > CG
Jankowicz-Szymanska et al.[25]	ADOS	⬀ only for COG-radius circle in EC	NS (all)	NS (all)	NM
Villaroya et al. [26]	ADOS	⬀ only for COP-RMS (M-L, EC, CFS) and COP-velocity (EC, CFS; ratio EC-CFS/EO-FFS)	NS (all)	NM	NM

Note. ADOS = adolescents; A-P = anterior-posterior; CFS = compliant-foot-support; CG = control group; CHILD = children; COG-radius circle = time spent by the vertical projection of the general center of gravity within a 13-mm radius circle; COP-RMS = root mean square error of the center of pressure excursion; COP-velocity = mean velocity of the center of pressure; EC = eyes closed; EO = eyes open; FFS = fixed-foot-support; IG = intervention group; M-L = medio-lateral; NM = not mentioned; NS = non-significant; ⬀ improvement.

Online Supplemental Materials for:

Effects of Exercise Interventions Designed to Improve Balance for Children and Adolescents with Down Syndrome: A Systematic Review

References of Full-Text Articles Assessed for Eligibility but Excluded from the Systematic Review

Abdel-Rahman, S., & Shaheen, A. A. M. (2010). Efficacy of weight bearing exercises on balance in children with Down syndrome. *Egyptian Journal of Neurology, Psychiatry and Neurosurgery*, *47*, 37-46.

Barreto, F., Gomes, G., da Silva, I. S., & Gomes, A. M. (2007). Proposal of a multidisciplinary program for an individual with down syndrome, through activities of riding therapy, from the principles of human motricity. *Fitness & Performance Journal*, *6*, 82-88.

Berg, P., Becker, T., Martian, A., Danielle, P. K., & Wingen, J. (2012). Motor control outcomes following Nintendo Wii use by a child with Down syndrome. *Pediatric Physical Therapy*, *24*, 78-84.

Drzewowska, I., Sobera, M., & Sikora, A. (2013). Posture control after 5 months body balance training in Down syndrom children and youth. *Physiotherapy / Fizjoterapia*, *21*, 3-15.

El-Meniawy, G. H., Kamal, H. M., & Elshemy, S. A. (2012). Role of treadmill training versus suspension therapy on balance in children with Down syndrome. *Egyptian Journal of Medical Human Genetics*, *13*, 37-43.

Hovorka, R. M., & Virji-Babul, N. (2006). A preliminary investigation into the efficacy of virtual reality as a tool for rehabilitation for children with Down syndrome. *International Journal on Disability and Human Development*, *5*, 351-356.

Mirela, D., Cristian, P., & Corina, P. (2015). Bosu exercises for improvement of balance to

children with down syndrom. *Gymnasium: Scientific Journal of Education, Sports & Health*, *16*, 151-166.

Nejadsahebi, N., Sadeghi, H., & Nabavi, S. M. (2013). Effect and sustainability of 8-weeks rebound therapy exercise on dynamic and static balance of high school male students affected by down syndrome. *Advances in Environmental Biology*, *7*, 4294-4299.

Park, T. J. (2014). The effects of wobble board training on the eyes open and closed static balance ability of adolescents with down syndrome. *Journal of Physical Therapy Science*, *26*, 625-627.

Satiansukpong, N., Pongsaksri, M., & Sasat, D. (2015). Thai elephant-assisted therapy programme in children with down syndrome. *Occupational Therapy International*, *23*, 121–131.

Wang, W. Y., & Ju, Y. H. (2002). Promoting balance and jumping skills in children with Down syndrome. *Perceptual and Motor Skills*, *94*, 443-448.