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Evaluation of upper limb movements in children with Down's syndrome: A systematic review

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ABSTRACT

The aim of the present study was to perform a review of the literature on current quantitative clinical methods for the evaluation of upper limb movements in children and adolescents with Down syndrome, with a focus on describing the variables, protocols, motor function and motor control.

Methods: A survey of PubMed, Scielo, BVS Bireme and PEDro databases using the following key words: upper limb and EMG and Down syndrome; upper limb and kinematics and Down syndrome; upper limb and motion analysis and Down syndrome; movement and upper limb and Down syndrome; upper limb and Down syndrome; reach and Down syndrome.

Results: In all, 344 articles and five were selected to compose the present systematic review. No standardization was found among the studies analyzed with regard to data collection, data processing or procedures for the evaluation of the variables.

Conclusion: A kinematic evaluation is effective for the discussion of the results, but methodological differences among the studies and inconsistent results exert a negative influence on clinical interpretations and the possibility of reproducibility. The standardization of an upper limb movement evaluation protocol using kinematic analysis is important, as it would provide the basis for comparable, reproducible results and facilitate the planning of treatment interventions.

1. Introduction

Down's syndrome (DS) is a genetic disease with a high incidence throughout the world (De Kegel et al., 2010) and is the most common chromosome disorder among live births. In the United States, it is estimated that 5400 of the four million children born per year have DS (proportion: one out of every 700 births) (Aiello-Vaisberg, 1999; Almeida, Corcos, & Hansan, 2000; Bell, Pearn, & Firman, 1989; Curie, Nazir, & Brun, 2014; Dessen and Pereira-Silva, 2000; Ferreira, Salles, & Marques, 2009). This condition is caused by an additional copy of chromosome 21 and affected children generally exhibit congenital anomalies, including heart or gastrointestinal defects, varying degrees of intellectual disability, hypotonia and ligament laxity (Dessen and Pereira-Silva, 2000; Ferreira et al., 2009; Ferreira and Salles, 2009; Gage and Novacheck, 2001; Gianni MAC, 2005; Lewada, Matsoff, Revenis, Harahsheh, & Futterman, 2016; Lin and Wuang, 2012).

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According to Ferreira et al. (2009), changes in movement patterns occur throughout life in individuals with typical motor development (no neuromotor abnormalities), which may be related to the age of each individual (Ferreira et al., 2009) and interactions between perceptual and motor processes during the production, correction and comprehension of movement. The population with DS exhibits deficits with regard to the learning process and development, which compromises the acquisition of motor skills and functional independence (Bell et al., 1989; Curie et al., 2014; Dessen and Pereira-Silva, 2000). This compromised neuropsychomotor development causes delays in all phases of development, requiring a longer time for children with DS to acquire motor skills, such as controlling the head and trunk, rolling over, sitting, crawling, walking and running (Ferreira and Salles, 2009; Gage and Novacheck, 2001).

The current discussions found in the literature on selective motor development and dexterity are of considerable importance (Goldinf, Emmentt, Caven- lhes, & Steer, 2014). Fine motor coordination, which is also denominated adaptive motor behavior, is responsible for hand movements and dexterity (Sonne and Jennifer, 2004; Mancini, Silva, Gonçalves, & Martins, 2003). Fine motricity consists of a set of movements of particular segments of the body and the capacity to control these movements with minimal effort to achieve precise responses to a given task (Bomono and Rosseti, 2010; Butler and Rose, 2012). Deficiencies in dexterity can exert a negative impact on the ability to perform activities of daily living in an independent fashion (Andel, Cole, & Pepping, 2016). Recovering or enhancing dexterity signifies the recuperation of at least part of one's autonomy, giving an individual with motor deficits more independence as well as enhancing his/her self-esteem and potentiating performance throughout the treatment process (Andel et al., 2016).

Many therapeutic approaches and different techniques have been studied for the rehabilitation of individuals with upper limb impairment and the evaluation, planning and monitoring of therapies aimed at improving functional capacity of the upper limbs has become a vast field of research. Current methods for upper limb evaluations are based on function, motor control, sensory deficiency, dexterity, muscle tone and range of motion (Guimarães and Blascovi-Assis, 2012; Sonne and Jennifer, 2004). The diversity of upper limb functions and the numerous possibilities of hand movements have led to a large number of standardized scales and objective assessment tools for measuring upper limb movements (Guimarães and Blascovi-Assis, 2012; Lopes, Grecco, & Moura, 2017; Moura, Grecco et al., 2016a). However, quantitative measures are needed to describe upper limb movement patterns. Such measures could provide an objective description of upper limb performance based on technical measurements and calculations, such as joint angles, movement duration and velocity.

Three-dimensional (3D) movement analysis is a powerful tool for the quantitative evaluation of movement in all degrees of freedom (Grecco, Duarte, & Zanon, 2014). Researchers have recommended the use of kinematics as an objective, quantitative analysis of upper limb movements in children (Duarte, Grecco, Galli, Fregni, & Oliveira, 2014; Jaspers et al., 2011; Lazzari, Politti, & Santos, 2015). Motion analysis is considered the gold standard for the evaluation of the lower limbs during gait in individuals with neurological disorders (Moura, Almeida et al., 2016b). Motion analysis of the upper limbs is technically more challenging due to the non-cyclic use of the upper limb and the complexity of shoulder movements (Santos et al., 2015). Besides joint kinematics, spatiotemporal variables, such as the duration, velocity, smoothness and trajectory of a given movement, provide important quantitative information on the quality of upper limb movements (Schneiberg et al., 2010). However, no studies were found that clearly address the best method for objective upper limb analysis in the population with DS.

The aim of the present study was to perform a review of the literature on current quantitative clinical methods for the evaluation of upper limb movements in children and adolescents with Down syndrome with a focus on describing the variables, protocols, motor function and motor control used in the performance of upper limb movements.

2. Materials and methods

2.1. Eligibility criteria

Studies that met the following inclusion criteria were selected for the present review: clinical trials and cross-sectional studies published in English in the previous five years. Studies that met one of the following criteria were excluded from the review: publication date more than five years ago; study design that did not meet the needs of the present systematic review; non-analysis of upper limb movement in patients with DS as the primary outcome; and studies not involving humans.

2.2. Search strategy

A systematic review of the literature was performed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The PubMed (National Library of Medicine), Scielo, BVS Bireme and PEDro databases were searched from February to August 2016 for original articles, clinical trials and cross-sectional studies using the following key words: Down syndrome; upper limb and kinematics and Down syndrome; upper limb and motion analysis and Down syndrome; movement and upper limb and Down syndrome; upper limb and Down syndrome; reach and Down syndrome) (Macedo et al., 2010; Moher, Liberati, Tetzlaff, & Altman, 2009).

2.3. Review process

The title and abstract of the articles retrieved during the initial search were analyzed independently by the researchers (RDL, NACE and RCFM) using a systematic strategy based on defined inclusion criteria. Any divergences of opinion among the reviewers

Table 1
Representation of search strategy – PICO criteria for inclusion of studies.

PICO Criteria for inclusion of studies	Population: Main criterion:	Down's syndrome Evaluation methods
PICO	Comparator (control): Outcome:	Upper limb motor skills and function Quantitative evaluations

regarding the inclusion or exclusion of an article were discussed until a consensus was reached. The abstracts were analyzed based on the following criteria: 1) inclusion of a population with a diagnosis of Down syndrome; (Aiello-Vaisberg, 1999) evaluation of this population focused on upper limb movements; and 3) publication in previous five years. No restrictions were imposed with regard to minimum sample size. Articles not based on data (books, theoretical articles and secondary reviews), systematic reviews, studies not performed with the identified population, and studies not clearly focused on evaluation methods for this population were excluded. All studies identified were analyzed and duplicates were removed (Table 1). The PICO question of the study characterizes the search strategy. However, there are items wich are essential and should be present in all reviews as the clear definition of the research question: a good review is not the one that answers a number of questions, but is the one that answers specific questions clearly and with the least bias as possible. Therefore, the definition of the research question is essential. One guideline to delineate well a question for systematic reviews is to use the PICO framework (Patient, Intervention, Comparison and Outcomes). The redaction of questions can make use of the PICO structure in a flexible way, for example letting the comparison term be known later in the review. Other way of make the PICO structure flexible is when the review does not asses the intervention effect, in which case the term "I" is attributed to the focus of the study. In this systematic reviews used the PICO framework (Patient, Intervention, Comparison and Outcomes) to delineate well the search strateg (Borenstein, Hedges, Higgins, & Rothstein, 2009; Mancini, Cardoso, & Rosana, 2014; Perera and Heneghan, 2008).

The population was individuals with DS. The criteria used as the outcome were clinical trials and cross-sectional studies with an experimental group and a control group to demonstrate the methods use for upper limb movements in articles published in English in the previous five years in the aforementioned databases.

2.4. Quality assessment

The appraisal of the methodological quality of the studies selected to compose this systematic review was based on the inclusion criteria and quantified using the Crowe Critical Appraisal Tool (CCAT) (Crower, Sheppard, & Campbell, 2012; Crower and Sheppard, 2011). The CCAT list was developed to facilitate the assessment of studies with different designs, including cross-sectional studies. The strong points and specific gaps in the methodological reporting are identified through eight CCTA subscales, enabling the separate evaluation of each aspect of the article. The scores of the subscales are summed and expressed as percentage values. To facilitate the interpretation of the results, Andel et al. (2016) divided the scores into quintiles: I) 0–20% = very low quality; II) 21–40% = low quality; III) 41–60% = moderate quality; IV) 61–80% = high quality; and V) 81–100% = very high quality. Table 2 displays the results of the quality assessment of the studies included in the present review (Table 2) (Crower et al., 2012; Crower and Sheppard, 2011) Divergences of opinions between the two blinded reviewers regarding the classification of the studies based on the CCAT scale were discussed until a consensus was reached on the score of each study. If no consensus was reached, a third reviewer was consulted to make the final decision.

3. Results

A total of 344 articles were retrieved during the initial search, 84 of which were excluded for not meeting the inclusion criterion with regard to study design. Among the remaining 260 clinical trials and cross-sectional studies, 61 were excluded for being duplicated in different databases or having been published more than five years earlier, leading to 199 articles. After analyses of the titles and abstracts, 44 articles were preselected for full-text analysis. To enhance the reliability of the selection process, three researchers reviewed all potentially relevant articles. After the reading of the full texts, only five articles were selected to compose the present systematic review. All researchers were in agreement with regard to which articles met the inclusion criteria (Fig. 1).

A methodological quality score higher than 50% was required for inclusion in this review, which is indicative of moderate to high quality. All studies included in the present review had a cross-sectional design and reported estimates of precision and variability,

Table 2
Evaluation of methodological quality.

Author/Year	Preliminaries	Introduction	Design	Sampling	Data Collection	Ethical Matters	Results	Discussion	Score	Quality%
Vimercati et al. (2015)	3	2.5	4	4	5	3.5	4	3	29	72.5%
(Vimercati et al., 2013b)	3	2.5	4	3	4.5	3.5	5	3	28.5	71.25%
(Vimercati et al., 2015)	5	5	4.5	5	3.5	3.5	4	4.5	35	87.5%
(Masumoto et al., 2012)	2	2	3.5	2	4	3.5	3	3	23	57.5%
(Chen et al., 2015)	2	2	3	3	4	4	4	3	25	62.5%

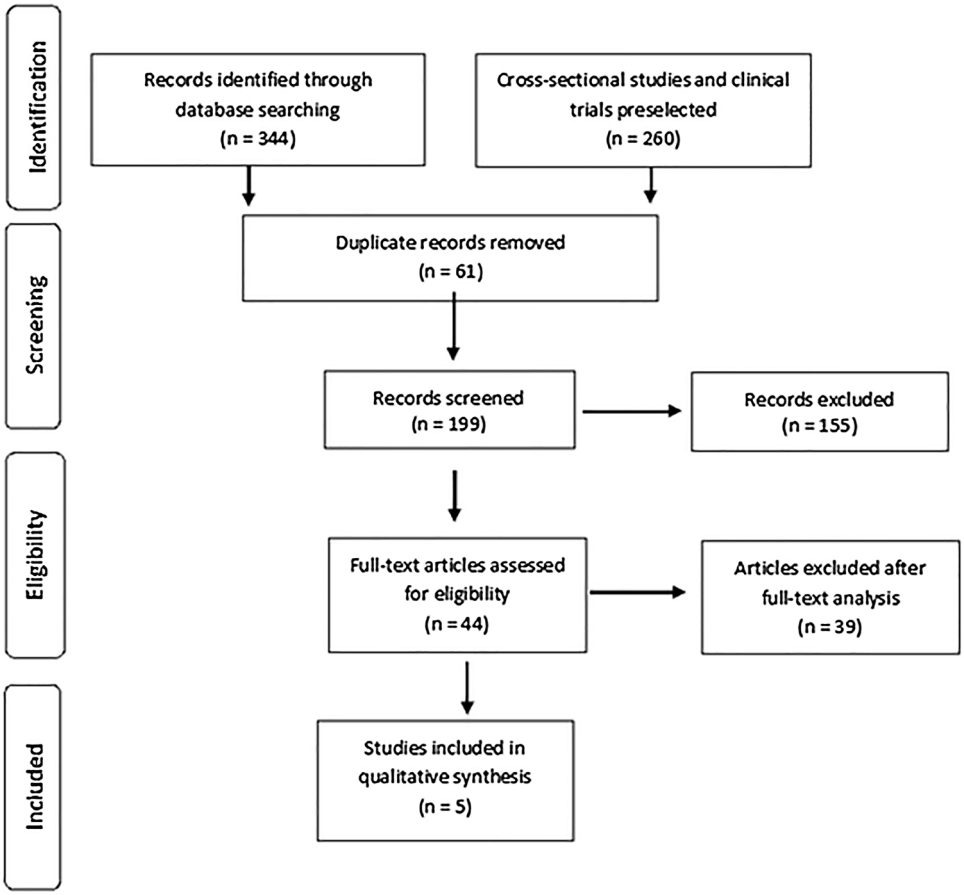

Fig. 1. Flow chart of study selection process.

analyzing differences between groups. The risk of bias was moderate in all studies. The studies involved an experimental group with DS and a control group of individuals with typical development (Table 3). Three studies 3D kinematic analysis with the aim of analyzing skills and strategies for selective motor control of the upper limb. Chen, Yeh, and Howe (2015) used a force plate for the same outcome, but addressing the effects on postural control (Chen et al., 2015).

4. Discussion

The analysis of the studies included in the present review demonstrates the predominance of the use of kinematics for the evaluation of the upper limb movement in children with DS. Other relevant studies not included in this review have also demonstrated the positive results of the kinematic analysis of upper limb movements in this population (Cioni, Cocilovo, Rossi, Paci, & Valle, 2001; Galli et al., 2007).

However, no standardization was found among the studies included in the present review with regard to data collection, data processing and evaluation procedures. The kinematic evaluation is effective for a discussion of the results, but we believe that the methodological differences and inconsistent results exert a negative impact on clinical interpretation and the possibility of reproducibility (Anastasia et al., 2012; Geerts, Einspieler, Dibiasi, Garzarolli, & Bos, 2003).

In the context of neurological disorders, the goal of therapy is to reduce the dependence individuals by providing greater functionality, which enables the performance of activities of daily living with greater efficiency and independence. Assessment tools and specific measures assist in the evaluation of aspects such as muscle strength, range of motion, dexterity, velocity and the efficacy of movements. Adequate treatment requires ample knowledge of all upper limb disorders. The clinical evaluation of the upper limbs combined with objective, quantitative measures can provide the necessary basis for the determination of the most adequate form of treatment. The clinical application of a three-dimensional upper limb movement protocol requires the establishment of a biomechanical model and a set of relevant tasks (Guimarães and Blascovi-Assis, 2012).

The kinematic analysis of upper limb function is considered an evaluation of the level of the strategy to be analyzed. A large number of kinematic variables are used to reflect the characteristics of the movement proposed in each study. By quantifying specific kinematic variables, key components can be identified and the influence of motor impairment on movement can be analyzed. Considering the kinematic variables analyzed in different studies, there is no consensus on the data collection method, data

Table 3
Characteristics of studies included in present review.

Authors	Type of study	Sample	Age	Evaluation	Objective	Methods	Outcomes
(Vimercati et al., 2013a)	Cross-sectional	DS: 23 N: 13	DS: 14.9 ± 4.6 N: 8.1 ± 2.9	Kinematic movement of drawing task	Describe characteristics of fine motor skills	Quantitative movement analysis consisting of optoelectronic system (Elite 2002, BTS) with eight infrared cameras. The optoelectronic system records 3D coordinates of markers through time. Markers placed on specific body landmarks using marker setup derived from previous studies	Individuals with DS tended to draw more quickly, but with less precision than controls.
(Vimercati et al., 2013b)	Cross-sectional	DS: 13 N: 21	DS: 23.7 ± 7.0 N: 24.9 ± 2.4	Kinematic movement	Describe differences in movements and provide means to interpret such differences	Quantitative movement analysis consisting of optoelectronic system (Elite 2002, BTS), which records 3D coordinates of markers through time. Markers placed on specific body landmarks using marker setup derived from previous studies.	Individuals with DS depended more on feedback and had more problems with planning of movements and feed-forward than controls.
(Vimercati et al., 2015)	Cross-sectional	DS: 16 N: 21	DS: 23.2 ± 6.5 N: 24.9 ± 2.4	Kinematic movement	Determine whether obstacles generate difference in motor control strategies	a) Internet-connected laptop computer for accessing databases; b) peripheral devices (pen drive) for storage and transport of the collected data; c) Software: Excel®.	Presence of obstacles led to changes in motor strategies in both groups, with a destabilizing effect that led the subjects to trust more in the feedback.
(Masumoto et al., 2012)	Cross-sectional	DS: 9 N: 9	DS: 15–17 N: 16–17	One-hand and two-hand tasks + self-stimulated test involving audible synchroniza-tion with simultan-eous feedback of force output	Examine control of force and time in one-hand and two-hand activities	Kyowa electronic instruments (model lub–5 kb), udes for fingers tapping were amplified by a strain amplifier (Leader Electronic Corp.) The force output was also recorded by a personal computer and monitored on a screen after the amplified signal was converter from analog to digital.	DS demonstrated greater magnitude of positive constant error and variable error for peak force than typical adolescents. DS also exhibited greater magnitude of negative constant error and variable error for intercalation interval than typical adolescents.
(Chen et al., 2015)	Cross-sectional	DS: 16 N: 14	DS: 8.26 ± 0.82 N: 8.04 ± 0.74	Dynamic balance − force plate	Investigate dynamic postural control in DS	Force plate (Advanced Mechanical Technology Inc., USA) with 1080 Hz to record ground reaction force and center of pressure (CoP); three foot markers placed on both heels and second metatarsal head of one foot; six-camera Vicon MX system with 120 Hz sampling rate to record 3D kinematic data of reaching arm with reflective markers.	Demand of reaching task affected dynamics of postural control and reaching performance among children with DS, especially when reaching past the length of the arm.

Legend: DS − Down syndrome; N − Normal.

processing, analysis procedures or communication of the results (Anastasia et al., 2012; Cioni et al., 2001; Galli et al., 2007; Geerts et al., 2003).

Most studies analyzed herein involved the kinematic analysis of upper limb movements of individuals with DS. (Vimercati et al., 2015) employed this analysis to evaluate fine motor skills during a drawing task and found that individuals with DS tended to draw more quickly, but with less precision in comparison to individuals with typical development (Vimercati, Galli, Rigoldi, Ancillao, & Albertini, 2013a). Vimercati et al. (2013a); Vimercati, Galli, Rigoldi, Ancillao and Albertini (2013b) found that the presence of obstacles during a movement task led to changes in motor strategies in individuals with DS, with a destabilizing effect that made the subjects trust more in the feedback control (Vimercati et al., 2013b). Thus, focused rehabilitation could help patients with DS develop more effective motor strategies in the presence of motor uncertainty.

In the present review, a variety of mechanical models, number of segments, degrees of freedom and marker placement methods were found, with no consensus on a standardized evaluation (Anastasia et al., 2012). In the next section, the characteristics of kinematic analysis are presented for the different tasks, including spatiotemporal variables, joint angles and movement trajectories, along with the contextual influences of the interventions (Anastasia et al., 2012; Cioni et al., 2001; Galli et al., 2007).

There is substantial interest among researchers, therapists and physicians in the use of three-dimensional movement analysis for the evaluation of upper limb movements in pediatrics. The objectivity of this form of analysis furnishes more sensitive information regarding the movement pattern in comparison to clinical assessments, thereby assisting in the planning of treatment. Various biomechanical models have been proposed. However, such models vary considerably in terms of complexity, the number of segments, degrees of freedom and marker placement (Guimarães and Blascovi-Assis, 2012).

Two of the five studies analyzed herein did not use kinematic analysis as the main form of evaluation. The aim of the study by Masumoto, Abe, and Inui (2012) was to examine the control of force and time during one-hand and two-hand reaching activities to determine the different strategies employed between adolescents with DS and a population with typical development. A self-stimulated test was used after three practice trials, synchronized to simultaneous audible feedback of the force output. All tasks consisted of a target force of 2N and a target intercalation interval of 500 ms. The adolescents with DS demonstrated a greater magnitude of positive constant error and variable error for peak force in comparison to adolescents with typical development. Those with DS also demonstrated a greater magnitude of negative constant error and variable error for the intercalation interval. Although a linear relationship between peak force and press duration was found among the adolescents with typical development, the relationship was not linear for adolescents with DS (Chen et al., 2015; Masumoto et al., 2012; Vimercati et al., 2013a; Vimercati et al., 2013b; Vimercati et al., 2015).

One study did not perform a specific evaluation of the upper limbs, but was included in the present review due to its aim of investigating dynamic postural control in children with DS. Dynamic balance was evaluated on a force plate during the task of touching a button after receiving an audible signal. The movement was performed at three different distances. The results demonstrated that the task affected both the dynamics of postural control as well as reaching performance in the children with DS, especially when reaching past the length of the arm, as greater postural adjustment strategies were recruited when the distance was beyond arm length. Children with DS tend to use inefficient, conservative strategies for stability and reaching, performing a reaching task with increases in reaction and execution time as well as a reduction in the amplitude of displacements of the center of pressure (Masumoto et al., 2012).

The analysis of the studies included in the present review demonstrates the predominance of the use of kinematics for the evaluation of the upper limb movement in children with DS, however, no standardization was found among the studies included in the present review with regard to data collection, data processing and evaluation procedures.

Standardization of an upper limb movement analysis protocol using kinematics would provide the basis for comparable, reproducible results and facilitate the planning of treatment interventions. Thus, there is a need for future clinical trials to employ standardized methods.

Conflict of interest

The authors declare that they have no conflicts of interest.

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References

Aiello-Vaisberg, T. M. J. (1999). Dreams of born and the primary maternal concern. *Psyche, 3*, 131–143.

Almeida, G. L., Corcos, D. M., & Hansan, Z. (2000). Horizontal-plane arm movements with direction reversals performed by normal individuals and individuals with Down syndrome. *Journal of Neurophysiology, 84*(4), 1949–1960.

Anastasia, T., et al. (2012). Biomechanical evaluation of the push-up exercise of the upper extremities from various starting points. *Journal of Physical Education and Sport, 12*(1), 71–80.

Andel, S. V., Cole, M. H., & Pepping, G. J. (2016). A systematic review on perceptual-motor calibration to changes in action capabilities. *Human Movement Science, 51*,

59–71.
Bell, J. A., Pearn, J. H., & Firman, D. (1989). Childhood deaths in Down's Syndrome. Survival curves and causes of death from a total population study in Queensland, Australia, 1976–1985. *Journal of Medical Genetics, 26*, 764–768.
Bomono, L. M. M., & Rosseti, C. B. (2010). Aspects in perceptual-motor development and sensory-motor intelligence in Down syndrome. *Revista Brasileira de Crescimento e Desenvolvimento Humano, 3*.
Borenstein, M., Hedges, L. V., Higgins, J. P. T., & Rothstein, H. R. (2009). *Introduction to meta analysis.* Chichester: John Wiley & Sons.
Butler, E. E., & Rose, J. (2012). The pediatric upper limb motion index and a temporal-spatial logistic regression: Quantitative analysis of upper limb movement disorders during the Reach & Grasp Cycle. *Journal of Biomechanics, 45*, 945–951.
Chen, H. L., Yeh, C. F., & Howe, T. S. (2015). Postural control during standing reach in children with Down syndrome. *Research in Developmental Disabilities, 38*, 345–351.
Cioni, M., Cocilovo, A., Rossi, F., Paci, D., & Valle, D. (2001). Analysis of ankle kinetics during walking in individuals with down syndrome. *American Journal of Mental Retardation, 106*(5), 470–478.
Crower, M., & Sheppard, L. (2011). A review of critical appraisal tools show they lack rigor: Alternative tool structure is proposed. *Journal Clinic of Epidemiologic, 64*(1), 79–89.
Crower, M., Sheppard, L., & Campbell, A. (2012). Reliability analysis for a proposed critical appraisal tool demonstrated value for diverse research designs. *Journal Clinic of Epidemiologic, 65*(4), 375–383.
Curie, A., Nazir, T., Brun, A., et al. (2014). The c.429_452 duplication of the *ARX* gene: A unique developmental-model of limb kinetic apraxia. *Orphanet Journal of Rare Diseases, 9*, 25.
De Kegel, A., Dhooge, I., Peersman, W., Rijckaert, J., Baetens, T., Cambier, D., et al. (2010). Construct validity of the assessment of balance in children who are developing typically and in children with hearing impairments. *Physical Therapy, 90*, 1783–1794.
Dessen, M. A., & Pereira-Silva, N. L. (2000). Deficiência mental e família: uma análise da produção científica. *Cadernos de Psicologia e Educação Paidéia, 10*, 12–23.
Duarte, N. A. C., Grecco, L. A., Galli, M., Fregni, F., & Oliveira, C. S. (2014). Effect of transcranial direct-current stimulation combined with treadmill training on balance and functional performance in children with cerebral palsy: a double-blind randomized controlled trial. *PLoSOne, 9*(8), e105777.
Ferreira, D. M., & Salles, B. F. (2009). Miranda DVl Funcionalidade de crianças com e sem Síndrome de Down. *Revista Neurociências, 17*, 231–238.
Ferreira, M. D., Salles, B. F., Marques, D. V. M., et al. (2009). Functionality of children with and without Down Syndrome. *Revista Neurociências, 17*, 231–328.
Gage, J. R., & Novacheck, T. F. (2001). An update on the treatment of gait problems in cerebral palsy. *Journal of Pediatric Orthopaedics B, 10*, 265–274.
Galli, M., Rigoldi, C., Mainardi, L., Tenore, N., Onorati, P., & Albertini, G. (2007). Postural control in subjects with Down Syndrome. *Disability and Rehabilitation, 30*(17), 1274–1278.
Geerts, W. K., Einspieler, C., Dibiasi, J., Garzarolli, B., & Bos, A. F. (2003). Development of manipulative hand movements during the second year of life. *Early Human Development, 75*(1-2), 91–103.
Gianni MAC, Aspectos clínicos In: Moura EW, Silva PAC. (org.). Fisioterapia aspectos clínicos e práticos da reabilitação. São Paulo: Artes Médicas, 2005. p. 13-25.
Goldinf, J., Emmentt, P., Caven- lhes, Y., Steer, C., et al. (2014). A review of environmental contributions to childhood motor skills. *Journal of Child Neurology, 29*(November (11)), 1531–1547.
Grecco, L. A., Duarte, N. A., Zanon, N., et al. (2014). Effect of a single session of transcranial direct current stimulation on balance and spatiotemporal gait variables in children with cerebral palsy: A randomized sham-controled study. *Brazilian Journal of Physical Therapy, 18*(5).
Guimarães, R., & Blascovi-Assis, S. (2012). Uso do Teste Caixa e Blocos na avaliação de destreza manual em crianças e jovens com síndrome de Down. *Revista de Terapia Ocupacional da Universidade de São Paulo, 23*(1), 98–106.
Jaspers, E., Feys, H., Bruyninckx, H., Harlaar, J., Molenaers, G., & Desloovere, K. (2011). Upper limb kinematics: Development and reliability of a clinical protocol for children. *Gait and Posture, 33*(2), 279–285.
Lazzari, R. D., Politti, F., Santos, C. A., et al. (2015). Effect of a single session of transcranial direct-current stimulation combined with virtual reality training on the balance of children with cerebral palsy: A randomized, controlled, double-blind trial. *Journal of Physical Therapy Science, 27*(3), 763–768.
Lewada, A. F., Matsoff, A., Revenis, M., Harahsheh, A., Futterman, C., Nino, G., et al. (2016). Preoperative evaluation and comprehensive risk assessment for children with Down syndrome. *Pediatric Anesthesia, 26*(4), 356–362.
Lin, H. C., & Wuang, P. Y. (2012). Strength and agility training in adolescents with Down syndrome: A randomized controlled trial. *Science Direct, 33*, 2236–2244.
Lopes, J. B. P., Grecco, L. A. C., Moura, R. F. C., et al. (2017). Protocol study for a randomised, controlled, double-blind, clinical trial involving virtual reality and anodal transcranial direct current stimulation for the improvement of upper limb motor function in children with Down syndrome. *BMJ Open, 7*, e016260.
Macedo, L. G., Elkins, M. R., Maher, C. G., Moseley, A. M., Herbert, R. D., & Sherrington, C. (2010). There was evidence of convergent and construct validity of physiotherapy evidence database quality scale for physiotherapy trials. *Journal of Clinical Epidemiology, 63*(8), 920–925.
Mancini, M. C., Silva, P. C., Gonçalves, S. C., & Martins, S. (2003). Comparison of functional performance among children with Down syndrome and children with age-appropriate development at 2 and 5 years of age. *Arqu. Neuro. Psiqui. Arq. Neuropsiquiatr, 61*(2–B), 409–415.
Mancini, M. C., Cardoso, J. R., Rosana, F., et al. (2014). Tutorial para elaboração de revisões sistemáticas para o. *Braz Journal of Physical Therapy Science, 18*(November-December (6)), 471–480.
Masumoto, J., Abe, T., & Inui, N. (2012). Adolescents with Down syndrome exhibit greater force and delay in onset of tapping movements. *Perceptual Motor Skills, 114*, 826–836.
Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & PRISMA Group (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *British Medical Journal, 21*(339), b2535.
Moura, R. C. F., Almeida, C. S., Dumont, A., Lazzari, R. D., Lopes, J. B., Duarte, N. A., et al. (Almeida et al., 2016b). Kinematic upper limb evaluation of children and adolescents with cerebral palsy: A systematic review of the literature. *Journal of Physical Therapy Science, 28*(2), 695–700.
Moura, R. F. C., Grecco, L. A. C., Santos, C., Lazarri, R. D., Duarte, N. C., & Lopes, J. B. P. (Grecco et al., 2016a). Transcranial direct current stimulation combined with upper limb functional training in children with spastic, hemiparetic cerebral palsy: Study protocol for a randomized controlled trial. *Clinical Trials, 17*(405).
Perera, R., & Heneghan, C. (2008). Interpreting meta-analysis in systematic reviews. *Evidence-Based Medicine, 13*(3), 67–69.
Santos, C. A., Moura, R. C. F., Lazzari, R. D., Dumont, A. J. L., Braun, L. A., & Oliveira, C. S. (2015). Upper limb function evaluation scales for individuals with cerebral palsy: A systematic review. *Journal of Physical Therapy Science, 27*(6), 1617–1620.
Schneiberg, S., McKinley, P. A., Sveistrup, H., Gisel, E., Mayo, N. E., & Levin, M. F. (2010). The effectiveness of task-oriented intervention and trunk restraint on upper limb movement quality in children with cerebral palsy. *Developmental Medicine & Child Neurology, 52*(11), 245–253.
Sonne, J., & Jennifer, J. (2004). Motor skill learning research looks beyond Outcomes—Understanding the components needed for skilled performance helps develop instructions and training methods. *Biomechanics, 69*(June (1)).
Vimercati, S. L., Galli, M., Rigoldi, C., Ancillao, A., & Albertini, G. (2013a). Feedback reliance during an arm-tapping task with obstacle avoidance in adults with Down syndrome. *Experimental Brain Research, 226*(4), 631–638.
Vimercati, S. L., Galli, M., Rigoldi, C., Ancillao, A., & Albertini, G. (2013b). Motor strategies and motor programs during an arm tapping task in adults with Down syndrome. *Experimental Brain Research, 3*, 333–338.
Vimercati, S. L., Galli, M., Stella, G., Caiazzo, G., Ancillao, A., & Albertini, G. (2015). Clumsiness in fine motor tasks: Evidence from the quantitative drawing evaluation of children with Down syndrome. *Journal of Intellectual Disability Research, 59*(3), 248–256.