THE EFFECT OF MUSCULAR STRENGTH ON BALANCE IN INDIVIDUALS WITH INTELLECTUAL DISABILITIES AND DOWN SYNDROME

by

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ABSTRACT

Objective: To review the current status of research on the role of lower limb strength in postural control in people with intellectual disabilities, specifically Down syndrome.

Data Sources: All articles were published from 2000 to 2021 and retrieved through the electronic databases PubMed and SportDISCUS using keywords "lower limb strength," "postural control," "balance," "Down syndrome," "intellectual disability," and/or "disability."

Study Selection: Studies selected for review were peer reviewed and included and used lower limb strength as the independent variable and balance as the dependent variable. Of the initial 142 articles retrieved, 11 met the criteria for this study.

Data Extraction: Pre- and post-intervention studies and treatment and control studies were used. Their means and standard deviations were extracted to compute effect sizes using a Cohen's D effect size calculator.

Data Synthesis: Of 11 articles, four were found to have a positive effect (> 0.8). Four other articles were found to have a negative effect (< -0.8). The remaining three articles were found to have little to no effect (-0.8 - 0.8).

Conclusions: This systematic review and meta-analysis demonstrated some significant effects of strength or strength training on balance. The measures with a positive effect were strength measures that included the entire lower limb working as a unit.

The effect of muscular strength on balance in individuals with intellectual disabilities and Down syndrome

Down syndrome (also known as Trisomy 21) is one of the most common genetic causes of intellectual disability worldwide (National Down Syndrome Society, 2008). The World Health Organization (WHO) estimates the worldwide incidence to be 1 out of every 600 – 1000 live births (NDSS, 2008). In the United States there are nearly 5400 children born with Down syndrome each year. Most instances (94%) of Down syndrome are caused by a trisomy of the 21st chromosome. This genetic overexpression contributes to the unique Down syndrome phenotype. The Down syndrome phenotype includes distinct facial features, short stature and intellectual impairments (Hayes & Batshaw, 1993). In addition to intellectual impairments, individuals with Down syndrome also experience motor delays. These motor delays result from various neurological, musculoskeletal, and sensorimotor impairments (Angelopoulou, Tsimaras, Christoulas, Kokaridas, & Mandroukas, 1999; Carmeli, Ayalon, Barchad, Sheklow, & Reznick, 2002; Cioni, Cocilovo, Di Pasquale, Araujo, Siqueira, and Bianco, 1994; Connolly & Michael, 1986; Connolly, Morgan, & Russell, 1984; Cowie, 1970; Duger, Bumin, Uyanik, Aki, & Kayihan, 1999; Hayes & Batshaw, 1993; Jobling & Mon- Williams, 2000; Selikowitz, 1997). More specifically individuals with Down syndrome have ligamentous laxity, decreased strength, hypotonia, & excessive hip abduction, and external rotation. This combination helps explain why many individuals with Down syndrome have poor postural control (Boswell, 1991; Tsimaras & Fotiadou, 2004).

Postural control, also known as balance, is operationally defined as one's ability to keep themselves upright and stable in both static and dynamic situations (Winter, 1995). In order to maintain postural control, it is necessary to control and manipulate one's center of pressure within either a static or dynamic base of support. The three ways that balance is accomplished is by achieving, maintaining, and restoring the center of gravity within the base of support (Pollock, Duward, Rowe, Paul, 2000). Achieving balance occurs when transitioning from one base of support to another, such as moving from a seated position to a standing position. The ability to maintain balance allows an individual to be able to have postural control even under changing conditions, such as an unexpected gust of wind or walking on uneven ground like gravel. Restoring balance keeps an individual within their base of support, even when unexpected conditions cause their center of gravity to creep close to the edge of their base of support, nearly ending in a loss of postural control. Regardless of the situation, postural control is an essential component required for many activities of daily living.

Activities of Daily Living are often a focus of both occupational and physical therapists. Generically, activities of daily living are the functional day-to-day skills essential to living independently. By definition limitations in activities of daily living contribute to disability status. These functional skills include bathing, dressing, eating, and walking. A key rate limiter to many of these tasks is balance. Balance is a way of measuring functional performance, which in turn, determines one's community integration (Kwong et al., 2017). Good balance augments self-efficacy to carry out daily activities and participating in social life. An individual is less likely to actively engage in the community around them is they are reliant on other people or assistant devices to carry out the everyday activities that people with good balance do with ease. Even activities such as vacuuming, reaching a high shelf, or walking down the hallway become daunting to those with poor balance.

Balance is a common issue in a variety of clinical populations. Individuals of all ages with Down syndrome experience impairments in balance. In addition to various neurological, musculoskeletal, and sensorimotor impairments, individuals with Down syndrome demonstrate slower postural response and inefficiencies in maintaining quiet stance (Webber, Virji-Babul, Edwards, Lesperance, 2004; Stancliffe & Anderson, 2017; Galli, et al, 2011; Biec et al, 2014). This is shown in Figure 1.

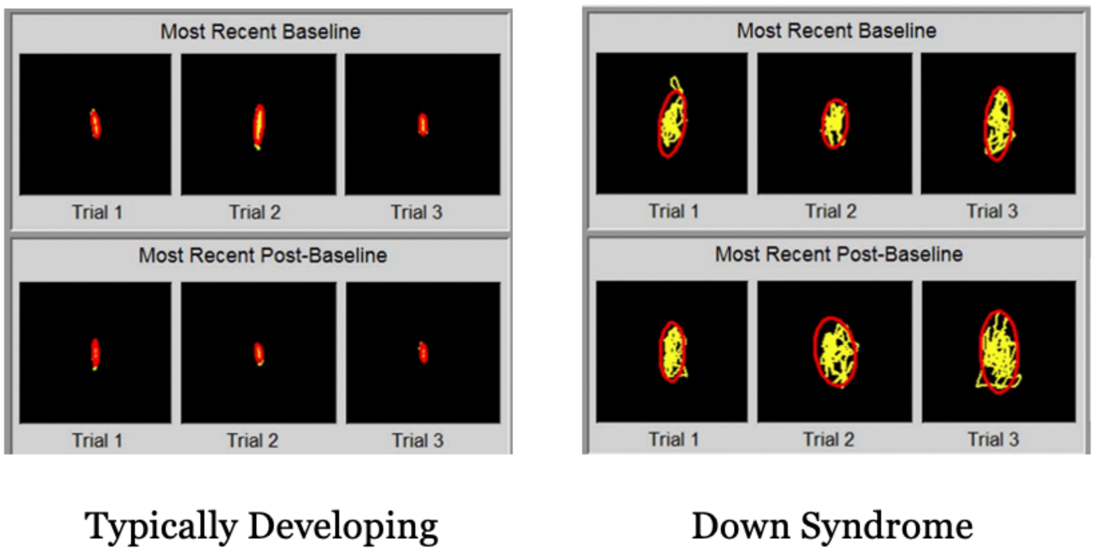


Figure 1.

BTrackS detects disruptions in balance via center of pressure (CoP) data & generates a fall risk assessment & postural sway analysis.

This figure demonstrates the difference in postural sway that is experienced by an individual with Down syndrome when participating in quiet stance compared to a typically developing individual of the same age group.

Individuals with intellectual disabilities, including those with Down syndrome experience a high incidence of falls (Hsieh, Heller, Miller, 2001; Wagemans & Cluitmans, 2006). Many of these falls often result in individuals requiring medical attention. Falls are associated with adverse outcomes such as fractures, hospitalizations, and even death (Zanotto et al., 2019). All of these side effects of falls are avoidable if postural control is never lost. The fear of a possible fall can present challenges for parents, teachers, and clinicians working with people with Down syndrome. In addition, it can cause decrease an individual with Down syndrome’s self-efficacy to carry out activities of daily living, causing them to be dependent on other and devices for basic tasks.

Previous research has investigated balance training and balance interventions for individuals with Down syndrome. Balance training programs and interventions are highly structured and aim to reduced or minimize known balance constraints. These interventions have included creative dancing, movement exploration, jumping, treadmill walking, and ball exercises (Boswell, 1991; Carmeli et al., 2003; Carmeli, Kessel et al., 2002; Tsimaras & Fotiadou, 2004; Wang & Chang, 1997; Wang & Ju, 2002). Other research has tried to identify and target aspects of balance designed to improve balance in individuals with Down syndrome (Boswell, 1991; Carmeli, Ayalon et al., 2002; Carmeli et al., 2003; Carmeli, Kessel et al., 2002; Le Blanc et al., 1977; Wang & Ju, 2002). One factor to examine is muscular strength in individuals with Down syndrome.

In typically developing individuals, increasing lower limb strength is widely recognized as being correlated with better balance in typically developing individuals (Citaker et al., 2013) (Beauchamp et al., 2012) (Hong et al., 2012). Strengthening the lower limbs is often used as the first intervention to augment balance in a typical patient within the physical therapy setting. The presence of efficient coordination of intersegmental muscle forces is a predictor of the transition to independent walking in typically developing infants (Begnoche et al., 2015). Children with Down syndrome are known to experience hypotonia and reduced strength in their lower limbs, especially in their hip abductors and knee extensors, when compared to typically developing children (Gupta et al., 2010). Hypotonia or strength deficits will lead to poor standing balance, which is associated with an increased risk of falling (Carmeli, Bar-Chad, Lotan, Merrick, & Coleman, 2003; Carmeli, Kessel, Coleman, & Ayalon, 2002). The role of strength is important for balance due to the muscles ability to become stiff. This stiffness enhances overall neuromuscular function by increasing proprioception. Complicating this issue is most studies focus on muscle weakness making it difficult to determine the relationships between strength and balance. Overall there is inconsistent information related to the relationship between strength and balance.

As a result, a key focus of this study is to determine if a decrease in lower limb strength is the main affectable contributor to the decrease in balance seen in people with Down syndrome. This will be determined by examining whether increasing lower limb strength of someone with Down syndrome will positively affect their balance.

Qualitative studies, quantitative studies, meta-analyses, reviews, and articles addressing balance for individuals with intellectual disabilities and Down syndrome were categorized into 1 of the 5 phases described by Sallis (citation). Rules for coding included the following: (1) if an article fit into multiple phases, it was coded into the highest phase; (2) articles using interventions measuring balance were coded as phase 1; and (3) articles using interventions looking at improving balance were coded as phase 4. A summary of the framework is summarized in Table 1.

Table 1 Behavioral epidemiology framework phases

Phase	Type of Research
Phase 1	Establishes links between balance and strength. These studies provide evidence for associations between balance and strength as well as a basis for describing dose-response relationships.

Phase 2	Focuses on measures of strength &/or balance. Reliability and validity studies are included in phase.
Phase 3	Examines factors affecting balance including moderators, mediators, and direct correlates. Studies include those that describe correlates of balance and those testing theories that describe the relationship between determinants and balance.
Phase 4	Involves interventions that target balance. These interventions change balance and/or target specific determinants of balance in an effort to improve participants' balance. Research from phases 1, 2, and 3 provides the basis for the development and assessment of interventions in phase 4.
Phase 5	Includes articles that focus on the dissemination of phase 4 research into practice.

There is a noted gap between research and practice. This is further noted in the research. There is an abundance of research on balance and balance deficits in this populations. If practitioners wish to improve balance it is necessary to have a deep understanding of the factors contributing to balance. One factor commonly cited in improving balance is muscular strength. The purpose of the current study is to review the current status of balance research related to muscular strength in individuals with intellectual disabilities and Down syndrome. A behavioral epidemiological framework was used to categorize the research into 5 unique phases.

METHOD

Study Design

This study follows the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) as outlined by Moher & colleagues (Moher et al., 2009). A systematic search and review were conducted using PubMed, EBSCOHOST, SportDiscus, and Google Scholar.

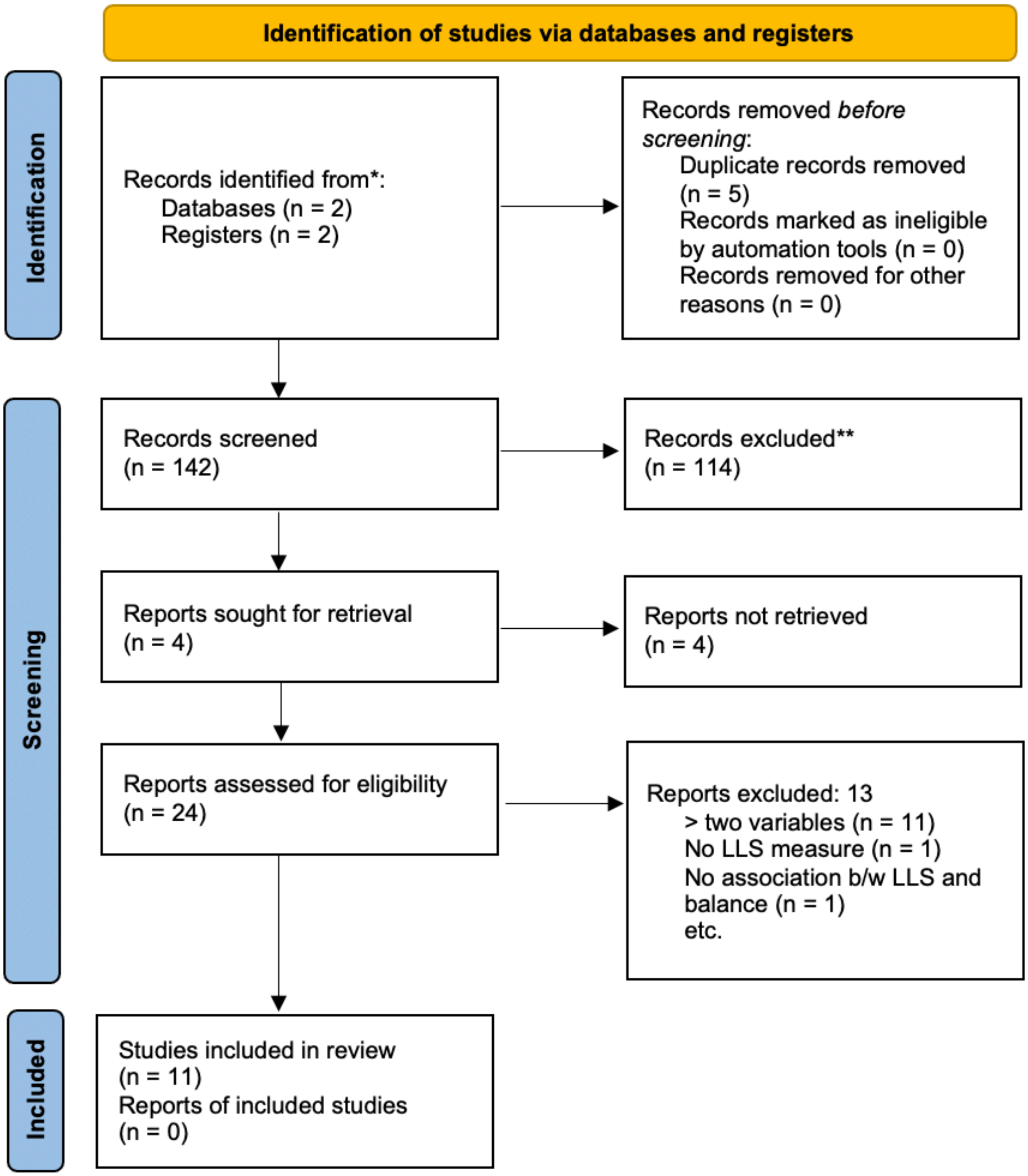
Search Strategy

A comprehensive database search of PubMed, EBSCOHOST, SportDiscus, and Google Scholar was conducted from (date to date). Search limitations included peer-reviewed research articles published between 2000 and 2021. Keywords and search terms included (disability OR intellectual disability) AND (postural control OR balance) AND (lower limb strength).

Inclusion Criteria

Studies were included if they met the following criteria: [1.) statistical examination of lower limb strength as the independent variable, 2.) statistical examination of balance as the dependent variable, and 3.) the examination was done comparing and physically or intellectually disabled population to a typically developing population] Duplicate titles were removed after initial searches. Phase 1 included screening of abstracts as completed by one reviewer (MCG). Phase 2 included additional screening of each of the selected articles from phase 1 by examining the entire article, completed independently by three reviewers (MCG, MB, and PE).

PRISMA 2020 flow diagram for new systematic reviews which included searches of databases, registers, and other sources



From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71. For more information, visit: http://www.prisma-statement.org/

Data Extraction

Data on the study sample, intervention, descriptive statistics, and outcomes measures were extracted and recorded using a standardized form. Pre- and post-intervention means and standard deviations were extracted to compute effect sizes. Treatment and control means and standard deviations were also extracted to compute effect sizes. Data was input so positive effect sizes would indicate improvement or a positive effect. Participant demographics were also extracted and recorded.

Type of study

Types of interventions

Data from 3 studies were clinical vs. control studies (Beauchamp et al., 2012) (Begnoche et al., 2016) (Citaker et al., 2013) (Guerra et al., 2014) (Nikaido et al., 2019) (Ramari et al., 2018). 3 studies utilized pre- and post-designs (Aider et al., 2018) (Kwong et al., 2018) (McLoughlin et al., 2014). Common measures of strength included measuring the maximal isometric force (McLoughlin et al., 2014), measuring isometric strength on a multi-joint evaluation system (Zanotto et al., 2019), measuring isokinetic muscle strength by an isokinetic dynameter (Beauchamp et al., 2012) (Ramari et al., 2018), using a handheld dynamometer (Citaker et al., 2013) (Kwong et al., 2018), Maximum Isometric Voluntary Contraction (MIVC) (Guerra et al., 2014), sit-to-stand test (Aider et al., 2018), and by using a medical isokinetic system (Carmeli et al., 2005). Balance was measured using a variety of methods including an eight camera ViconMX3 system (McLoughlin et al., 2014), a stabilimeter platform (Zanotto et al., 2019), a gross motor function measure (Begnoche et al., 2016), following the displacement of the center of pressure on a force platform (Ramari et al.,2018), using the Balance Evaluation

Systems Test (BESTest) (Beauchamp et al., 2012), and the BERG Balance Scale (Aider et al., 2018) (Guerra et al., 2014) (Kwong et al., 2018) (Nikaido al., 2019).

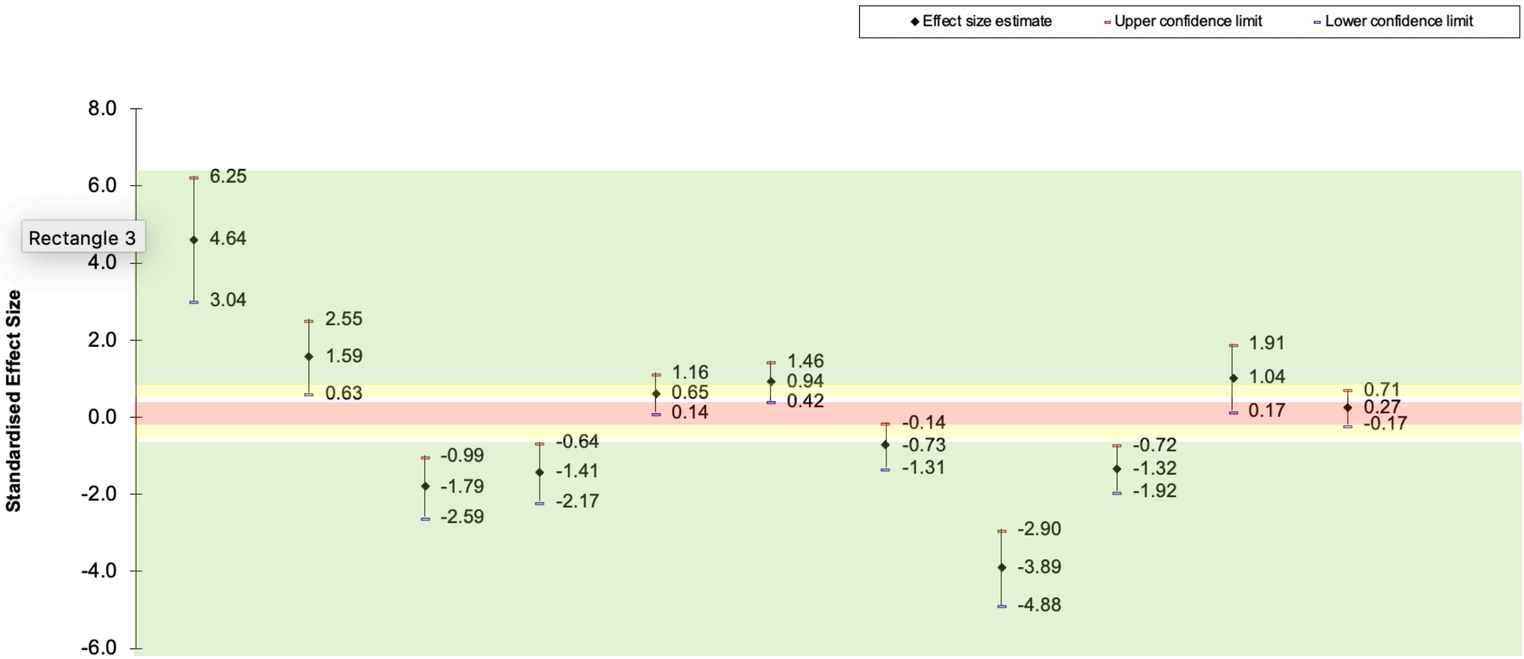
Types of participants

The participants in all of the studies were either typically developing, have multiple sclerosis, are a child with cerebral palsy (ages 2-6), are in end stage renal disease with a kidney transplant, have COPD, have idiopathic normal pressure hydrocephalus, or have experienced a stroke.

Data abstraction

For the data analysis of the research articles, a Cohen's D Effect Size Calculator was used. This method created a unitless comparison of the articles, even though many of them used different measures of strength. The effect size calculator requires the mean and standard deviations of two groups to create a statistic. Positive numbers indicate a positive effect, while negative numbers indicate a negative effect. Values between -0.4 to 0 and from 0 to 0.4 are considered to have no effect. Values from -0.8 to -0.4 and from 0.4 to 0.8 are considered to have a small effect. Values less than -0.8 or greater than 0.8 are considered to have a significant effect.

Results



The studies that were found to have a significant positive effect (>0.8) lie in the top green. These studies and measures are dynamic torque measured by using a medical isokinetic system (Carmeli et al., 2005), functional strength measured with a gross motor function measure (Begnoche et al., 2016), and squat repetitions through a sit-to-stand test (Aider et al., 2018). The studies that were found to have a significant negative effect (<-0.8) lie in the bottom green. These studies and measures include knee extension strength and ankle dorsiflexion strength measured by the maximal isometric force (McLoughlin et al., 2014), knee flexion strength measured by using a handheld dynamometer (Citaker et al., 2013), knee flexion peak torque by measuring using an isokinetic dynameter (Beauchamp et al., 2012). All other statistics were found to have little to no effect.

Discussion

The primary aim of this systematic review and meta-analysis was to review the current status of lower limb strength research related to balance in individuals with intellectual disabilities and Down syndrome. The secondary aims of the present review were to identify components and explore potential aspects of strength related to balance. Through the process of data analysis, a common theme can be established between the data with a positive effect and the data with a negative effect. The measures that lie within the positive effect range are the measures that included many muscles within the lower limb, such as dynamic torque, squat, and functional strength. The measures that lie within the negative effect range are measures that isolate a specific muscle or muscle group of the lower limb, such as the knee extensors, knee flexors, and the ankle dorsiflexors.

A possible explanation for the phenomenon of the negative effect caused by isolating specific muscles may be explain by the specific muscles that were targeted in the isolated muscle group interventions. Ringsberg et al. (1999) found that knee extension strength is not related to improved static and dynamic balance. Similar findings by Verfaillie et al. (1997) showed little support for knee or ankle training on improving either static or dynamic balance in typically developing individuals. This may mean that isolating other muscle groups could have a positive effect on balance.

The benefit of exercise interventions that involve the entire lower limb may have the greatest positive effect because of how these exercises improve joint movement in the entire lower extremities (Osugi et al., 2014). The activities that created a positive effect (squat, torque, and functional strength) involve the three main lower limb joints, the joints of the hip, knee, and ankle (Kritz et al., 2009; Schoenfeld, 2010). This is a contrast to the isolated muscle groups that only involved one of the joints. Using all three joints together to create a movement increases the strength of the entire lower limb and teaches the limb to work as a unit. Decreased strength of the muscles that stabilize and move these major joints have been found to be associated with a reduced ability to stabilize the lower extremity (Schoenfeld, 2010; Nguyen et al., 2011). Because of all of these findings, clinicians should focus on using exercise interventions that involve multiple joints within the lower limb in order to have the greatest positive effect on balance.

Conclusion

This systematic review and meta-analysis demonstrated some significant effects of strength or strength training on balance. The measures with a positive effect were strength measures that included the entire lower limb working as a unit. The use of the theoretical framework may help inform the development and evaluation of appropriate targeted interventions to improve balance outcomes in individuals with intellectual disabilities and Down syndrome. Continued research is necessary to gain a better and more complete understanding of the factors associated with balance. More specifically understanding these factors so training programs and interventions can be developed for individuals with balance deficits.

Limitations

The study did have a few limitations to be notes. The first of which is the limited selection of resources. Only two databases were used for the article search process. It is quite possible that other articles on this topic exist that are not included in those two databases. Additionally, the two databases only allowed for the search to be of contemporary research. The databases are both self-limited to research that was completed after the year 2000. Any research on the topic that was conducted before 2000 was not eligible to be included in the two databases used for article extraction. The last limitation was the constrictions of the Cohen's D Effect Size Calculator. While the effect size calculator allowed for useful data extraction of articles that compared two groups or had a pre/post test design, it did not allow and effect to be calculated based on one group or on three or more groups. There had to be two means and two standard deviations for the effect size calculator to be able to give a statistical value of the effect of the intervention.

Future Research

Future research on the role of lower limb strength in postural control would be beneficial to individuals with Down syndrome if different lower limb interventions were tested for their effectiveness on individuals with Down syndrome. The current body of research does not include articles on how individuals with Down syndrome are specifically affected by different interventions; instead, clinicians must make predictions on how individuals with Down syndrome would respond to different interventions based on the response of individuals with other disabilities with overlapping symptoms. Conducting research with individuals with Down syndrome would eliminate some of the assumptions that have to be made by clinicians when reading research on individuals with similar disabilities. Another direction that future research could take it to look at other factors that impact balance. This could include core strength or vestibular function.

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References

Aidar, F. J., Carneiro, A. L., Costa Moreira, O., Patrocínio de Oliveira, C. E., Garrido, N. D., Machado Reis, V., Raineh, I., Vilaça, J. M., & Gama de Matos, D. (2018). Effects of resistance training on the physical condition of people with multiple sclerosis. *The Journal of Sports Medicine and Physical Fitness*, *58*(7–8), 1127–1134. https://doi.org/10.23736/S0022-4707.17.07621-6

Angelopoulou, N., Tsimaras, V., Christoulas, K., Kokaridas, D., & Mandroukas, K. (1999). Isokinetic knee muscle strength of individuals with mental retardation, a comparative study. *Perceptual and motor skills*, *88*(3), 849-855.

Baptista, F., Varela, A., & Sardinha, L. B. (2004). Bone mineral mass in males and females with and without Down syndrome. Osteoporosis International, 16(4), 380-388. doi:10.1007/s00198-004-1687-1

Beauchamp, M. K., Sibley, K. M., Lakhani, B., Romano, J., Mathur, S., Goldstein, R. S., & Brooks, D. (2012). Impairments in systems underlying control of balance in COPD. *Chest*, *141*(6), 1496–1503. https://doi.org/10.1378/chest.11-1708

Begnoche, D. M., Chiarello, L. A., Palisano, R. J., Gracely, E. J., McCoy, S. W., & Orlin, M. N. (2016). Predictors of Independent Walking in Young Children With Cerebral Palsy. *Physical Therapy*, *96*(2), 183–192. https://doi.org/10.2522/ptj.20140315Busse, M. E., Hughes, G., Wiles, C. M., & Rosser, A. E. (2008). Use of hand-held dynamometry in the evaluation of lower limb muscle strength in people with Huntington's disease. Journal of Neurology,255(10), 1534-1540. doi:10.1007/s00415-008-0964-x

Bieć, E., Zima, J., Wójtowicz, D., Wojciechowska-Maszkowska, B., Kręcisz, K., & Kuczyński, M. (2014). Postural stability in young adults with Down syndrome in challenging conditions. *PLoS One*, *9*(4), e94247.

Blackburn, T., Guskiewicz, K. M., Petschauer, M. A., & Prentice, W. E. (2000). Balance and joint stability: the relative contributions of proprioception and muscular strength. Journal of sport rehabilitation, 9(4), 315-328

Boswell, B. (1991). Comparison of two methods of improving dynamic balance of mentally retarded children. Perceptual and Motor Skills, 73(3), 759-764.

Cakt, B. D., Nacir, B., Genç, H., Saraçoğlu, M., Karagöz, A., Erdem, H. R., & Ergün, U. (2010). Cycling progressive resistance training for people with multiple sclerosis: a randomized controlled study. *American Journal of Physical Medicine & Rehabilitation*, *89*(6), 446–457. https://doi.org/10.1097/PHM.0b013e3181d3e71f

Capio, C. M., Mak, T. C. T., Tse, M. A., & Masters, R. S. W. (2018). Fundamental movement skills and balance of children with down syndrome: FMS and balance - children with Down syndrome.Journal of Intellectual Disability Research, 62(3), 225-236. doi:10.1111/jir.12458

Carmeli, E., Bar-Chad, S., Lotan, M., Merrick, J., & Coleman, R. (2003). Five clinical tests to assess balance following ball exercises and treadmill training in adult persons with intellectual disability. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *58*(8), M767-M772

Carmeli, E., Zinger-Vaknin, T., Morad, M., & Merrick, J. (2005). Can physical training have an effect on well-being in adults with mild intellectual disability? *Mechanisms of Ageing and Development*, *126*(2), 299–304. https://doi.org/10.1016/j.mad.2004.08.021

Carter, K., & Horvat, M. (2016). Effect of taekwondo training on lower body strength and balance in young adults with down syndrome: Taekwondo training for down syndrome.Journal of Policy and Practice in Intellectual Disabilities, 13(2), 165-172. doi:10.1111/jppi.12164

Cho, K. H., Bok, S. K., Kim, Y. J., & Hwang, S. L. (2012). Effect of lower limb strength on falls and balance of the elderly. *Annals of rehabilitation medicine*, *36*(3), 386–393. https://doi.org/10.5535/arm.2012.36.3.386

Chougala, A., & Akhil, A. (2016). Evaluation of gait parameters and balance in obese down syndrome: An observational study. Indian Journal of Physiotherapy and Occupational Therapy - an International Journal, 10(4), 102. doi:10.5958/0973-5674.2016.00128.3

Citaker, S., Guclu-Gunduz, A., Yazici, G., Bayraktar, D., Nazliel, B., & Irkec, C. (2013). Relationship between lower extremity isometric muscle strength and standing balance in patients with multiple sclerosis. *NeuroRehabilitation*, *33*(2), 293–298. https://doi.org/10.3233/NRE-130958

Epstein, C. J. (2016). Down syndrome McGraw-Hill Education. doi:10.1036/1097-8542.204400

Gil, A. W., Oliveira, M. R., Coelho, V. A., Carvalho, C. E., Teixeira, D. C., & Jr, R. A. (2011). Relationship between force platform and two functional tests for measuring balance in the elderly. Brazilian Journal of Physical Therapy,15(6), 429-435. doi:10.1590/s1413-35552011005000024

Fujita, T., Sato, A., Iokawa, K., Yamane, K., Yamamoto, Y., Tsuchiya, K., Ohira, Y., & Otsuki, K. (2019). A path analysis model for grooming performance in stroke patients. *Disability & Rehabilitation*, *41*(24), 2958–2964.

Gagnon, C., Brais, B., Lessard, I., Lavoie, C., Côté, I., & Mathieu, J. (2018). From motor performance to participation: a quantitative descriptive study in adults with autosomal recessive spastic ataxia of Charlevoix-Saguenay. *Orphanet Journal of Rare Diseases*, *13*(1), 165. https://doi.org/10.1186/s13023-018-0898-z

Galli, M., Cimolin, V., Vismara, L., Grugni, G., Camerota, F., Celletti, C., ... & Capodaglio, P. (2011). The effects of muscle hypotonia and weakness on balance: A study on Prader–Willi and Ehlers–Danlos syndrome patients. *Research in developmental disabilities*, *32*(3), 1117-1121.

González-Agüero, A., Vicente-Rodríguez, G., Moreno, L. A., Guerra-Balic, M., Ara, I., & Casajús, J. A. (2010). Health-related physical fitness in children and adolescents with Down syndrome and response to training. Scandinavian Journal of Medicine & Science in Sports, 20(5), 716-724. doi:10.1111/j.1600-0838.2010.01120.x

Guerra, E., di Cagno, A., Mancini, P., Sperandii, F., Quaranta, F., Ciminelli, E., Fagnani, F., Giombini, A., & Pigozzi, F. (2014). Physical fitness assessment in multiple sclerosis patients: a controlled study. *Research in Developmental Disabilities*, *35*(10), 2527–2533. https://doi.org/10.1016/j.ridd.2014.06.013

Gupta, S., Rao, B., & Kumaran, S. (2011). Effect of strength and balance training in children with down's syndrome: A randomized controlled trial. Clinical Rehabilitation, 25(5), 425-432. doi:10.1177/0269215510382929

Hale, L. A., Mirfin-Veitch, B. F., & Treharne, G. J. (2016). Prevention of falls for adults with intellectual disability (PROFAID): a feasibility study. *Disability & Rehabilitation*, *38*(1), 36–44.

Han, L., & Yang, F. (2015). Strength or power, which is more important to prevent slip-related falls? *Human Movement Science*, *44*, 192–200. https://doi.org/10.1016/j.humov.2015.09.001

Hayes, A., & Batshaw, M. L. (1993). Down syndrome. *Pediatric Clinics of North America*, *40*(3), 523-535.

Hong, W.-H., Chen, H.-C., Shen, I.-H., Chen, C.-Y., Chen, C.-L., & Chung, C.-Y. (2012). Knee muscle strength at varying angular velocities and associations with gross motor function in ambulatory children with cerebral palsy. *Research in Developmental Disabilities*, *33*(6), 2308–2316. https://doi.org/10.1016/j.ridd.2012.07.010

Hsieh, K., Heller, T., & Miller, A. B. (2001). Risk factors for injuries and falls among adults with developmental disabilities. *Journal of Intellectual Disability Research*, *45*(1), 76-82.

Jacob, M. E., Travison, T. G., Ward, R. E., Latham, N. K., Leveille, S. G., Jette, A. M., & Bean, J. F. (2019). Neuromuscular Attributes Associated With Lower Extremity Mobility Among Community-Dwelling Older Adults. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *74*(4), 544–549.

Karlsson, A., & Frykberg, G. (2000). Correlations between force plate measures for assessment of balance. Clinical Biomechanics, 15(5), 365-369. Doi: 10.1016/s0268-0033(99)00096-0

Keller, J. L., Wang, J. I., Kang, J. Y., Hanson, J. A., Kamath, P., Swain, J. O., Raymond, G. V., & Zackowski, K. M. (2012). Strength: a relevant link to functional performance in the neurodegenerative disease of adrenomyeloneuropathy. *Neurorehabilitation and Neural Repair*, *26*(9), 1080–1088. https://doi.org/10.1177/1545968312441682

Kritz M, Cronin J, Hume P. The bodyweight squat: A movement screen for the squat pattern. *Strength & Conditioning Journal.* 2009;31:76–85.

Kwong, P. W. H., Ng, G. Y. F., Chung, R. C. K., & Ng, S. S. M. (2018). Bilateral Transcutaneous Electrical Nerve Stimulation Improves Lower-Limb Motor Function in Subjects With Chronic Stroke: A Randomized Controlled Trial. *Journal of the American Heart Association*, *7*(4). https://doi.org/10.1161/JAHA.117.007341

Kwong, P. W. H., Ng, S. S. M., Chung, R. C. K., & Ng, G. Y. F. (2017). A structural equation model of the relationship between muscle strength, balance performance, walking endurance and community integration in stroke survivors. *PloS One*, *12*(10), e0185807. https://doi.org/10.1371/journal.pone.0185807

Lee, N. K., Kwon, J. W., Son, S. M., Kang, K. W., Kim, K., & Hyun-Nam, S. (2013). The effects of closed and open kinetic chain exercises on lower limb muscle activity and balance in stroke survivors. *NeuroRehabilitation*, *33*(1), 177–183. https://doi.org/10.3233/NRE-130943

McLoughlin, J. V., Barr, C. J., Crotty, M., Sturnieks, D. L., & Lord, S. R. (2014). Six minutes of walking leads to reduced lower limb strength and increased postural sway in people with Multiple Sclerosis. *NeuroRehabilitation*, *35*(3), 503–508. https://doi.org/10.3233/NRE-141143

Mégarbané, A., Ravel, A., Mircher, C., Sturtz, F., Grattau, Y., Rethoré, M. O., ... & Mobley, W. C. (2009). The 50th anniversary of the discovery of trisomy 21: the past, present, and future of research and treatment of Down syndrome. Genetics in Medicine, 11(9), 611.

Mengarelli, A., Verdini, F., Cardarelli, S., Nardo, F. D., Burattini, L., & Fioretti, S. (2018). Balance assessment during squatting exercise: A comparison between laboratory grade force plate and a commercial, low-cost device. Journal of Biomechanics,71, 264-270. doi:10.1016/j.jbiomech.2018.01.029

Moreno-Navarro, P., Gomez-Illán, R., Carpena-Juan, C., P Sempere, Á., Vera-Garcia, F. J., & Barbado, D. (2020). Understanding the Deterioration of Gait, Postural Control, Lower Limb Strength and Perceived Fatigue Across the Disability Spectrum of People with Multiple Sclerosis. *Journal of Clinical Medicine*, *9*(5). https://doi.org/10.3390/jcm9051385

Morlino, P., Balbi, B., Guglielmetti, S., Giardini, M., Grasso, M., Giordano, C., Schieppati, M., & Nardone, A. (2017). Gait abnormalities of COPD are not directly related to respiratory function. *Gait & Posture*, *58*, 352–357. https://doi.org/10.1016/j.gaitpost.2017.08.020

Muehlbauer, T., Besemer, C., Wehrle, A., Gollhofer, A., & Granacher, U. (2012). Relationship between strength, power and balance performance in seniors. Gerontology, 58(6), 504-512.

Nguyen AD, Shultz SJ, Schmitz RJ, Luecht RM, Perrin DH. A preliminary multifactorial approach describing the relationships among lower extremity alignment, hip muscle activation, and lower extremity joint excursion. *J Athl Train.* 2011;46:246–256.

Nikaido, Y., Kajimoto, Y., Akisue, T., Urakami, H., Kawami, Y., Kuroda, K., Ohno, H., & Saura, R. (2019). Dynamic Balance Measurements Can Differentiate Patients Who Fall From Patients Who Do Not Fall in Patients With Idiopathic Normal Pressure Hydrocephalus. *Archives* *of Physical Medicine and Rehabilitation*, *100*(8), 1458–1466. https://doi.org/10.1016/j.apmr.2019.01.008

Nocera, J. R., Buckley, T., Waddell, D., Okun, M. S., & Hass, C. J. (2010). Knee extensor strength, dynamic stability, and functional ambulation: are they related in Parkinson's disease? *Archives of Physical Medicine and Rehabilitation*, *91*(4), 589–595. https://doi.org/10.1016/j.apmr.2009.11.026

Osugi, T., Iwamoto, J., Yamazaki, M., & Takakuwa, M. (2014). Effect of a combination of whole body vibration exercise and squat training on body balance, muscle power, and walking ability in the elderly. *Therapeutics and clinical risk management*, *10*, 131–138. https://doi.org/10.2147/TCRM.S57806

Ozgozen, S., Guzel, R., Basaran, S., & Coskun Benlidayi, I. (2020). Residual Deficits of Knee Flexors and Plantar Flexors Predict Normalized Walking Performance in Patients with Poststroke Hemiplegia. *Journal of Stroke and Cerebrovascular Diseases : The Official Journal of National Stroke Association*, *29*(4), 104658.

Parker, S.E., Mai, C.T., Canfield, M.A., Rickard, R., Wang, Y., Meyer, R.E., Anderson, P., Mason, C.A., Collins, J.S., Kirby, R. S., and Correa, A. (2010). Updated National Birth Prevalence estimates for selected birth defects in the United states 2004-2006. Birth Defects Research, 88 (12), 1008-1016.

Pitetti, K., Baynard, T., & Agiovlasitis, S. (2013). Children and adolescents with Down syndrome, physical fitness and physical activity. Journal of Sport and Health Science, 2(1), 47-57. doi:10.1016/j.jshs.2012.10.004

Pollock, A. S., Durward, B. R., Rowe, P. J., & Paul, J. P. (2000). What is balance? *Clinical Rehabilitation*, *14*(4), 402–406. https://doi.org/10.1191/0269215500cr342oa

Ramari, C., Moraes, A. G., Tauil, C. B., von Glehn, F., Motl, R., & de David, A. C. (2018). Knee flexor strength and balance control impairment may explain declines during prolonged walking in women with mild multiple sclerosis. *Multiple Sclerosis and Related Disorders*, *20*, 181–185. https://doi.org/10.1016/j.msard.2018.01.024

Rasmussen, S. A., Whitehead, N., Collier, S. A., & Frias, J. L. (2008). Setting a public health research agenda for Down syndrome: summary of a meeting sponsored by the Centers for Disease Control and Prevention and the National Down Syndrome Society. *American Journal of Medical Genetics Part A*, *146*(23), 2998-3010.

Ringsberg K., Gerdhem P., Johansson J., Obrant K. (1999) Is there a relationship between balance, gait performance and muscular strength in 75-year-old women? *Age and Ageing* 28, 289-293

Schoenfeld BJ. Squatting kinematics and kinetics and their application to exercise performance. *J Strength Cond Res.* 2010;24:3497–3506.

Schoneburg, B., Mancini, M., Horak, F., & Nutt, J. G. (2013). Framework for understanding balance dysfunction in Parkinson's disease. Movement Disorders, 28(11), 1474-1482. doi:10.1002/mds.25613

Seron, B. B., Modesto, E. L., Stanganelli, L. C. R., Carvalho, Emanuel Messias Oliveira de, & Greguol, M. (2017). Effects of aerobic and resistance training on the cardiorespiratory fitness of young people with down syndrome. Brazilian Journal of Kinanthropometry and Human Performance, 19(4), 385. doi:10.5007/1980-0037.2017v19n4p385

Shields, N., & Taylor, N. F. (2010). A student-led progressive resistance training program increases lower limb muscle strength in adolescents with Down syndrome: A randomized controlled trial. Journal of Physiotherapy,56(3), 187-193. doi:10.1016/s1836-9553(10)70024-2

Suomi, R. (1993). *Effects of a lower limb strength training program on balance measures in men with mental retardation*.

Tsimaras, V. K., & Fotiadou, E. G. (2004). Effect of training on the muscle strength and dynamic balance ability of adults with down syndrome. Journal of strength and conditioning research, 18(2), 343-347.

Under-five mortality rate (per 1000 live births) (SDG 3.2.1) [Internet]. Who.int. 2020 [cited 3 October 2020]. Available from: https://www.who.int/data/maternal-newborn-childadolescent-ageing/indicator-explorer-new/mca/under-fivemortality-rate-(per-1000-live-birth).

Verfaillie D., Nichols J., Turkel E., Hovell M. (1997) Effects of resistance, balance and gait training on reduction of risk factors leading to falls in elders. *Journal of Aging and Physical Activity* 5, 213-228

Vernadakis, N., Derri, V., Tsitskari, E., & Antoniou, P. (2014). The effect of Xbox Kinect intervention on balance ability for previously injured young competitive male athletes: A preliminary study. Physical Therapy in Sport,15(3), 148-155. doi:10.1016/j.ptsp.2013.08.004

Wagemans, A. M. A., & Cluitmans, J. J. M. (2006). Falls and fractures: a major health risk for adults with intellectual disabilities in residential settings. *Journal of Policy and Practice in Intellectual Disabilities*, *3*(2), 136-138.

Wang, H., Long, I., & Liu, M. (2012). Relationships between task-oriented postural control and motor ability in children and adolescents with down syndrome. Research in Developmental Disabilities, 33(6), 1792-1798. doi:10.1016/j.ridd.2012.05.002

Williams, G., Ada, L., Hassett, L., Morris, M. E., Clark, R., Bryant, A. L., & Olver, J. (2016). Ballistic strength training compared with usual care for improving mobility following traumatic brain injury: protocol for a randomised, controlled trial. *Journal of Physiotherapy (Elsevier)*, *62*(3), 164.

Wolff, D. R., Rose, J., Jones, V. K., Bloch, D. A., & al, e. (1998). Postural balance measurements for children and adolescents. *Journal of Orthopaedic Research, 16*(2), 271-5. http://library.tcu.edu/PURL/EZproxy_link.asp?/login?url=https://www.proquest.com/scholarly-journals/postural-balance-measurements-children/docview/235099319/se-2?accountid=7090

Zanotto, T., Gobbo, S., Bullo, V., Vendramin, B., Roma, E., Duregon, F., Bocalini, D. S., Di Blasio, A., Cugusi, L., Furian, L., Di Bella, C., Neunhaeuserer, D., Battista, F., Bergamin, M., & Ermolao, A. (2020). Postural balance, muscle strength, and history of falls in end-stage renal disease patients living with a kidney transplant: A cross-sectional study. *Gait & Posture*, *76*, 358–363. https://doi.org/10.1016/j.gaitpost.2019.12.031