DOI: 10.1590/1809-2950/e23004523en

Use of the modified sphygmomanometer test to assess muscle strength in children and adolescents: a systematic review

Aplicação do teste do esfigmomanômetro modificado na avaliação da força muscular de crianças e adolescentes: uma revisão sistemática

Aplicación de la prueba del esfigmomanómetro modificada en la evaluación de la fuerza muscular en niños y en adolescentes: una revisión sistemática

Júlia Caetano Martins[1], João Osmar Teixeira Matos[2], Taluane Vívian Gomes Alves[3], Alice Caroline Arnaldo Andrade[4], Cecília Ferreira de Aquino[5]

ABSTRACT: Evaluating muscle strength in the pediatric population allows comparing healthy and affected individuals, establishing recovery goals, tracking the results of interventions and the evolution over time due to health conditions, as well as monitoring load progression and level of training. The Modified Sphygmomanometer Test (MST) is a technique used to measure isometric muscle strength in this population. The objective of the study is to gather and synthesize studies that used MST to measure the muscular strength of children and adolescents, identifying the muscle groups, measurement properties investigated, and the applied protocols. Bibliographic search was conducted on the MEDLINE, Embase, PEDro, SciELO, and LILACS databases. Original, peer-reviewed studies published up to September 2021 that evaluated isometric muscle strength using MST in children and adolescents aged 0 to 19 years were selected. A total of 1,610 studies were identified, and 17 were considered eligible. Of these, 12 studies (70.6%) were conducted with a mixed population and five (29.4%) with only children and adolescents. The most evaluated muscle groups were hip adductors (47.5%) and handgrip (29.4%) with a predominance of the non-adapted sphygmomanometer (47.1%) and 20mmHg pre-insufflation (47.1%). Only six studies (35.3%) evaluated MST measurement properties . In conclusion, there are few studies aimed at the pediatric population, which hinders the standardization of MST application in clinical practice, despite being easy to access and handle.

Keywords | adolescents, children, muscle strength.

RESUMO: A avaliação da força muscular na população pediátrica possibilita comparar indivíduos saudáveis e com alguma condição de saúde, estabelecer metas de recuperação, acompanhar os resultados das intervenções e a evolução ao longo do tempo, além de permitir monitorar a progressão de carga e o nível de treinamento. O teste do esfigmomanômetro modificado (TEM) é uma técnica que pode ser usada para mensurar a força muscular isométrica dessa população. O objetivo do estudo foi reunir e produzir uma síntese dos estudos que utilizaram o TEM para mensuração da força muscular de crianças e adolescentes, identificando os grupos musculares e as

Partial results were presented on the 22º Seminário de Pesquisa e Extensão at UEMG, held on November 2020.

[1] Universidade do Estado de Minas Gerais, Divinópolis (MG), Brazil. E-mail: julcmart@gmail.com.
Orcid: https://orcid.org/0000-0002-9084-1019
[2] Universidade do Estado de Minas Gerais, Divinópolis (MG), Brazil. E-mail: joaoosmar18@gmail.com.
Orcid: https://orcid.org/0000-0002-8429-264X
[3] Universidade do Estado de Minas Gerais, Divinópolis (MG), Brazil. E-mail: taluvivian@gmail.com.
Orcid: https://orcid.org/0000-0001-6768-031X
[4] Universidade do Estado de Minas Gerais, Divinópolis (MG), Brazil. E-mail: aliceecarolineaa@gmail.com.
Orcid: https://orcid.org/0000-0002-7464-6117
[5] Universidade do Estado de Minas Gerais, Divinópolis (MG), Brazil. E-mail: ceciliafaquino@gmail.com.
Orcid: https://orcid.org/0000-0001-8393-771X

Corresponding address: Cecília Ferreira de Aquino – Avenida Paraná, 3001, Belvedere II, – Divinópolis (MG) – Zip Code: 35.501-170 – E-mail: ceciliafaquino@gmail.com –
Financing source: Nothing to declare – Conflict of interests – Nothing to declare – Presentation: Ago. 17th 2023 – Publication: Apr. 29th 2024 – Project registered at PROSPERO under protocol CRD42021230195.

propriedades de medida investigados e os protocolos aplicados. A busca foi realizada nas bases de dados MEDLINE, EMBASE, PEDro, SciELO e LILACS. Foram selecionados estudos originais, revisados por pares, publicados até setembro de 2021, que avaliaram a força muscular isométrica com o uso do TEM em crianças e adolescentes com idade entre 0 e 19 anos. Um total de 1.610 estudos foram obtidos na busca, sendo 17 elegíveis. Destes, 12 estudos (70,6%) foram realizados com população mista, e cinco (29,4%), somente com crianças e adolescentes. Os grupos musculares mais avaliados foram os adutores de quadril (47,1%) e preensão palmar (29,4%), com predominância do esfigmomanômetro não adaptado (47,1%) e pré-insuflação de 20mmHg (47,1%). Apenas seis estudos (35,3%) avaliaram as propriedades de medida do TEM. Conclui-se que existem poucos estudos voltados à população pediátrica, o que dificulta padronizar a aplicação do TEM na prática clínica, apesar de o instrumento ser de fácil acesso e manuseio.

Descritores | Adolescentes; Crianças; Força muscular.

RESUMEN: La evaluación de la fuerza muscular en la población pediátrica permite comparar a individuos sanos con alguna condición de salud, establecer metas de recuperación, monitorear los resultados de las intervenciones y la evolución en el tiempo, además de monitorear la progresión de la carga y el nivel de entrenamiento. La prueba del esfigmomanómetro modificado (TEM) es una técnica que se puede utilizar para medir la fuerza muscular isométrica de esta población. El objetivo de este estudio fue recopilar y producir una síntesis de los estudios que utilizaron la TEM para medir la fuerza muscular en niños y en adolescentes, identificando los grupos musculares, las propiedades de medición investigadas y los protocolos aplicados. La búsqueda se realizó en las bases de datos MEDLINE, EMBASE, PEDro, SciELO y LILACS. Se seleccionaron estudios originales, revisados por pares, publicados hasta septiembre de 2021, que evaluaron la fuerza muscular isométrica con el uso de TEM en niños y en adolescentes de entre 0 y 19 años de edad. Se obtuvieron un total de 1.610 estudios en la búsqueda, de los cuales 17 fueron elegibles. De estos, 12 estudios (70,6%) se realizaron con una población mixta, y cinco (29,4%) solo con niños y adolescentes. Los grupos musculares más evaluados fueron los aductores de la cadera (47,1%) y agarre de palma (29,4%), con predominio del esfigmomanómetro no adaptado (47,1%) y preinflado de 20mmHg (47,1%). Solo seis estudios (35,3%) evaluaron las propiedades de medición de TEM. Se concluye que existen pocos estudios centrados en la población pediátrica, lo que dificulta la estandarización de la aplicación de TEM en la práctica clínica, a pesar de que el instrumento es de fácil acceso y manejo.

Palabras clave | Adolescentes; Niños; Fuerza muscular.

INTRODUCTION

Muscle strength is directly related to one's quality of life and functionality[1]. Deficits in muscle strength can limit activities of daily living and restrict social participation since this physical attribute is necessary for the proper performance of various activities, e.g., reaching and manipulating objects, walking, self-care, and work activities[2]. In children and adolescents, muscle strength is indispensable for adequate motor development and is directly related to a good health prognosis[3]. Hence, evaluating muscle strength in the pediatric population is essential for the functional diagnosis and prescription of an adequate intervention plan in physiotherapy rehabilitation[4].

To assist in strength training and rehabilitation, it is essential to use appropriate and accessible instruments to perform assessments. By assessing muscle strength we can compare healthy and affected individuals, establish recovery and rehabilitation goals, track the results of interventions and evolution over time, as well as monitor load progression and training level[5]. It is therefore necessary to know the evidence on the use of a muscle strength assessment instrument so that it can be used in clinical practice.

Currently, the modified sphygmomanometer test (MST) is an alternative method being used to measure muscle strength. It encompasses the advantages of manual muscle testing and the portable dynamometer, providing objective measurements at low cost[6]. MST measures isometric muscle strength using a conventional aneroid sphygmomanometer[7]. It is portable, easy to handle and maintain, and often accessible to healthcare providers[6]. MST has already demonstrated adequate measurement properties when used to evaluate muscle strength in healthy adults and older adults, individuals with rheumatoid arthritis, post-stroke, and Parkinson's disease[8-13].

Two reviews on sphygmomanometer use to measure muscle strength have already been described in the literature[6,14]. Souza et al.[6] investigated MST use to assess muscle strength in different muscle groups and populations and mentioned previously studied measurement properties.

The authors identified only two studies that used MST to assess grip strength in children[15-16]. Toohey et al.[14] investigated MST measurement properties in measuring the isometric strength of hip muscles among different populations, such as hospitalized older adults, soccer athletes, and healthy students. The authors identified only three studies that used MST to assess hip muscle strength in adolescents[17-19]. Consequently, the results obtained in these two reviews do not allow us to extract precise information on MST use in children and adolescents, as they did not focus on the pediatric population and did not involve the terms in which this population is referred to in the search strategies. Moreover, the body of knowledge regarding MST must be updated since the last available review was published in 2015. Considering the importance of measuring muscle strength in the pediatric population and the advantages of using MST in clinical practice[3,2,8], an in-depth study on MST use to assess muscle strength in children and adolescents is necessary. Thus, this study gathered and produced a synthesis of studies that used MST to measure muscle strength in children and adolescents. As such, we identified the muscle groups already studied, the protocols used for MST use, the measurement properties investigated in this population and the existing gaps on the topic to guide new research in rehabilitation.

METHODOLOGY

Study design

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) recommendations and was registered in Prospero under CRD protocol 42018106702.

Eligible studies

We included original, peer-reviewed studies conducted with children and adolescents aged 0 to 19 years that assessed isometric muscle strength with MST. Studies that included part of this population in their sample were also included. Studies that used MST to measure blood pressure and not muscle strength, as well as gray literature (abstracts published in events, theses, dissertations, etc.) were excluded. There was no restriction regarding study design, date, or language of publication.

Data sources and search strategies

Bibliographical search was conducted on the MEDLINE (via PubMed), Embase, PEDro, SciELO, and LILACS databases. A search strategy was developed for MEDLINE involving descriptors related to the instrument used (sphygmomanometer) and the population (children and adolescents) (see Appendix). This strategy was adapted for the other databases.

SELECTION OF STUDIES

After searching the electronic databases, two independent evaluators selected the studies published up to September 2021. After excluding duplicates, study selection was divided into three stages. First, the evaluators analyzed the titles of all the studies identified and excluded those that did not meet the established inclusion criteria. Next, the abstracts of the previously selected studies were read and analyzed, and those that did not meet the eligibility criteria were excluded. Finally, the evaluators read the remaining studies in full.

The references of the included articles and previous reviews were analyzed and used as an additional source to identify other studies of interest. The inclusion of studies in the review was made after discussion and consensus between the two evaluators.

Data extraction

We extracted from each selected study the following information: date of publication; study design; number of participants, together with sample characterization (age, sex and body mass index); muscle groups evaluated; protocol used to assess muscle strength; type of sphygmomanometer used (adapted or not adapted); and measurement properties investigated (validity, reliability, and responsiveness).

Magnitude of the intraclass correlation coefficient and Pearson's correlation coefficient was evaluated using the Munro et al.[20] classification. In the case of significant correlations between variables, the magnitude of the correlation was classified as very low≤0.25, low=0.26-0.49, moderate=0.50-0.69, high=0.70-0.89, and very high=0.90-1.00.

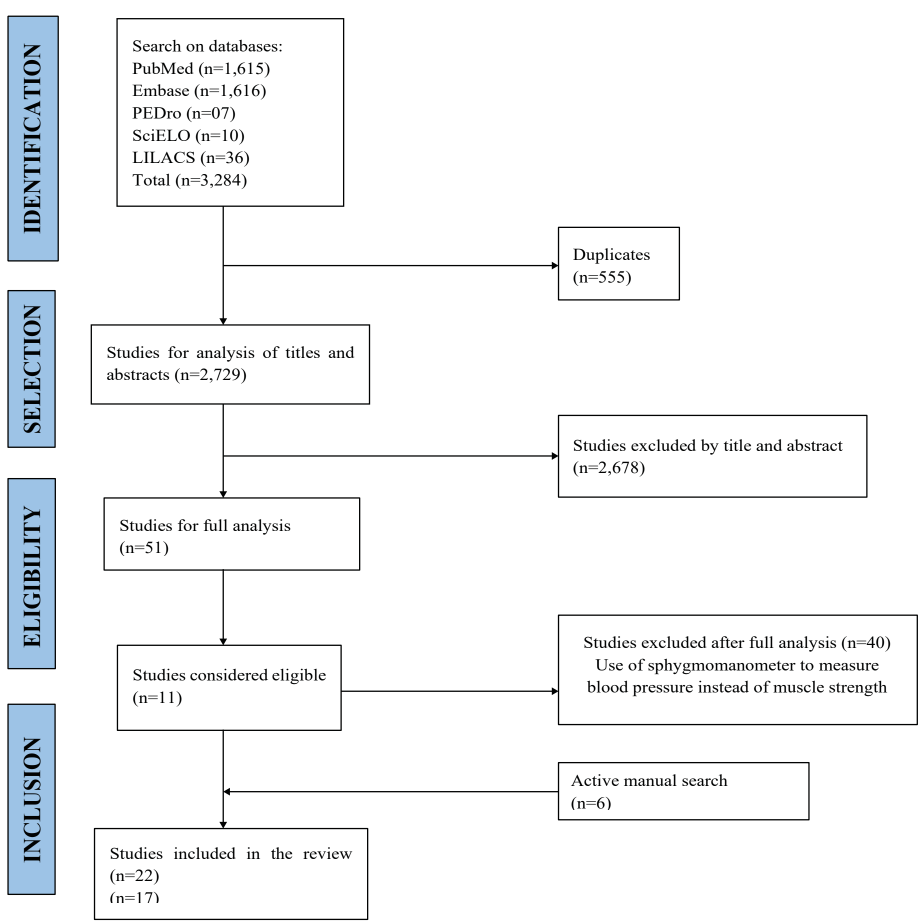
Quality assessment of studies

The methodological quality of the studies was assessed using the Consensus-based Standards for the Selection of Health Measurement Instruments (COSMIN), which aims to improve the selection of instruments for measuring results, both in research and in clinical practice, developing tools for selecting the most appropriate instrument. COSMIN evaluates nine measurement properties grouped into three domains: reliability, validity, and responsiveness[21,22]. Reliability evaluates internal consistency, test-retest, intra- and inter-rater reliability, and measurement error[21,22]. Validity assesses construct validity (structural validity and hypothesis testing), criterion validity, and content validity[21,22]. Each measurement property has four to 18 items to be evaluated and scored on a four-point rating scale[22]. The lowest score received on an item consists of the overall classification of the methodological quality of the measure property analyzed. The methodological quality of each measurement property was then classified as excellent, good, moderate, or poor, following the COSMIN criteria[23].

RESULTS

The electronic searches identified a total of 3,284 studies. After removing duplicates (n=555), 2,729 studies remained. Next, the selection based on titles and abstracts considered 51 studies as potentially eligible. After full text analysis, only 11 studies met the eligibility criteria, whereas the others were excluded for using MST to measure blood pressure instead of measuring muscle strength. Active manual search performed on the reference list of included studies identified other six articles, totaling 17 studies. Figure 1 shows the flowchart for search and studies selection.

Figure 1. Flowchart for search and studies selection



Of the 17 studies included, 12 (70.6%)[10,17-19,24-31] were conducted with mixed population (children/adolescents and adults) and five (29.4%)[15-16,32-34] only with children and adolescents (0 to 19 years old). Overall, the age of the samples ranged from 6 to 65 years. In the studies that reported participant gender (n=15), male subjects predominated (n=12; 80%). Thirteen studies (76.5%) were conducted with healthy subjects [16-19,24-25,27-32,34], five (n=5; 38.5%) included rugby or basketball and volleyball athletes, and the others were non-athletes (n=8; 61.5%). Three studies (17.6%) involved individuals with different health conditions: patients with spinal muscular atrophy (n=1; 33.3%)[33] and rheumatoid arthritis (n=2; 66.7%)[15-16]. Table 1 presents the characteristics of the included studies.

Table 1. Characteristics of reviewed studies that used the modified sphygmomanometer test (MST) to assess muscle strength in children and adolescents (n=17)

Study(study design)	Objectives	Sample	Sphygmomanometer fitting and calibration	Protocol
Helewa et al., 198110 (cross-sectional) Database/source (MEDLINE) Ethical approval NR	To evaluate the concurrent criterion validity and inter-rater reliability of the sphygmomanometer and a weight measurement method for measuring knee EXT strength in individuals with rheumatoid arthritis	Population: individuals with rheumatoid arthritis N=5 Age: 18 to 65 years Gender: F: 3 (66%) M: 2 (34%) BMI: NR	Adaptation: bag and cuff Equipment preparation: 20mmHg pre-inflation Calibration: Yes	Muscle group: knee EXT Familiarization with the test: the methods were explained to each individual and pre-tested on the opposite leg Number of repetitions: 1 Contraction time: 5s Resting time: NR Verbal stimulus: NR Participant positioning: SP, upper limbs at the side of the body, thighs supported, hip joint flexed at 45° and knee flexed at 90°; The examiner passively positioned the subject's MI to maintain a 90° angle at the knee joint; the individual was asked to maintain the position while the examiner applied resistance gradually (with open hands on the equipment). Position of the equipment: placed above the ankle, longitudinally
Balogun et al., 199024 (cross-sectional) Database/source (retrieved from Toohey et al., 2018)29 Ethical approval NR	To evaluate the modified sphygmomanometer reproducibility during HG force measurement; determine the relations between the modified sphygmomanometer and dynamometer readings, derive a linear regression equation to predict HG strength from modified sphygmomanometer measurements and to determine the relative contribution of age, body, weight, and height to predicting HG strength	Population: healthy adolescents and adults N=34 Age: 16 to 28 years Gender: F: 6 (18%) M: 28 (82%) BMI: NR	Adaptation: bag Equipment preparation: 20mmHg pre-inflation Calibration: NR	Muscle group: HG Familiarization with the test: each individual underwent two experimental sessions Number of repetitions: 2, considering the higher value Contraction time: 5 s + 2 s for reading Resting time: 5 min Verbal stimulus: NR Participant positioning: standing with the shoulder adducted and rotated neutral, elbow joint kept in full extension and the forearm in a neutral position Equipment Position: palm

Dunn, 199316 (cross-sectional) Database/source (MEDLINE) Ethical approval NR	To gather data on HG strength of typical children aged 3 to 7 years using MST, and to compare the HG strength of a preliminary sample of children with rheumatic disorders with the HG strength of typical children	Population: children with rheumatic disorders and typical children N=273 Age: 3 to 7 years Gender: F: 132 (48%); M: 141 (52%) BMI: NR	Adaptation: bag Equipment preparation: 20mmHg pre-inflation Calibration: Yes	Muscle group: HG Familiarization with the test: the position was explained verbally and demonstrated as many times as necessary Number of repetitions: 3, analysis with arithmetic mean Contraction time: NR Resting time: 15s Verbal stimulus: Yes Participant positioning: child seated in a chair, hip joint flexed at 90° bilaterally, both feet resting on the floor before the chair. upper limbs adducted, elbows flexed at 90°, forearm supinated and wrist in neutral position Equipment position: palm
Koch and Simenson, 199233 (prospective cohort) Database/source (MEDLINE) Ethical approval NR	To document how the muscles of the distal extremities of upper limbs may function as a primary resource for hand function, ADLs, and mobility in children with spinal muscular atrophy type II and to describe the natural history of the disease	Population: children with spinal muscular atrophy type II N=10 Age: NR Gender: NR BMI: NR	Adaptation: NR Equipment preparation: NR Calibration: NR	Muscle group: HG Familiarization with the test: NR Number of repetitions: NR Contraction time: NR Resting time: NR Verbal stimulus: NR Participant positioning: NR Equipment Position: NR
Barden et al., 199515 (case report) Database/source (MEDLINE) Ethical approval NR	To describe a physical therapy protocol for treating wrist subluxation in children with arthritis	Population: children with arthritis N=2 Age: 5 and 17 years Gender: F: 1 (50%); M: 1 (50%) BMI: NR	Adaptation: NR Equipment preparation: NR Calibration: NR	Muscle group: HG Familiarization with the test: NR Number of repetitions: 3 (analysis with the highest value) Contraction time: 10s Resting time: NR Verbal stimulus: NR Participant positioning: NR Equipment Position: NR

Soares & Riedel, 199725 (cross-sectional) Database/source (MEDLINE) Ethical approval NR	To compare the manual forceps of individuals affected by leprosy with healthy individuals using a neonatal sphygmomanometer	Population: individuals with leprosy and unaffected N=78 Age: 15 to 55 years Gender: NR BMI: NR	Adaptation: bag (neonatal sphygmomanometer) Equipment preparation: 20mmHg pre-inflation Calibration: NR	Muscle group: palmar pinch, tree-point pinch, and lateral pinch Familiarization with the test: NR Number of repetitions: NR Contraction time: NR Resting time: NR Verbal stimulus: NR Participant positioning: NR Position of the equipment: palmar pinch: between the thumb and each of the fingers; lateral pinch: between the thumb and the side of the index finger; and three-point pinch: between the index and middle fingers, middle and ring fingers, ring and little fingers
Perossa et al., 199819 (cross-sectional) Database/source (retrieved from Souza et al., 2013)6 Ethical approval NR	To investigate the intra-examiner reliability of manual shoulder and hip muscle assessment using MST	Population: typical student volunteers N=80 Age: 19 to 22 years Gender: F: 40 (50%); M: 40 (50%) BMI: NR	Adaptation: none Equipment preparation: 20mmHg pre-inflation Calibration: NR	Muscle group: FLX, EXT, ABD, shoulder RI and RE, EXT, hip FLX and ABD Familiarization with the test: the participant was allowed to practice the movements before performing the test Number of repetitions: NR Contraction time: NR Resting time: 30 to 35s Verbal stimulus: NR Participant positioning: Shoulder FLX: seated, shoulder flexed at 30°; Shoulder EXT: seated, shoulder extended at 20°; Shoulder ABD: seated, shoulder abducted at approximately 35°; RI: seated, elbow flexed at 90°; RE: seated, elbow flexed at 90°; Hip EXT: prone position, equipment behind the knee. Participant bent their leg at 90º and raised their thigh 15º to 20º from the table; Hip FLX: supine position, with thigh and knee bent at 90º. Equipment positioned in the anterior region near the knee; Hip ABD: LD, equipment on the side of the knee, instructed to initiate the action by pushing upwards Equipment Position: Shoulder FLX: on the forearm above the elbow; EXT of shoulder: on the inside of the forearm; Shoulder ABD: in the middle of the forearm; Shoulder RI: NR; Shoulder RE: above the outside of the wrist; Hip EXT: behind the knee; Hip FLX: in front of the knee; Hip ABD: on the side of the knee

Suresh et al., 200826 (prospective cohort) Database/source (MEDLINE) Ethical approval Indian Council of Medical Research and the Research Ethics Committee of the JALMA Central Institute of Leprosy in Agra	To evaluate hand muscle weakness using dynamometry as an indicator of alteration in motor nerve function detected by the voluntary test of muscles innervated by the ulnar and median nerves	Population: individuals newly diagnosed with multibacillary leprosy N=303 Age: 12 to 60 years old (mean of 32.8) Gender: F: 83 (27%) M: 220 (73%) BMI: NR	Adaptation: cuff Equipment preparation: 20mmHg pre-inflation Calibration: NR	Muscle group: HG, palmar pinch, and lateral pinch Familiarization with the test: all test procedures were described in detail in a procedure manual Number of repetitions: 3, analysis with arithmetic mean Contraction time: NR Resting time: NR Verbal stimulus: Yes Participant positioning: seated in a chair whose arms served as support for the upper limbs, feet resting on the floor. Palmar pinch: forearm in neutral position, wrist slightly extended, finger joints slightly flexed, thumb between flexion and opposition, interphalangeal joint extended; lateral pinch: UL close to the trunk, elbow flexed, forearm pronated, wrist extended, metacarpophalangeal joint of the index finger flexed, interphalangeal joints extended, thumb in opposition. HG: shoulder abducted, elbow flexed at 90°, forearm in neutral position, wrist extended Equipment Position: NR
Malliaras et al., 200918 (prospective cohort) Database/source (retrieved from Toohey et al., 201514)29 Ethical approval La Trobe University, Melbourne, Australia	To identify reliable hip flexibility and strength measures among junior elite soccer players with and without groin pain	Population: soccer players N=29 Age: 15 to 21 years Gender: M: 29 (100%) BMI: NR	Adaptation: none Equipment preparation: 10mmHg pre-inflation Calibration: NR	Muscle group: Hip ABD Familiarization with the test: measurements were taken after a trial, for familiarization Number of repetitions: NR Contraction time: NR Resting time: NR Verbal stimulus: NR Participant positioning: supine position, three angles of hip flexion: 0°, 30° and 45° Equipment position: between the player's knees

Delahunt et al., 201127 (cross-sectional) Database/source (retrieved from Hodgson et al., 201428) Ethical approval College Dublin University	To evaluate the intra-rater reliability of a commercially available sphygmomanometer to measure ADD compression values in Irish soccer athletes and to determine if different compression values are associated with the three commonly used test positions	Population: Irish soccer athletes N=18 Age: 21.11±2.53 years Gender: M: 18 (100%) BMI: NR	Adaptation: none Equipment preparation: 10mmHg pre-inflation Calibration: NR	Muscle group: Hip ABD Familiarization with the test: 3 practical trials were allowed in each test position for familiarization with the protocol Number of repetitions: 3, considering the higher value Contraction time: NR Resting time: 2 min Verbal stimulus: NR Participant positioning: supine position with arms crossed and head resting on a cushion. Hip joints were kept in neutral rotation in each of the test positions. Three angles: 0º, 45º and 90º hip flexion Position of the equipment: between the knees at the most prominent point of the medial femoral condyles
Delahunt et al., 201127 (cross-sectional) Database/source (MEDLINE) Ethical approval College Dublin University	To investigate adductor muscle activity and concomitant pressure values while performing hip ADD compression test at 0°, 45° and 90° hip flexion of Irish soccer athletes without any history of groin injury	Population: Irish soccer athletes N=18 Age: 21.11±2.53 years Gender: M: 18 (100%) BMI: NR	Adaptation: none Equipment preparation: 10mmHg pre-inflation Calibration: NR	Muscle group: Hip ABD Familiarization with the test: three attempts at submaximal practice were allowed in each test position for familiarization with the procedures. Number of repetitions: 3, considering the higher value Contraction time: 5s Resting time: NR Verbal stimulus: NR Participant positioning: at 0° the hip joint was kept in a neutral rotation position. For the 45° and 90° hip flexion test positions, the knee joint was held at 90° flexion Equipment position: the sphygmomanometer cuff was placed between the knees

Coughlan et al., 201432 (cross-sectional) Database/source (retrieved from Souza et al., 201634)6 Ethical approval College Dublin University	To establish normative values of the ADD compression test in asymptomatic junior elite rugby players and to investigate whether there are differences between the player's position on the field and the category	Population: asymptomatic rugby players N=104 Age: 17.56±0.54 years Gender: M: 104 (100%) BMI: NR	Adaptation: none Equipment preparation: 10mmHg pre-inflation Calibration: NR	Muscle group: Hip ABD Familiarization with the test: before the validity test, each participant became familiar with the protocol, was informed about the test procedure and allowed to perform three submaximal efforts in each of the test positions Number of repetitions: 3, considering the higher value Contraction time: NR Resting time: 15s between each rep and a 45s rest between each test position Verbal stimulus: NR Participant positioning: supine position, with the head resting on the stretcher and the arms on the chest. Three angles: 0º, 45º and 90º hip flexion Equipment position: the cuff was positioned so that the middle third rested at the most prominent point of the medial femoral condyles
Hodgson et al., 201428 (cross-sectional) Database/source (Embase) Ethical approval NR	To determine the normative values of hip ADD strength in professional rugby players using a sphygmomanometer cuff in different test positions	Population: rugby players N=81 Age: <18 to >30 years Gender: M: 81 (100%) BMI: 29.0kg/m2 (3.0kg/m2)	Adaptation: none Equipment preparation: 20mmHg pre-inflation Calibration: NR	Muscle group: Hip ABD Familiarization with the test: all participants were familiar with the tests and had received training in their use to improve inter-rater reliability Number of repetitions: NR Contraction time: 2 to 3s Resting time: NR Verbal stimulus: NR Participant positioning: 0° test: athlete in SP on the pedestal with the ankles together. 60° test: athlete in SP and then flexing the knee and hip until the heel of the foot aligned with the medial joint line of the opposite knee, the other foot was brought to mirror this position, providing approximately 60° of hip flexion. 90° test with support, the athletes were instructed to place their legs in 90° hip and knee flexion and the examiner made the corrections relevant to the position while resting their arms under the athletes' knees and instructing them to relax to perform the test. For the 90° test without support, the athlete maintained this position without support of the examiner Equipment Position: NR

Roe et al., 201634 (prospective cohort) Database/source (retrieved from Tiernan et al., 201930) Ethical approval Leeds Beckett University	Firstly, to investigate the magnitude of the change in ADD strength after a match in rugby players using the ADD compression test. Secondly, to examine the relation between game displacement demands and changes in ADD strength	Population: rugby players N=14 Age: 17.4±0.8 years Gender: M: 14 (100%) BMI: NR	Adaptation: none Equipment preparation: 10mmHg pre-inflation Calibration: NR	Muscle group: Hip ABD Familiarization with the test: NR Number of repetitions: 3, considering the higher value Contraction time: NR Resting time: 30s Verbal stimulus: NR Participant positioning: SP with hip joints positioned in neutral rotation Equipment position: between the knees at the most prominent point of the medial condyles
Toohey et al., 201829 (prospective cohort) Database/source (MEDLINE) Ethical approval La Trobe University (FHEC13/064)	To investigate sphygmomanometer intra- and inter-rater reliability for assessing ADD compression test and isometric strength of the hip ABD muscles and to establish its concurrent validity for evaluating the same measurements compared with the reference standard of portable dynamometry	Population: soccer players N=32 Age: 23.9±4.5 years Gender: M: 32 (100%) BMI: NR	Adaptation: cuff Equipment preparation: 10mmHg pre-inflation Calibration: Yes	Muscle group: Hip ADD and ABD Familiarization with the test: NR Number of repetitions: NR Contraction time: 5s Resting time: 60s Verbal stimulus: NR Participant positioning: LD with the tested LL positioned superiorly at 0° flexion and abduction at the hip and full knee extension. Knee of the LL positioned inferiorly was flexed at 90° to provide stability Equipment position: the center of the device was placed 5cm proximal to the lateral malleolus
Tiernan et al., 201930 (prospective cohort) Database/source (MEDLINE) Ethical approval University of Limerick	To investigate the relation between ADD compression force values, subjective markers of recovery, and training load in elite rugby players	Population: elite rugby players N=19 Age: 19.7±1.1 years Gender: M: 19 (100%) BMI: NR	Adaptation: none Equipment preparation: 10mmHg pre-inflation Calibration: NR	Muscle group: Hip ABD Familiarization with the test: players were familiar with all testing protocols as a result of previous years of monitoring Number of repetitions: 1 Contraction time: 2 to 3s. Resting time: NR Verbal stimulus: NR Participant positioning: players lay on the floor with their hips held in a neutral position, knees bent at 90°, and hips flexed at 45° Equipment position: between the knees with the middle third of the cuff located at the most prominent point of the medial femoral condyles

Vishesh et al., 2020[31] (cross-sectional) Database/source (Embase) Ethical approval NR	To measure dominant HG strength with a modified sphygmomanometer and Its association with various hand and forearm anthropometric measurements in basketball and volleyball players	Population: basketball and volleyball players N=60 Age: 15 to 20 years Gender: F: 16 (27%) M: 44 (73%) BMI: 18.57±2.33	Adaptation: cuff Equipment preparation: 20mmHg pre-inflation Calibration: NR	Muscle group: HG Familiarization with the test: NR Number of repetitions: 3 Contraction time: NR Resting time: 5s Verbal stimulus: NR Participant positioning: players were positioned in a straight-backed chair, with both feet fully supported on the floor. Each player was instructed to place their left hand on the right thigh and assume the position with adducted shoulders in neutral rotation. For the arm tested, the elbow was flexed up to 90°, the forearm and wrist were in a neutral position, and the fingers were flexed Equipment Position: NR

Caption: ABD: abductors; ADD: adductors; ROM: range of motion; ADLs: activities of daily living; SP: supine position; LD: lateral decubitus; EXT: extensors; F: female; FLX: flexors; BMI: body mass index; M: male; LL: lower limbs; min: minutes; mmHg: millimeters of mercury; UL: upper limbs; NR: not reported; HG: handgrip; ER: external rotators; IR: internal rotators; s: seconds; MST: modified sphygmomanometer test.

To assess muscle strength, eight studies (47.1%)[17-19,27-28,30,32,34] used MST without any adaptation, four studies (23.5%) [10,16,24-25] used bag adaptation, and another four (23.5%)[10,26,29,31] the cuff method. Only Soares & Riedel[25] reported the use of a neonatal sphygmomanometer (bag method). Two studies (11.8%)[15,33] did not provide information about equipment adaptations. Regarding sphygmomanometer pre-inflation, seven studies (41.2%)[17-18,27,29-30,32,34] used an initial pressure of 10 mmHg, eight studies (47.1%)[10,16,19,24-26,28,31] 20mmHg, and two studies (11.8%)[15,33] did not provide this information.

The muscle groups evaluated were: hip adductors (n=8; 47.1%)[17-18,27-30,32,34]; handgrip (n=5; 29.4%)[15-16,24,26,31]; hip abductors (n=2; 11.8%)[19,29]; palmar and lateral pinch (n=2; 11.8%)[25-26]; hip flexors and extensors (n=1; 5.9%)[19]; knee extensors (n=1; 5.9%)[10]; flexors, extensors, abductors, internal and external rotators of the shoulder (n=1; 5.9%)[19]; and three-point pinch (n=1; 5.9%)[25].

MST protocols for muscle strength assessment in this population varied greatly. Eleven studies (64.7%)[10,15-17,24,26-27,30-32,34] reported the number of repetitions which ranged from one to three. Rest time between repetitions was reported in eight studies (47.1%)[16-17,19,24,29,32-31,34] and ranged from 15 seconds to five minutes. Contraction time during the test was reported in seven studies (41.2%)[10,15,24,27-30] and ranged from two to ten seconds. Eleven studies (64.7%)[10,16-19,24,26-28,30,32] reported participants' familiarity with the test, and only two

(11.8%)[16,26] described the verbal stimulus provided during the test.

Of the 17 studies included, six (35.3%)[10,17,18,19,24,29] evaluated some MST measurement property. Three (17.6%) studies evaluated concurrent criterion validity, comparing MST measurements with those provided by a loading method[10] and by portable dynamometry[24,29]. All three studies (100%) reported that MST has adequate concurrent criterion validity with magnitude ranging from high to very high. Five studies (29.4%)[17,18,19,24,29] evaluated MST intra-rater reliability and reported adequate results, with magnitude ranging from moderate to very high. Three studies (17.6%)[10,18,29] evaluated MST inter-rater reliability and reported adequate results, with magnitude ranging from high to very high. Table 2 presents the results of studies that investigated MST measurement properties.

Table 2. Results of studies investigating the measurement properties of the modified sphygmomanometer test (n=6)

Study (study design)	Measurement properties	Muscle groups	Results
Helewa et al., 198110 (cross-sectional)	Concurrent criterion validity	Knee extensors	*r*=0.92 to 0.94
Balogun et al., 199024 (cross-sectional)	Concurrent criterion validity Intra-rater reliability	Handgrip Handgrip	*r*=0.84 to 0.99
Perossa et al., 199819 (cross-sectional)	Intra-rater reliability	Shoulder flexors, extensors, abductors, and internal and external rotators; flexors, extensors, hip abductors	*ICC*=0.86 to 0.97
Malliaras et al., 200918 (prospective cohort)	Intra-rater reliability	Hip adductors	*ICC*=0.81 to 0.94
	Inter-rater reliability	Hip adductors	*ICC*=0.80 to 0.83
Delahunt et al., 201127 (cross-sectional)	Intra-rater reliability	Hip adductors	*ICC*=0.89 to 0.92
Toohey et al., 201829 (prospective cohort)	Intra-rater reliability	Hip adductors and abductors	*ICC*=0.61 to 0.92
	Inter-rater reliability	Hip adductors and abductors	*ICC*=0.77 to 0.91
	Concurrent criterion validity	Hip adductors and abductors	*r*=0.77 to 0.91

Caption: ICC: intraclass correlation coefficient; r: Pearson's correlation coefficient.

Table 3 summarizes the COSMIN evaluation of the methodological quality of studies. The methodological quality of studies investigating MST measurement properties ranged from poor to excellent[10,24,29,17,18,19].

Table 3. COSMIN evaluation of the methodological quality of studies (n=6)

Author	Validity of concurrent criteria	Intra-rater reliability	Inter-rater reliability
Helewa et al., 198110 (cross-sectional)	Excellent	NE	NE
Balogun et al., 199024 (cross-sectional)	Moderate	Excellent	NE
Perossa et al., 199819 (cross-sectional)	NE	Weak	NE
Malliaras et al., 200918 (prospective cohort)	NE	Moderate	Moderate
Delahunt et al., 201127 (cross-sectional)	NE	Weak	NE
Toohey et al., 201829 (prospective cohort)	Weak	Weak	Weak

Caption: NE: not evaluated.

DISCUSSION

Our literature review showed the scarcity of studies investigating MST use to assess muscle strength in children and adolescents. Hip adductors and handgrips were the most evaluated muscle groups. MST protocols for use in this population varied greatly. We observed significant intraclass correlation coefficients among the studies that investigated MST measurement properties, with magnitudes ranging from moderate to very high. However, when investigating their methodological quality, we noted that most were classified as weak to moderate.

Most of the reviewed studies used MST in healthy, typical children and adolescents. Investigating MST use in pediatric populations that present deficits in muscle strength, such as children with neurological diseases (cerebral palsy, Down syndrome, neuromuscular diseases, among others) can be useful for clinical decision-making and monitoring of treatment evolution. Moreover, muscle strength is fundamental in children and adolescents who practice or intend to enter some sport or physical activity, playing a key role in sports performance. Muscle strength determines the speed of execution of technical skills and provides joint stabilization in various sports activities, helping to prevent injuries[35]. Thus, muscle strength tests have been commonly used in sports to provide normative values (athletic profile), talent detection, distinguish between different levels of performance or evaluate adaptations to training[3,36]. Additionally, the load progression recommended in strength training programs for children and adolescents[37] can be more assertive when guided by the results of strength tests. As such, a better understanding of MST use as an instrument for assessing strength in the pediatric population for this purpose would be greatly beneficial.

Only two studies were conducted with a sample involving exclusively children[15,16]. Published more than 20 years ago, they did not evaluate any MST measurement properties for this population, which reveals a gap in the literature regarding MST use in children and the investigation of its measurement properties in this group. Assessing children's muscle strength is an important health marker and is fundamental for adequate motor development and execution of functional activities[3]. Thus, future studies should be conducted on using MST to assess muscle strength in this population.

As for MST adaptation, most studies made no sphygmomanometer adaptation. The absence of adaptation increases its clinical applicability, as it reduces costs and application time. Studies with adult individuals have already shown that MST can be used as is, or with bag or cuff adaptation[38]. For children, the adapted sphygmomanometer may be an easier alternative to stabilize the equipment, given its small size and application to small limbs[39]. However, no study investigated the best MST adaptation to assess children and adolescents.

Five lower limb muscle groups were evaluated: knee extensors[10]; hip flexors and extensors[19]; hip abductors[19,29]; and hip adductors[17,18,27,28-30,32,34]. These are important muscle groups for sports performance and functional activities such as walking, going up and down stairs, running, and jumping[40]. However, other LL muscle groups considered essential for one's functionality—e.g., plantar flexors, dorsiflexors, knee flexors, and external hip rotators—lacked evaluation. Plantar flexors (soleus and medial and lateral gastrocnemius) are associated with speed and joint force generation during gait[41]. Thus, these muscle groups need greater focus and, consequently, a more appropriate evaluation method which the selected studies lacked, highlighting the need for further research in this area.

Seven upper limb muscle groups were evaluated: grip muscles[15-16,24,26,31,33], pinch[25-26], shoulder flexors and extensors, shoulder abductors, and internal and external shoulder rotators[19]. These are important muscle groups in the execution of activities of daily living. Measuring grip strength provides an objective index of UL functional integrity and is important in the clinical application of disability assessment, treatment response, and assessment of individuals' ability to perform activities of daily living like reaching and manipulating objects[42]. Performing an adequate evaluation of this musculature is essential and can be used in the clinical environment as a tool to establish a functional prognosis, evolution, and treatment efficacy[4]. Priosti et al.[43] correlated functional performance and manual dexterity with grip strength in children with Down syndrome. They also showed that self-care activities (handling cutlery, brushing teeth, untangling hair, using the bathroom, bathing, etc.) are related to grip strength.

Our review noted the absence of studies investigating MST use to evaluate other upper limb muscle groups, such as elbow and wrist flexors and extensors. According to Carvalho[44], muscle strength of the elbow flexors and extensors is important for daily activities, such as supporting one's own body weight, feeding, and personal hygiene, contributing to the development and maintenance of children's quality of life. The studies by Evans et al.[45] and Lacourse[46] address the importance of elbow extensor strength in the functional independence of wheelchair users with neurological impairments, showing that this muscle is essential for lifting and moving in wheelchairs. Studies on the evaluation of muscle strength in this body segment using MST are therefore also important.

We identified no studies that evaluated trunk muscle strength in children and adolescents. Strength deficit of the trunk muscles can prevent individuals from performing various functional activities like sitting, reaching for objects, standing up, among others[47]. The trunk muscles are critical for anticipatory postural control and create a stable foundation for limb movement in children[48]. Studies on the evaluation of muscle strength in this body segment using MST are therefore also important.

The MST protocols for evaluating children and adolescents lacked standardization. Differences were observed in positioning, stabilization sites, contraction time, and number of repetitions used to obtain measurements. Studies with post-stroke adult individuals have already identified that a single repetition, after familiarization, is enough to obtain muscle strength measurements using MST[8,11-12]. However, no study has investigated the recommended number of repetitions when assessing muscle strength in children and adolescents. Investigating the best MST protocol to be used in the evaluation of this population is essential to guide clinical practice.

Studies that investigated MST measurement properties showed adequate test validity and reliability when used to evaluate adolescents. However, the COSMIN analysis revealed a low methodological quality of said studies; thus, the MST validity and reliability results for this population should be analyzed with caution. This poor classification can be explained by the small sample size. New studies should be conducted with larger samples to investigate MST measurement properties in children and adolescents.

Although bibliographical search was conducted in five electronic databases, and additional references were included by active manual search, some relevant study on the topic may have escaped our notice. Moreover, the inclusion of only original, peer-reviewed articles may have excluded other studies on MST in the population of interest. Among them, Drumond's[39] study conducted with children and adolescents aged 6 to 19 years investigated MST measurement properties for evaluating LL muscle strength and found adequate reliability, with magnitudes ranging from moderate to very high. As it is a master's thesis, its results were not included in the present review.

As most of the included studies involved mixed populations (children/adolescents and adults), caution is needed when analyzing the results regarding the measurement properties investigated. Given the variability in the MST protocols used with the pediatric population, it was not possible to establish a technique standardization. Nonetheless, the information gathered can serve as a guide for new studies in the area.

CONCLUSION

Studies on MST in the pediatric population are scarce. Moreover, the great variability of protocols employed hinder standardizing MST use. Few studies have investigated the properties of MST measurements among children and adolescents, and most present low methodological quality. Although MST is easy to access and perform, its use in the pediatric population needs further exploration.

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APPENDIX

Search strategy elaborated for MEDLINE (Pubmed)

[INSTRUMENT]
1. sphygmomanometer
2. "modified sphygmomanometer"
3. "sphygmomanometer modified"
4. "adapted sphygmomanometer"
5. "manometer method"
6. "modified manual sphygmomanometer"
7. "modified sphygmomanometer dynamometer"
8. #1 OR #2 OR #3 OR #4 OR #5 OR #6 OR #7

[POPULATION]
9. children
10. child
11. childhood
12. kids
13. boys
14. girls
15. infant
16. young
17. adolescent
18. teenager
19. teen
20. youth
21. student
22. "high school"
23. "secondary school"
24. "middle school"
25. "elementary school"
26. "primary school"
27. #10 OR #11 OR #12 OR #13 OR #14 OR #15 OR #16 OR #17 OR #18 OR #19 OR #20 OR #21 OR #22 OR #23 OR #24 OR #25 OR #26
28. **#8** AND **#27**