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Review

Clinical Measures for Tone Assessment in Adults with Central Nervous System Disorders—A Scoping Review in a Rehabilitation Context

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Abstract: Assessment of muscle tone in a clinical setting is important for the physiotherapist to better analyse and establish appropriate treatments for CNS disorders. This study aims to review and summarise how to assess changes in tone in the context of adult rehabilitation. Secondarily, this study aimed to identify the central nervous system disorders, the respective variable/concept under study, and the testing procedures employed. PRISMA-ScR guidelines were followed using the "population", "concept", and "context" to define the eligibility criteria and to delineate the research question. PubMed®, Science Direct®, Web of Science™, and Google Scholar® databases were used to search the literature. The search included studies published between 2011 and March 2023 in Portuguese, English, French, and Spanish that assessed an adult population (>19 years) with CNS injury. Review articles, qualitative studies, conference proceedings, letters to the editor, and editorials were excluded. Initially, 1519 references were identified, of which eight met the eligibility criteria. The measurement instruments included the Modified Ashworth Scale (n = 5), the Modified Modified Ashworth Scale (n = 3), the BioTone™ system (n = 2), the Montreal Spasticity Measurement (n = 1), and the Tone Evaluation Scale (n = 1). The health conditions considered included stroke sequelae (n = 7), multiple sclerosis (n = 4), spinal cord injuries (n = 4), cerebral palsy (n = 2), brain tumour (n = 2), and traumatic brain injuries (n = 3). The concepts of spasticity (n = 7) and muscle tone (n = 2) were explored. Considering the variables spasticity and muscle tone in different CNS disorders, mainly stroke, subjective instruments were preferred compared to objective ones, with the Modified Ashworth Scale being highlighted.

Keywords: tone disorders; spasticity; evaluation; rehabilitation; adults

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Citation: Pinho, L.; Silva, S.; Freitas, M.; Figueira, V.; Pinho, F.; Cunha, C.; Sousa, A.S.P.; Sousa, F.; Silva, A. Clinical Measures for Tone Assessment in Adults with Central Nervous System Disorders—A Scoping Review in a Rehabilitation Context. *Appl. Sci.* **2024**, *14*, 8189. https://doi.org/10.3390/app14188189

Academic Editor: Qi-Huang Zheng

Received: 26 July 2024
Revised: 2 September 2024
Accepted: 9 September 2024
Published: 11 September 2024

1. Introduction

Human movement has been described as a complex activity with a multifactorial nature given its diverse involvement with the context [1]. The interaction between different sensorimotor, perceptual, and cognitive systems plays an important role in functional movement [2]. This interconnection, coordinated by the central nervous system (CNS), ensures motor responses with adequate stability and mobility. The nature of the interactions between posture and movement is an area of interest in movement neuroscience [1]. To ensure efficient movement, it is a prerequisite that the underlying postural control components, namely muscle tone, are intact [1,3].

Traditionally, muscle tone has been defined as "the tension in the relaxed muscle" [4,5] and the resistance to passive stretching [4,6]. It has therefore been defined as the resistance felt by the examiner when passively mobilizing a body segment [7], which is why it is commonly assessed, in a clinical context, in the extremities as a rapid and short-term response [2]. However, this definition refers to the phasic classification of muscle tone [8]. It should be considered that the postural classification of muscle tone is often associated with antigravity support through tonic activation, which provides a specific postural attitude and generates force against gravity [1,4]. This tonic activation, together with continuous minimal adjustments, allows the maintenance of a postural set such as sitting or standing [1,2,9] and facilitates the preparation and execution of movements, such as sit-to-stand or stand-to-sit, with adequate stability and motor control [10–12]. Without adequate muscle tone, motor functions and the ability to change position in space can be severely compromised [11,12]. Therefore, this assumption should also be considered when evaluating tone.

Thus, the assessment of muscle tone is a crucial aspect in the rehabilitation of adults with CNS disorders, as these conditions frequently result in significant alterations in muscle tone, which may manifest as muscle hypertonicity, rigidity, and dystonia [13]. These alterations may negatively impact on the ability to perform functional activities with repercussions on daily life functional tasks, patient quality of life, and health-related quality of life [14]. Therefore, accurate assessment of muscle tone is of paramount importance to set appropriate treatment goals for the diagnosis of the extent of motor impairment, the monitoring of the progression of neurological conditions, and the evaluation of the efficacy of therapeutic interventions [15,16]. Nevertheless, during the physical examination, despite its contribution to clinically relevant information, the concept of what is being assessed may not correspond unambiguously to what is intended [2,8]. It has been demonstrated that traditional clinical measures, such as the Modified Ashworth Scale (MAS), are not sufficiently reliable or valid for use in clinical practice, highlighting the need for more advanced and objective assessment instruments [2,17]. Furthermore, the use of different nomenclature for the purpose of assessment, such as rigidity, hypertonia, or spasticity, reflects a lack of consensus regarding the presumed underlying pathophysiology [15,16,18]. While traditional methods of tone assessment are widely used, they often rely on subjective measures and manual examination, which can lead to inconsistencies in inter-rater and intra-rater reliability [19]. Instruments such as the MAS and the Tardieu Scale provide a semi-quantitative measure of resistance to passive movement, but they fail to capture the complex nature of muscle tone alterations comprehensively [19,20]. These limitations highlight the pressing need for more sophisticated and standardised clinical measures that can offer precise, reliable, and objective data as well as comparable evaluations of different CNS clinical conditions across rehabilitation. Also, a standardized protocol for measuring muscle tone in the rehabilitation context is important to compare data from different studies and control the neuromuscular system [21].

Therefore, in clinical practice, the concept of pathophysiological neuromuscular response to passive muscle stretching should be considered implicit rather than explicit [22]. The lack of a clear conceptual diagnosis does not facilitate effective communication between professionals and makes it difficult to reach a consensus on the conceptualisation, interpretation, and measurement of outcomes [15,16,22]. Given this conceptual ambiguity and difficulty in defining tone, which is not precise and very "examiner-centred", there may be subjective variations during the clinical examination and variability in the same examination [2], causing some difficulty in its interpretation or measurement [5]. The variable nature of muscle tone definition and assessment in the context of neurological disorder rehabilitation can result in inconsistencies in treatment approaches and may compromise the effectiveness of rehabilitation strategies [19,23]. This inconsistency can result in varied interpretations of a patient's condition, which may influence the choice of therapeutic interventions and the expected outcomes [19]. The lack of a standardised method for assessing muscle tone can result in subjective differences that can hinder the development of cohesive, evidence-based intervention plans [24]. It is therefore challenging to determine whether the observed changes in muscle tone can be attributed to the natural evolution of the disorder, the impact of therapy, or variations in assessment techniques.

Considering the above, and in order to improve knowledge about clinical practice in physiotherapy, the aim of this study was to review and summarise the assessment tools that have been use for measuring muscle tone in CNS disorders within the context of adult rehabilitation.

Research Questions

- Primary question:

What are the measurement instruments used to assess tone disorders in a clinical context in adults?

- Secondary questions:
    - i. What clinical conditions of the CNS were considered in the identified studies?
    - ii. Which variable/concept is measured?
    - iii. What procedures were used to test the concept identified?

2. Materials and Methods

This scoping review was carried out according to the Preferred Reporting Items for Systematic Reviewers and Meta-Analysis extension for Scoping Reviews (PRISMA-ScR) guidelines [25] and the methodology proposed by the Joanna Briggs Institute (JBI) manual for synthesis evidence [26,27]. The protocol is registered on Open Science Framework registries at https://osf.io/2wmu8 (accessed on 7 March 2023). No ethical approval was required for this study, as the results were extracted from published papers without primary data collection.

2.1. Eligibility Criteria

The inclusion criteria considered in this study followed the PCC acronym, defined as:

- Population: adults (>19 years old) with CNS disorders;
- Concept: assessment of tone disorders;
- Context: clinical or rehabilitation.

Studies written in English, Portuguese, French, and Spanish without geographic limitations were included. Studies of the previously identified population in which the assessment of tone alterations was carried out in a clinical context were included. Review articles, qualitative studies, conference proceedings, letters to the editor, and editorials were excluded.

2.2. Information Source

For the results extraction, three databases, Science Direct®, PubMed®, and Web of Science™ (non-grey literature), and a scholarly literature web search engine (Google Scholar®) were used. Publications from 1 January 2011 to 17 March 2023 were considered. The search strategies used for the different databases are described in Table 1.

Table 1. Search strategies used for the different databases.

Database	Search Strategy	Filters
Science Direct®	(tone OR stiffness OR spasticity) AND "clinical measures" AND (injury OR lesion) AND adults	2011–2023 English, French, Portuguese, Spanish
PubMed®	((tone OR stiffness OR spasticity) AND ("clinical measures") AND (injury OR lesion) AND adults))	2011–2023 English, French, Portuguese, Spanish
Web of Science™	tone AND (stiffness OR spasticity) AND (clinical measures) AND (central nervous system) AND (injury OR lesion) AND adults	2011–2023
Google Scholar®	(tone AND (stiffness OR spasticity) AND ("clinical measures") AND ("central nervous system") AND (injury OR lesion) AND adults))	2011–2023 English, French, Portuguese, Spanish

2.3. Selection of Evidence Sources

Management of bibliographic references was carried out using Mendeley® software (v.1.19.8). After all records were imported into this software, the duplicates were removed.

The selection of the units considered the PCC acronym, the purpose, and the research questions [26,27]. The search was carried out by two researchers, independently, using the three databases and Google Scholar®, and any disagreements between them were resolved by discussion or with a third reviewer. According to Aromataris and Munn [27], a pilot test was carried out in which all reviewers analysed the same 25 records (the first 25 titles/abstracts of the PubMed® database). After 75% consensus, the reviewers started the screening process [27]. Then, following the eligibility criteria, the results obtained were analysed by reading the title and abstract. A second screening consisted of reading the full content of the records. Those studies that did not fit the defined criteria were excluded.

2.4. Data Extraction

Relevant data were extracted considering the research objectives and questions, according to the following categories: "author/year", "study design", "objective", "participant characteristics", "CNS disorder", "clinical measurement instrument", "instrument description", "variable/concept under study", and "test procedures".

This step was conducted by two authors independently, and the abovementioned data were extracted using a draft charting table adapted from the original JBI template. Any disagreements were resolved with a third author.

2.5. Data Presentation

The results are presented in a tabular form (Tables 2 and 3), which contains a summary description of the categories extracted from the articles, in order to respond to the objective and guiding questions of this study.

Table 2. Study design, characteristics of the participants, and clinical measurement instruments.

Author/Year	Study Design	Objective	Participants	CNS Disorder
Ghotbi et al., 2011 [28]	Test–retest	To investigate the intra-rater reliability of the MMAS for the assessment of spasticity in the lower limb.	n = 23 (M = 9) Mean age: 37.3 years	• Multiple sclerosis (n = 18) • Stroke (n = 5)
Kaya et al., 2011 [29]	Observational	To investigate the inter-rater reliability of the MAS and MMAS for the assessment of poststroke elbow flexor spasticity.	n = 64 (M = 41) (35–82 years) Mean age: 60.5 years	• Stroke (n = 64)
Ansari et al., 2012 [30]	Test–retest	To determine the effect of pain and contracture presence on the reliability of the MAS.	n = 30 (M = 19) (23–80 years) Mean age: 59.0 years	• Multiple sclerosis (n = 1) • Stroke (n = 25) • Tumour (n = 3) • Traumatic brain injury (n = 2)
Beseler et al., 2012 [31]	Quasiexperimental	To perform a functional assessment of therapeutic results in patients.	n = 10 (M = 7) (30–69 years) Mean age = 52.9 years	• Stroke (n = 6) • Tumour (n = 1) • Spinal cord injury (n = 2) • Traumatic brain injury (n = 1)
McGibbon et al., 2013 [17]	Experimental	To establish the construct validity of using a wearable sensor system for elbow flexor and extensor spasticity assessments.	n = 9 (M = 5) (28–74 years)	• Spinal cord injury • Multiple sclerosis • Cerebral palsy • Traumatic brain injury
McGibbon et al., 2018 [20]	Observational	To evaluate a new portable toolkit for quantifying upper and lower extremity muscle tone in patients with UMN syndrome.	n = 103 (M = 71) (26–65 years)	• Cerebral palsy (n = 12) • Multiple sclerosis (n = 14) • Stroke (n = 54) • Spinal cord injury (n = 23)
Aygun, 2021 [32]	Experimental	To determine the responsiveness of TSRT and the precision of the MSM device.	n = 46 (M = 29) (25–80 years)	• Stroke
Kim et al., 2020 [33]	Experimental	To determine the severity of elbow spasticity by analysing the acceleration and rotation attributes and using machine learning algorithms to classify the degree of spastic movement.	n = 48 (M = 26) Mean age: 61.2 (M); 77.8 (F) years	• Stroke (n = 44) • Spinal cord injury (n = 4)

F—female; M—male; CNS—central nervous system; UMN—upper motor neuron; TSRT—tonic stretch reflex threshold; MSM—Montreal Spasticity Measurement.

Table 3. Clinical measurement instruments, variables/concepts under study, and experimental protocols.

Author/Year	Clinical Measurement Instruments	Instrument Description	Variable/Concept Under Study	Test Procedures
Ghotbi et al., 2011 [28]	• ** Modified Modified Ashworth Scale	• ** It aims to improve the reliability of the MAS. It is a 5-point scale, where the authors omitted grade "1+" from the MAS * and slightly redefined grade "2" [34].	• Spasticity in lower limbs: (1) hip adductors (2) knee extensors (3) ankle plantar flexors	Patients were instructed to relax during the test and not to resist the passive movements applied by the PT. The joints were moved with a fast stretching velocity by counting "one-thousand-and-one". The passive movement was repeated three times for each joint. (1) • Patient: Supine with the head in a midline position and lower limbs extended. • PT: On the side being tested, with one hand underneath the lower limb, close to the knee and the other hand supporting it close to the ankle. The lower limb was moved into full abduction (without rotation). (2) • Patient: Side-lying, with hips and knees extended. Head and trunk aligned in a straight line. Pillow could be used behind the hips, if necessary, to stabilize the patient. • PT: Behind the patient, with one hand placed proximal to the knee on the lateral surface of the thigh to stabilize the femur, and the other hand proximal to the ankle. The knee was moved from maximum extension to maximum flexion. (3) • Patient: Supine with the head in a midline position and the arms alongside the trunk. Lower limbs were extended. • PT: On the side being tested with one hand under the ball of the foot, while the other hand stabilizes the lower limb around the ankle joint. The ankle was moved from maximum plantar flexion into maximum dorsiflexion.

Table 3. *Cont.*

Author/Year	Clinical Measurement Instruments	Instrument Description	Variable/Concept Under Study	Test Procedures
Kaya et al., 2011 [29]	• * Modified Ashworth Scale • ** Modified Modified Ashworth Scale **	• * It is a 6-point scale. Scores range from 0 to 4, where lower scores represent normal muscle tone and higher scores represent spasticity or increased resistance to passive movement.· It instructs examiners to place a joint in either maximal flexion or extension and move it to the opposite position over 1 s. The patient should relax while being tested on various muscles [35]. • ** As described	• Spasticity in elbow flexors	The unaffected side was used as control to compare the elbow ROM between the two sides. The passive movement was carried out over a duration of 1 s by counting "one-thousand-and-one" and repeated three times. • Patient: Supine, after resting for 10 min, with the head in a midline position and the arms alongside the trunk. • PT: Allowed to repeat the test, no more than two times, if he could not reach a decision concerning the grade of resistance felt in the first attempt.
Ansari et al., 2012 [30]	• ** Modified Modified Ashworth Scale	• ** As described	• Spasticity in upper limbs: (1) shoulder adductors (2) elbow (3) wrist flexors	Patients were evaluated on both sides. Each test movement was repeated over 1 s by counting "one-thousand-and-one". The passive movement was repeated three times for each joint. (1) • Patient: Supine with the head in a midline position and the arm alongside the trunk. The elbow was in 90° of flexion. • PT: Placed on the side being tested, with one hand underneath the elbow and the other hand grasping the wrist. The lower limb was moved into abduction (100°). (2) • Patient: Supine with the head in a midline position and the arm abducted to 90°. • PT: Placed on the side being tested, with one hand stabilizing the arm proximal to the elbow, and the other hand grasping the forearm proximal to the wrist. The forearm was placed in a neutral position of maximal possible flexion to maximal possible extension. (3) • Patient: Supine with the head in a midline position and the arm alongside the trunk. Forearm was in a midposition. • PT: On the side being tested, with one hand stabilizing the forearm proximal to the wrist, and the other hand grasping patient´s hand. The wrist was moved from maximum possible flexion to maximum possible extension.

Table 3. *Cont.*

Author/Year	Clinical Measurement Instruments	Instrument Description	Variable/Concept Under Study	Test Procedures
Beseler et al., 2012 [31]	• * Modified Ashworth Scale (a) • Adductors Tone Rating Scale (b)	• * As described • (b) It is a 5-point scale. Scores range from 0 to 4, where lower scores represent normal muscle tone and higher scores represent increased resistance to passive movement. It instructs examiners to passively abduct the thigh of the patient, which should relax while being tested [36].	• (a) Spasticity in hip adductors • (b) Tone in hip adductors	• (a) In a supine position with the head in the midline, the passive movement of the hip in adduction and abduction were assessed according to the methods described for MAS administration. • (b) Patients were in a supine position in a comfortable and relaxed state with their legs extended. The PT was beside the patient, allowing easy access to the patient's legs. The PT held the patient's leg and moved it passively to spread the lower limbs (abduction of the thigh). During this movement, the PT observed the resistance of the adductor muscles and classified it according to the ATRS.
McGibbon et al., 2013 [17]	• * Modified Ashworth Scale (a) • *** BioTone™ (b) to register EMG activity	• * As described • Two-channel EMG system that uses duotrode Ag-AgCl electrodes to collect EMG signals.	• Spasticity in elbow flexors and extensors.	• (a) In a supine position with the head in the midline and the arm alongside the trunk, the passive movement of the elbow in flexion and extension was assessed according to the methods described for MAS administration. • (b) During data collection, the patient was in a supine position with the head in the midline and the arm along the trunk. Two-channel surface EMG electrodes were placed on the biceps bracii and triceps bracii to record elbow kinematics and muscle activity during flexion and extension of the elbow. First, a single slow (~10–20 deg/s) flexion and extension trial (throughout the passive range) was performed, followed by a series of fast (~120–140 deg/s) flexion and extension trials (throughout the same passive range). A short rest period was permitted between tests to allow muscles to relax. Fast flexion and extension trials were each performed three times.

Table 3. *Cont.*

Author/Year	Clinical Measurement Instruments	Instrument Description	Variable/Concept Under Study	Test Procedures
McGibbon et al., 2018 [20]	• * Modified Ashworth Scale (a) • *** BioTone™ (b) to register EMG activity	• * As described • *** As described	• Muscular tone in: -elbow (1) -knee (2)	• (a,1,2) The passive movement of the elbow and the knee in flexion and extension were assessed according to the methods described for MAS administration. The PT moved the forearm slowly through elbow flexion and then rapidly through extension to stretch the elbow flexors. This was repeated for elbow extensors. Stretch–reflex tests were repeated at least three times for each muscle. Only the most involved body side was tested. • (b,1,2) Patients were positioned in a seated posture with limbs hanging freely over the edge of a plinth and the torso reclined to approximately 30°, while sensor measurements were displayed in real-time.
Aygun, 2021 [32]	• Montreal Spasticity Measurement	• Portable clinical device consisting of a two EMG channels, an electrogoniometer, and dedicated software implemented on a laptop computer.	• Spasticity in elbow	• In a sitting position, EMG signals were measured with surface electrodes placed on the biceps bracii and triceps bracii. After the initial angle was set, patients were asked to relax their elbows completely. Flexor muscles were stretched by the PT 20 times at different velocities (at random), with 10 s between each stretch.
Kim et al., 2020 [33]	• * Modified Ashworth Scale	• * As described	• Spasticity in elbow	• With the patient in a supine position with the head in the midline and the arm along the trunk, the passive movement of the elbow in flexion and extension was assessed according to the methods described for MAS administration.

*, **, ***, (1), (2), (3), (a), (b)—correspondent with; PT—physiotherapist(s); s—second; min—minutes; ROM—range of movement; MAS—modified Ashworth scale; EMG—electromyography; deg/s—degrees per second; ATRS—adductors tone rating scale.

3. Results

Initially, 1519 articles were identified, which were analysed using Mendeley® software (451 from Science Direct®, 27 from PubMed®, 1 from Web of Science™, and 1040 from Google Scholar®). Prior to sorting, 218 duplicate reading units were removed. After reading the title and abstract, 1233 articles were eliminated for not meeting the established criteria after reading them in full. Of the remaining 68 articles, 60 were eliminated for the following reasons: reports not retrieved (n = 1), type of study (n = 9), study population (n = 7) and no clinical context present (n = 43). The remaining eight articles were included in the review (Figure 1).

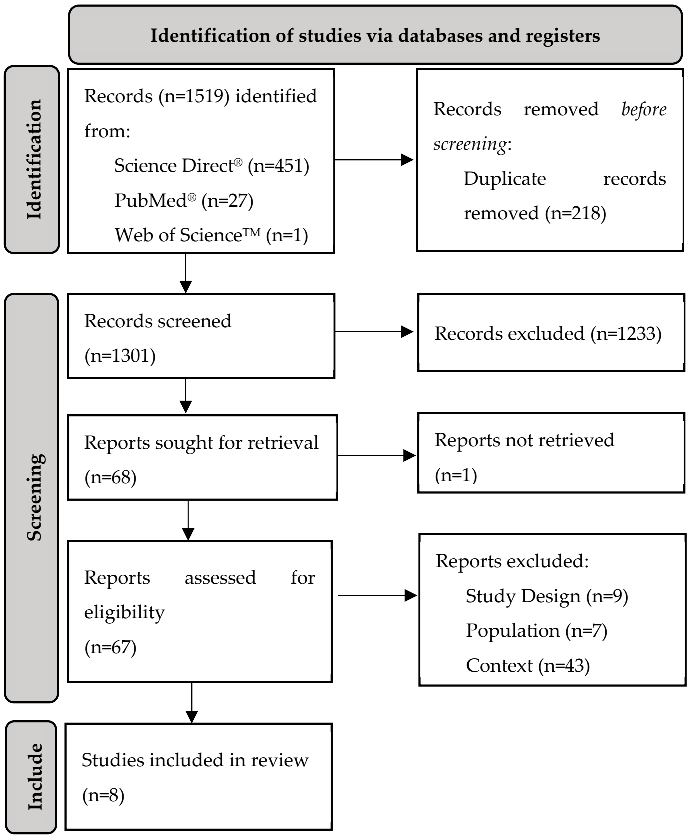

Figure 1. Flow diagram for the scoping review process adapted from the PRISMA-ScR statement [37].

After applying the eligibility criteria, this review included eight studies, with one published in Spanish and seven published in English, between 2011 and 2021: 2 in 2011 [28,29], 2 in 2012 [30,31], 1 in 2013 [17], 1 in 2018 [20], 1 in 2020 [33], and 1 in 2021 [32].

As for the type of study, two are observational aiming to investigate the inter-rater reliability between two scaled instruments [29] and to evaluate a new portable toolkit [20]; two are test–retest studies aiming to investigate the intra-rater reliability between two scaled instruments [28] and to determine the effect of pain and contracture presence on the reliability of a scaled instrument [30]; one quasi-experimental study was developed to perform a functional assessment of therapeutic results in patients [31]; and three are experimental studies aiming to establish the construct validity of using a wearable sensor system [17] to determine the responsiveness of the tonic stretch reflex threshold (TSRT) and the precision of the MSM device [32] as well as the severity of elbow spasticity [33]. All studies included males and females [17,20,28–33], and 7 of the studies included mostly males [17,20,29–33]. Participants mean age ranged from 37.3 years [28] to 77.8 years [33]. The CNS disorders identified included stroke sequelae (n = 7) [20,28–33], multiple sclerosis (n = 4) [17,20,28,30], spinal cord injury (n = 4) [17,20,31,33], cerebral palsy (n = 2) [17,20], tumour sequelae (n = 2) [30,31], and traumatic brain injury (n = 3) [17,30,31].

For the eight included studies, the identified clinical instruments to measure tone changes included the Modified Ashworth Scale (n = 5) [17,20,29,31,33] to assess spasticity (n = 4) [17,29,31,33] and muscle tone (n = 1) [20]; the Modified Modified Ashworth Scale for assessing spasticity (n = 3) [28–30]; the BioTone™ system (n = 2) to access EMG activity [17,20]; the Montreal Spasticity Measurement (n = 1) for accessing spasticity [32]; and the Adductors Tone Rating Scale (n = 1) to access muscle tone [31]. Different body segments were considered for tone assessment by the majority of the included studies (n = 6) [17,28–30,32,33]. One study assessed muscle tone at the elbow and knee [20], while another accessed spasticity and tone in the hip adductors [31].

Regarding the test procedures used during tone evaluation, the seven studies [17,20,28–31,33] that used the MAS or MMAS as measurement tools considered the methods described for MAS administration. For that reason, patients were positioned in supine position, and the procedure was repeated by the physiotherapist three times. The patient was placed in the side-lying position to apply the MMAS one study [28] according to its indications, specifically to evaluate the knee joint. For seven studies [17,20,28–31,33], each repetition occurred over 1 s, with the physiotherapist counting "one-thousand-and-one" while passively and rapidly moving the joint under study. In two studies [17,20], during MAS or MMAS application, EMG signals were also collected to ensure the presence of variations in muscle activity. Thus, all MAS or MMAS test procedures were performed during the acquisition. One of the studies [31] used ATRS for tone assessment also following manufacturer's recommendations. The procedures are similar to those of the MAS or MMAS in terms of positioning the patient and application of the test. In one study [32], a different set-up was followed to respect the measurement instrument that was being used. Thus, while the EMG was being performed, the patient was seated with the elbow relaxed, and the physiotherapist passively mobilised the joint 20 times at different velocities (randomly) with 10 s between each repetition.

Regarding the aim of the study and the research questions defined, Figure 2 shows the distribution of the measurement instruments used to assess tone disorders in a clinical context, the clinical conditions of the CNS, and the variable/concept proposed to be measured in the studies.

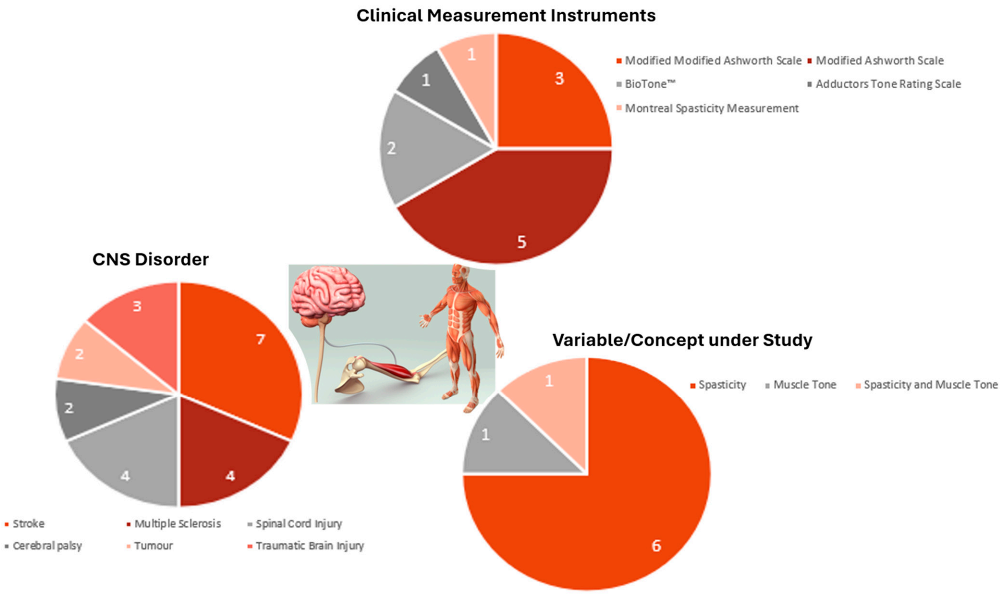

Figure 2. Clinical measurement instruments, central nervous system disorders, and variables/concepts under study.

4. Discussion

This scoping review sought to bring together studies that identified the instruments used to assess changes in muscle tone in adults with CNS disorders in a clinical context. Among the eight articles included, few differences were noted in the extracted characteristics.

4.1. Clinical Measurement Instruments

The following clinical assessment instruments were used in the studies: the Modified Ashworth Scale (MAS) [17,20,29,31,33], the Modified Modified Ashworth Scale (MMAS) [28–30], the combination of the MMAS with BioTone™ [17,20], the Montreal Spasticity Measurement (MSM) [32], and the Tone Evaluation Scale [31].

The MAS or its modification was the main clinical measure of spasticity used in the studies assessed, with the exception of the studies by Béseler et al. [31] and McGibbon et al. [20], which claimed to assess muscle tone with the same tool. Its application involves assessing the resistance, felt by the examiner, of a distal segment, which is passively moved from an initial position to a final position [18,32]. The MMAS was later published in 2006 and aimed to improve the reliability of the MAS [30]. Both are practical and easy to apply; however, despite the proposed modification [33], it is still described as a subjective scale [17].

Van den Noort et al. [22] defined spasticity as involuntary muscle activity induced by stretching velocity as part of the neural contributions to increased resistance perceived during passive muscle stretching. In the studies by Ghotbi et al. [28], Kaya et al. [29], Ansari et al. [30], and Kim et al. [33], the proposed scales, which have already been identified, do not consider the speed factor, as they only assess the component of muscle tension in response to passive movement, thus not discriminating between the known neural and non-neural contributions of tone [22]. Furthermore, it is known that this component of muscle tension to passive stretching is solely related to the non-neural mechanical response [6]. There is also the fact that the identified scales indicate a result recorded by the examiner based on subjective perception [6,38] with information about the properties of muscle tissue [22]. These scales therefore seem to have limitations in terms of construct, reliability, sensitivity, quantification, and objectivity. This information could serve as the basis for the development of measurement tools with better defined psychometric properties and objectivity.

Given the specificity of the Béseler et al. [31] study that applied botulinum toxin to the lower limbs, they considered it relevant to add a specific scale that could measure the results of their intervention to provide more information. They complemented the MAS evaluation of spasticity with the Tone Evaluation Scale in the hip adductors to accomplish their study aim.

To reduce potential subjectivity and improve the objectivity of the assessment, McGibbon et al. [17] and McGibbon et al. [20] used a sensor system concomitantly with the evaluation by passive stretching of muscle structures to quantify passive muscle resistance more objectively in a clinical context. Thus, the BioTone™ system, that incorporates a two-channel EMG system and a single degree of freedom fibre-optic goniometer, was used in combination with kinematic and electromyographic evaluations [17]; the system was demonstrated to be a reliable and valid method for enhancing the information obtained about neural contributions and non-neural characteristics that define muscle tone [22]. However, its large-scale use in clinical practice is limited due to the need for continuous technical training and maintenance and specific equipment that could be expensive [17]. A potential solution is the development of simple and less expensive methods that retain the reliability and validity of these instruments while making them more accessible.

In line with that described, Kim et al. [33] proposed a low-cost instrument to quantify spasticity using inertial data collected with a portable device equipped with sensors, a three-axis accelerometer, a three-axis gyroscope, and a three-axis magnetometer, and this system exhibited characteristics compatible with the MAS. This form of assessment, in addition to being less expensive, is also simpler and more accessible [33]. Therefore, this evaluation method seems viable and acceptable, but its use in this context still needs further validation.

The MSM, a handheld device that provides a quantitative measurement of the tonic stretch reflex threshold (TSRT), consists of an electromyography amplifier and an electrogoniometer, which collects information on three aspects of stretching: angular position, angular velocity, and electromyographic activity [39]. Except for studies that combined the MAS with BioTone™ [17,20], all other evaluation methods seem to only measure resistance to passive stretching, which reflects the non-neural component of muscle tone. Nevertheless, it is important to understand the neural components of the intrinsic muscle characteristics that have repercussions on global function, such as viscoelasticity and force/economy production [2], and consequently the influence on global postural tonic activity. Evidence supports that typical movement predominantly implies a global and integrated activation of neural pathways that act on several muscles (or myofascial units) in a synergic pattern rather than on isolated muscles [40].

It seems pertinent to carry out studies that allow the development of new, more objective measurement instruments with the aim of better characterizing and defining the concepts of spasticity and changes in muscle tone for improved clinical applicability in the presence of CNS changes, for instance, by combining neural and non-neural components.

4.2. Central Nervous System Disorder

The CNS alterations identified in the articles included in this study, which are clinically manifested by increased muscle tone, include multiple sclerosis, stroke, cerebral palsy, brain tumour, brain injury (traumatic or acquired), and spinal cord injury. The changes described have been evaluated in terms of tone in a clinical context by assessing changes in muscle resistance during passive stretching [2,41]. These health conditions affect the upper motor neuron (UMN) and can manifest as increased muscle tone [8,28]. The UMN connects the cortex to the anterior horn cells of the spinal cord, which, in turn, extend via lower motor neurons through the peripheral nerve to skeletal muscle [8,9,32].

Movement disorders resulting from CNS injury have been described as a consequence of the presence of spasticity [42,43]. This was the variable under study that was consistently identified by the authors in the articles included in this review [17,28–30,32,33], followed by muscle tone, which was assessed in only one study [20]. According to the aforementioned definition of spasticity, this appears to be a consequence of altered tone modulation and a type of muscle hypertonia [2]. However, in the studies included in this review, the assessment of resistance to passive movement of a segment at rest was proposed [17,28–30,32,33], although it is described in the literature as a clinical assessment of muscle tone [2,8].

In fact, although this assessment is often mentioned as a way to assess changes in muscle tone, in reality it seems to refer only to the implicit non-neural component [6], without considering its neural component [2,8]. For this reason, it seems essential to unequivocally distinguish between non-neural (tissue-related) and neural (CNS-related) contributions related to changes in muscle tone.

4.3. Variable/Concept under Study and Test Procedures

The concept/variable to be evaluated is referred to using a variety of terms, including spasticity [17,20,28–30,32,33], muscle tone [17,20,28,29] or even increased muscle tone [28,30,33], and this notion is consistent with that reported by Van den Noort et al. [22]. Variations in the existing definitions in the literature about muscle tone and its changes make it difficult to interpret or measure, leaving room for professionals to create their own version [5]. The lack of a clear conceptual framework prevents effective communication between professionals and the quantification of results that are based on an unequivocal conceptualization [22], interfering with decision-making to outline the best intervention strategies and procedures in a clinical context.

The literature attempts to overcome this difficulty and has tried to homogenise the conceptualisation of the different conditions of muscle tone, providing more concrete definitions depending on the occurrence. In 2018, Lundy-Echman [8] presented a summary of the variations and the underlying neurophysiological characteristics in order to improve understanding and to provide clear conceptual definitions. This information could provide necessary insights for a better approach for practical contact with patients regarding physiotherapy evaluations and consequent interventions. It was proposed that, in an awake person with a normal neuromuscular system, slight muscle resistance to passive stretch is normal, and muscle tone is categorized on a continuum. The resistance ranges from flaccid (complete lack of resistance) to abnormally low (hypotonia), to normal, to velocity-dependent hypertonia (abnormally high resistance that increases with faster movement), and finally to rigidity. According to the continuum and regarding the concepts identified in this study, namely, spasticity, muscle tone, or increased muscle tone, it is important to highlight how these concepts are being defined in literature (Figure 3) to better analyse the studies that were summarized in this review.

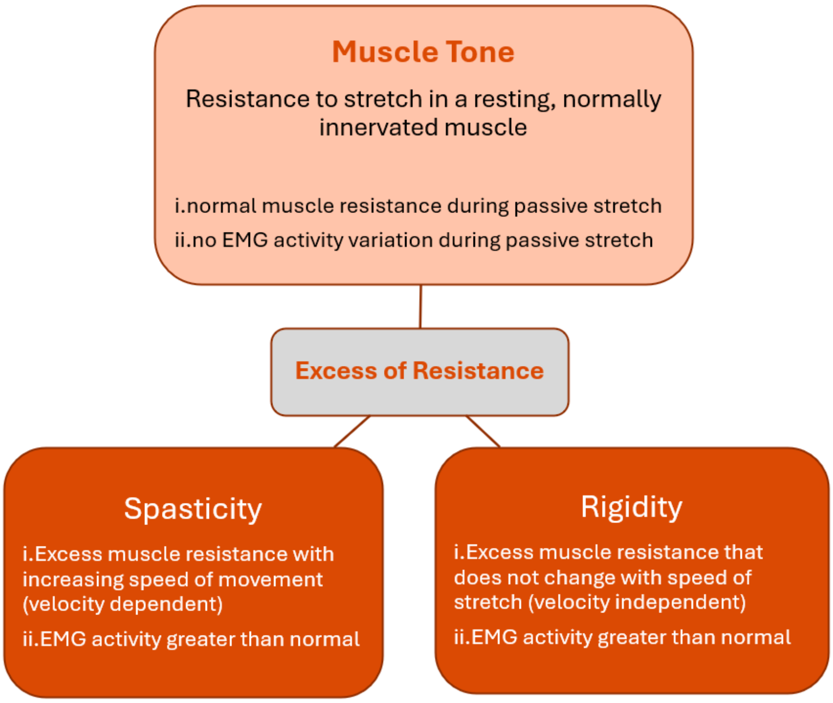

Figure 3. Definition of normal muscle tone and muscle tone in the presence of increased resistance [8].

While applying the clinical instruments identified, the authors included in this study followed the provided instructions for each instrument used in the testing procedures.

Considering the definitions of muscle tone in the presence of CNS alterations, particularly its increase (Figure 3), it is essential to explore the response to the passive mobility of the joints under study, taking into account the velocity and the electromyographic activity of the muscles involved. Of the studies included in this review, two of them [17,20] considered some of these aspects and complemented MAS application with EMG evaluation. Only Aygun (2021) considered velocity during the texting procedure because the study followed the Montreal Spasticity Measurement clinical instrument instructions.

It seems necessary to clarify how the different authors defined the concept under study. Specifically, if spasticity is velocity dependent, it is not sufficient to evaluate it with MAS or MMAS. It is also important to determine whether it is being used correctly for the concept under study. According to recent definitions (Figure 3), if velocity is not being considered, it may not be appropriate to define the concept under study as spasticity.

Nowadays, given the current challenges in rehabilitation and the different contexts of action, among which home-based physiotherapy also stands out, it is crucial to follow a patient-centred approach adapted to individual needs to promote more natural and efficient rehabilitation. In addition, homogeneous assessment and decision-making among professionals as well as concordant forms of assessment are crucial. With the current advances in movement analysis, studies that promote knowledge of new assessment tools, which could eventually be a valuable addition, such as combining different tools or using artificial intelligence, may be relevant. Given the results of this review, which showed some inconsistencies in professionals' assessments of muscle tone, it seems relevant to emphasise that is possible to combine the use of robotic devices that may help the difficulties identified to support decision-making in clinical practice [44,45].

Although not identified in this review, CNS disorders may include metabolic disorders that also affect muscle tone [46,47]. Therefore, it seems important that future studies should also try to better understand current clinical approaches in this population, knowing that the impact of metabolic disorders on muscle tone is profound, affecting mobility, posture, and overall physical function [46]. Whether resulting in hypotonia or hypertonia, these conditions require comprehensive management strategies to improve quality of life and prevent complications [46,47]. New approaches, such as stem cell therapy and other regenerative interventions, are being considered to restore or improve muscle function in cases of muscle tone abnormalities [46].

Small sample size was identified as an intrinsic limitation of the studies included in this analysis as cited by the respective authors [48,49]. The main aspects that hindered the analysis and discussion of the data were the inconsistency of the variable studied and the instrument proposed to assess it, as well as the lack of consensus in the conceptual literature supporting these choices [19]. In addition, other clinical measurement tools are known to exist, but the eligibility criteria of this review may not have allowed their inclusion [48,50].

4.4. Applications of the Research

- Accurate muscle tone assessment is crucial for making the most effective intervention decisions.
- In a clinical setting, assessing and understanding muscle tone enables physiotherapists to better analyse and establish appropriate interventions for patients with central nervous system disorders.
- Reaching a consensus on the conceptualization, interpretation, and measurement of results is essential to minimize subjective variations during clinical examinations. This contributes to effective communication among professionals and enhances decision-making for interventions.
- Testing procedures based on neurophysiological muscle tone characteristics are needed in order to improve understanding and clear conceptual definitions, which could provide necessary insights for a better approach in practical contact with patients for physiotherapy evaluations and consequent interventions.

5. Conclusions

The study revealed a lack of consensus in the conceptual literature to support clinicians' decisions and the need for more comprehensive clinical guidance and objective tools to measure muscle tone and its variations in the presence of CNS disorders that underlie the neurophysiological characteristics of patient. The combination of both a scaled clinical passive stretching model and the analysis of muscle activity is useful to quantify muscle tone more objectively in clinical settings. However, further investigations are needed to better understand how to access more objectively the underlying mechanisms associated with these conditions.

Author Contributions: Conceptualization, L.P. and A.S.; methodology, L.P., A.S. and A.S.P.S.; software, F.P.; validation, A.S., A.S.P.S. and F.S.; formal analysis, A.S.; investigation, L.P., M.F., S.S. and V.F.; resources, L.P., A.S. and A.S.P.S.; data curation, L.P.; writing—original draft preparation, L.P.; writing—review and editing, A.S.P.S. and F.S.; visualization, L.P., F.P. and C.C.; supervision, A.S., A.S.P.S., F.S. and L.P.; project administration, L.P., A.S. and A.S.P.S. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported through R&D Units funding (UIDB/05210/2020), Fundação para a Ciência e Tecnologia (FCT), Portugal.

Conflicts of Interest: The authors declare no conflicts of interest.

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