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Historical, theoretical and methodological aspects related to static balance analysis: an integrative review of literature.

Aspectos históricos, teóricos e metodológicos relacionados a análise do equilíbrio estático: uma revisão integrativa da literatura

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ABSTRACT

The assessment of balance performance has been the subject of study by researchers from various fields for over a century. Although there is a significant number of scientific publications, Results can divergent due to the various methods and variables of impact. Objective: To review the specialized literature regarding the historical, theoretical, and methodological aspects related to the analysis of static balance. Method: The search was conducted in the PubMed, PsycINFO, Scielo, Web of Science, and Scopus databases using the SPIDER strategy. Results: 86 studies were selected, which revealed 40 variables that can influence balance performance. Conclusion: There is a need for more robust standards, both for quantitative and qualitative methods, with the complexity of the analysis being directly proportional to the desired level of precision in the results.

Key words: Static balance; Assessment method; Biomechanics; Variables of impact;

RESUMO

A avaliação da performance do equilíbrio tem sido objeto de estudo por pesquisadores de diversas áreas por mais de um século. Embora haja um número significativo de publicações científicas, os resultados podem ser divergentes devido aos diversos métodos e variáveis de impacto. Objetivo: Revisar a literatura especializada sobre os aspectos históricos, teóricos e metodológicos relacionados à análise do equilíbrio estático. Método: A busca foi realizada nas bases de dados PubMed, PsycINFO, Scielo, Web of Science e Scopus utilizando a estratégia SPIDER. Resultados: Foram selecionados 86 estudos, que revelaram 40 variáveis que podem influenciar na performance do equilíbrio. Conclusão: Há uma necessidade de padrões mais robustos, tanto para métodos quantitativos quanto qualitativos, com a complexidade da análise sendo diretamente proporcional ao nível desejado de precisão nos resultados.

Palavras-chave: Equilíbrio estático; Metodologia de avaliação; Biomecânica; Variáveis de impacto.

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INTRODUCTION

Research on balance and postural control has progressed significantly over time, driven by technological advancements, a better understanding of the human body, and growing interest in the fields of rehabilitation and movement sciences. Body balance refers to the ability to maintain a stable and controlled position during static activities (e.g., standing) and dynamic activities (e.g., walking or running). As our Center of Mass (COM) shifts outside the base of support perimeter, typically within 100 ms, the Central Nervous System (CNS) already receives signals of instability (PATLA, 2003). Balance is also defined as the series of interactions between the muscular mechanisms controlled by the CNS, which are essential for the adjustment process between the COM and the support base (PAIXÃO; HECKMANN, 2002).

The assessment of balance allows for the identification of alterations in the ability to maintain postural stability, which may be associated with various clinical conditions, fall risks, and impairments in an individual's functionality (HORAK, 1997). It is crucial for evaluating neuromuscular function, diagnosing balance disorders, and planning therapeutic interventions or training programs (WINTER et al., 1990; CLARK et al., 2010; LEE; SUN, 2018). In a clinical context, it is useful for identifying neurological changes resulting from conditions such as neuromuscular diseases, traumatic brain injuries, or strokes. This assessment aids in diagnosis, treatment planning, and clinical progress monitoring (SHUMWAY-COOK; WOOLLACOTT, 2007). Athletes from various disciplines can benefit from the evaluation of body balance to enhance sports performance and prevent balance-related injuries (HORAK; MCPHERSON, 1996).

By the end of the 20th century, technological advances enabled researchers to develop sophisticated tools, such as posturography systems, to quantify and analyze postural stability (MANCINI; HORAK, 2010). However, it's important to note that the reliability of static body balance measurement results can vary depending on the studied population, the device used, and measurement environment conditions (CLARK et al., 2010). It should be emphasized that the discrepancies in measurements are common and can be influenced by various factors, such as differences in methodology (PAILLARD, 2012).

Currently, there are some questions and challenges regarding static balance measurement. These issues range from the validity and reliability of measurement instruments to the interpretation of results and clinical applicability (PAILLARD, 2012;

MICHALAK; PRZEKORACHA-KRAWCZYK; NASKRECKI, 2019). Thus, this study seeks to analyze, through an integrative review, the historical, theoretical, and methodological process of studying balance and describe the main variables that can affect the assessment and analysis of its measurements.

METHOD

This article was designed as an integrative review of the specialized literature. Therefore, considering its methodological nature, it did not require approval from the Ethics and Research Committee (ERC). For this purpose, the steps suggested by Whittemore R. and Knafl K. (2005) were adopted, which include steps 1, 2, 4, and 5, and Ursi E. and Gavão C. (2005) for step 3, where an adaptation of the table suggested by the authors was used for greater synthesis and objectivity of the information from each analyzed study, in accordance with the objective of this review.

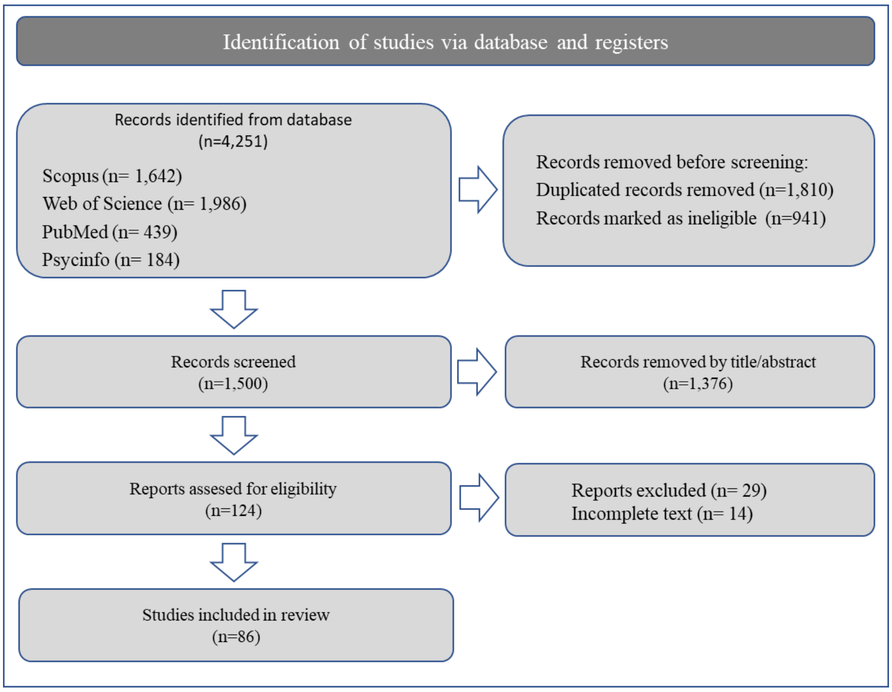
Based on the question that guides the issue of this review, which can be evidenced in studies such as Paillard (2012), who warns about the reliability of research results due to methodological variability in measurements and lack of standardization. This is also evident in the studies of Mancini (2010), who reveals that the scales used to assess balance provide measurements with a certain degree of imprecision because they are conducted subjectively and are subject to being easily influenced by the experience and knowledge of the evaluators.

Literature search was conducted based on an initial list of indexing terms or descriptors, which were used to identify records in Portuguese and English, following the SPIDER strategy by Methley and colleagues (2014). Regarding the sample, there was no specific definition about the phenomena of interest: Standing Position, Postural Balance, Anthropometry, and Equipment. As for the design, evaluation of the phenomenon and type of research, no restriction terms were defined. The electronic search platforms used include the Medical Literature Analysis and Retrieval System Online (via PubMed), PsycINFO, Scielo, Web of Science (WOS), and Scopus (Elsevier), with no publication year restrictions.

The inclusion criteria for publications consisted of identifying the expressions used in the title or keywords searches, or having it explicitly stated in the abstract, assuring that the text relates to the verification of methods and/or equipment used for the analysis of body balance. The initial amount of records from individually identified terms were not computed; only qualitatively analyzed records were used, following the current best scientific practices respecting copyright, according to each database or electronic library for each predefined search strategy. Due to the criteria established for the integrative review, the investigation took place between August and November 2022.

The search yielded 4,251 references related to measurements of static balance or fixed posture (Figure 1). Subsequently, the articles were included, following the guidelines for conducting revisional studies based on the SPIDER strategy, resulting in 86 articles.

Figure 1 – Flow Diagram



Source: Elaborated by author (2023)

After the final selection of studies, basic content analysis techniques (BARDIN, 2000) were employed to examine the data. Sub-themes were established to compose the analysis framework and guide the text writing process. Additionally, for articles containing relevant results selected for this study, the scale by Zandonai AP et al. (2010) was applied.

During the data collection phase of the studies identified in the selection phase, the use of a pre-determined instrument was essential to ensure that all relevant information was collected comprehensively. This approach aimed to reduce the risk of transcription errors and ensure accuracy in information verification, while also serving as a record. The data to be extracted included the author and publication year, sample size, participants' gender, and study type, as well as the objective described by the authors, the classification of the method (quantitative or qualitative), and a brief summary of the results focusing on the impact of the investigated variables.

RESULTS AND DISCUSSION

HISTORICAL AND THEORICAL APSECTS

Balance maintenance was presented as a distinct concept from posture, once it was observed that various body segments can assume different positions for specific postures in response to external or internal conditions, and, to adhere to the law of static equilibrium, these postures, in theory, should ensure that the center of gravity is positioned over the support base (MASSION, 1984). The relationship between the center of gravity (COG) and the fixed postural pattern had already been observed by Babinski in 1899, who monitored the displacement of the COG projected onto the ground, correlating neck and trunk dorsiflexion with knee flexion stimuli.

The ability of body control can be studied in two aspects: first, when the individual is in an upright posture, referred to as "static balance," meaning the ability to keep the center of gravity over their support base; the other aspect is during walking or any kind of motion, referred to as "dynamic balance." When the body is in a stable equilibrium and is displaced by an external force, it can react in three ways: return to its original position, move to a new position, or move away from the original position, referred to as stable, neutral, and unstable equilibrium, respectively (PAIXÃO; HECKMAN, 2002; HAMILL; KNUTZEN, 1995; SANVITO, 2000).

The study of balance and postural control has its first records dating from the mid-19th and early 20th centuries, with the pioneering work of Romberg in 1846 and Barany in 1906 in understanding the vestibular function and its role in balance (PEARCE, 2005). Investigations into the control of static posture have undergone various theoretical and practical changes over the last century (HORAK, 2006). Initially, it was considered that the foundation of static posture was the result of a series of mechanisms, including muscular tone, which helps maintain joints in a certain position due to the stiffness it imparts to the muscles (SHERRINGTON, 1910). In a similar line of research, Massion (1984) added that for muscles to exert force against gravity while maintaining postural control, increased muscle tone, especially in extensor muscles, is required. Earlier studies already identified the interaction of lower neural structures in limb flexion reflexes as reactive postural responses to external stimuli and the correlation between distance receptors (visual and auditory systems) and induced anticipatory reactions, concluding that muscle tone tends to increase as an anticipation of movement for postural control (SHERRINGTON, 1906). The reflexive aspects of muscles related to an individual's alertness and the influence of the environment on stimulus responses were extensively studied from the 1960s when significant disparities in results began to be found in different research laboratories (PROCHAZKA, 1989; EVARTS; TANJI, 1976). Further investigations, with a biomechanical approach, sought to understand the influence of movements on static balance, followed by the initial observations of Belenkii (1967) regarding anticipatory postural adjustments, and by various other authors who identified, for example, the activation of leg muscles such as the calf and hamstring muscles preceding arm movement (GRANIT; POMPEIANO, 1979; CORDO, NASHNER, 1982; BOUISSET, ZATARA, 1981; CLEMENT et al.; 1983).

The early balance models focused on the concept of an inverted pendulum, with efforts to understand human postural control based on mechanical principles (WINTER et al., 2009). Subsequent research shifted towards the importance of sensory integration and feedback in maintaining balance. The theory of sensory integration proposed that multiple sensory inputs, such as visual, vestibular, and somatosensory, play a significant role in postural control (HORAK; NASHNER, 1986). In the 1970s, the first studies emerged that linked limb positions, adopted as various balance strategies, to the vestibular, visual, and somatosensory systems together, when different types of reflexes used to maintain the center of gravity over the base of support were observed (DICHGANS et al., 1972; LESTIENNE et al., 1977; NASHNER, 1977). At the same time, Gurfinkel et al. (1973) observed the interference of internal forces on balance reflexes, noting that the displacement of the chest, caused by breathing movements, generated an opposing postural adjustment at the hip.

From these findings, researchers began to examine the role of the central nervous system in generating and adapting postural responses. This led to the development of motor control theories that emphasized the contribution of neural processes to postural control (SHUMWAY-COOK; WOOLLACOTT, 2007). The relationship between the CNS and reactions for balance maintenance had already been evidenced in the studies of Bassin et al. (1956), through electromyography measurements, and continued with research groups in the former Soviet Union and France. The interaction of neural activity patterns with static balance evolved systematically over a century through psychology, once the involvement of the central nervous system with the transmission of electrical impulses to the spinal cord and from there to the muscles was confirmed (GIBSON, 1941; BORING, 1957; WATSON, 1963; EVARTS, 1973; GURFINKEL; PAL'TSEV, 1965; STEIN; CAPADAY, 1988).

At the end of the 20th century, the theory of dynamic systems gained popularity, emphasizing the interaction between various bodily systems and environmental factors in balance maintenance (COLLINS; DE LUCCA, 1993). In 1997, Horak summarized the components and subcomponents involved in postural control and how these components are interconnected in three dimensions: biomechanics; motor coordination (MC) and; sensory organization (SO). The relation between biomechanics and motor coordination involves flexibility and muscular tone, between MC and SO are adaptation and predictive central set, and between biomechanics and SO the detection of instability.

Since then, the study of factors influencing static posture has been ongoing to this day, and even with over a century of research, we still do not fully understand all the mechanisms that can interfere with our balance capacity and how they interact with each other (CHIARI; ROCCHI; CAPELLO, 2002).

TECHNICAL-SCIENTIFIC AND METHODOLOGICAL ASPECTS

According to Horak (1997), clinical assessments of balance should always begin with musculoskeletal and biomechanical evaluations, which include not only measurements of individual joints and muscle functions but also assessments of strength, range of motion, flexibility, alignment, and functional postures such as standing and sitting. Additionally, factors related to the central nervous system (CNS) that interfere with stability should also be assessed. Senses like vision, cognitive function, the vestibular system, and somatosensory inputs can be sources of deficits in body balance (MAGNUS, 1924). Other external factors, such as temperature, chemical substance consumption, and the interface between the feet and the contact surface, can lead to performance impairments (DAYAN, 2011; SADOWSKA et al., 2019).

According to Zok et al. (2008), posturography can be classified into three groups based on methodology: data collection, subjects characteristics, and testing protocol or procedure. It is possible to include an additional group related to decision-making variables, which would determine the type of biomechanical approach, whether quantitative or qualitative.

DATA COLLECTION AND BIOMECHANICAL APPROACH

Measurement methods can be differentiated into two types of biomechanical approaches: qualitative and quantitative. Among the qualitative methods, the Berg Balance Scale (BBS) is very well accepted by clinicians and researches, which addresses the relationship between the risk of falling and the score in a non-linear means, resulting in a 98% test-retest reliability. The score evaluates the individual on a scale from 0 to 56, where a higher score indicates better postural control. For every point deducted in the assessment, the risk of falling increases. Scores between 56 and 54 result in a 3 to 4% increase in the risk of falling for each point lost, between 54 and 48, the percentages range from 6 to 8%, and scores below 36 indicate a risk of falling close to 100% (PIMENTEL; SCHEICHER, 2009).

In addition to the BBS, there are other qualitative approaches such as the Flamingo Test, Romberg Test, unipodal support test, Balance Error Scoring System (BESS), and Bass Stick Lengthwise Test Method (BSLTM). The Romberg test is considered the first test created to measure static balance, in which the individual stands with their feet together, eyes open, and arms at their sides, and the time they can maintain this orthostatic posture is measured (RICCI; GAZZOLA; COIMBRA, 2009). Qualitative approaches typically rely on scales that provide a score for balance performance or simply the time the evaluated subject can maintain a specific posture. The application is much simpler, and there is no need for complex data collection equipment, although an experienced evaluator is required. The complexity is more related to statistical analyses that, depending on the behavior of variables, may require non-parametric tests to check for possible correlations. Qualitative tests are widely used and have clinical validation but are deficient in identifying more sensitive variations (MOHAMMED; BASHA; JUNGADE, 2020).

Posturography methods primarily employ force platforms to measure variables related to the ground reaction vector or center of pressure (COP) (DOS SANTOS LEAL et al., 2015; ZOK; MAZZÀ; CAPPOZZO, 2008). These platforms typically consist of a rectangular surface supported by devices known as force transducers. These transducers are designed to establish a degree of linearity between electrical voltage and force. The electrical signals collected undergo conditioning, where they are amplified and filtered before reaching data processing systems, which present the electrical impulses in the form of arithmetic values (NAVES, 2001).

The performance of postural control can be evaluated through various variables. COP-related factors commonly collected include displacement in the medial-lateral (ML) and anterior-posterior (AP) directions, average velocity (calculated as the ratio of the COP's distance traveled and time), the surface area of the ellipse (with 95% or 90% confidence intervals), perimeter, and root mean square (RMS). The ability to maintain balance is assessed based on the information generated by these variables, with higher values indicating poorer performance. Some equipment uses the scaling of these parameters to provide indexes that quantify stability control, such as those used in Computerized Dynamic Posturography (CDP). CDP equipment typically consists of a force plate platform that measures the subtle shifts in a person's COP as they try to maintain balance, also incorporating visual and vestibular stimulation to challenge the individual's balance (NASHNER; PETERS, 1990). In addition to force platforms and CDP equipment, quantitative approaches can also utilize inertial sensors to extract COP behavior (BARACKS, 2018).

For data collection, evaluating the quantitative approach, there are numerous possibilities for assessing Center of Pressure (COP) variables. This makes this group the most complex among the three, not only due to the statistical methods employed but also because of the number of variables considered, as well as the process of acquiring and processing electrical impulses, where factors such as the types of filters used for collection and the time involved can influence the analyses (SCHMID et al., 2002).

The process of transforming electrical impulses into information typically involves four basic stages: data collection (measures obtained through sensors), processing (filters for noise removal), parameter extraction (mean, standard deviation, amplitude, power spectral density – transforms, entropy measures, fractal dimensions), and statistical analysis (descriptive, correlation, time domain, frequency domain, artificial intelligence). Each stage may vary in complexity (MENZ; LORD; FITZPATRICK, 2003; MOE-NILSSEN, 1998).

Research comparing data acquisition durations has shown that tests with at least 30 seconds of signals should be collected to ensure data reliability, with time intervals evaluated ranging from 10 to 60 seconds (LE CLAIR; RIACH, 1996). However, this has been challenged, and a time longer than 60 seconds has been proposed as an alternative, which is now advised for future investigations (CARPENTER et al., 2001; DOYLE et al., 2007; LAFOND; DUARTE; PRINCE, 2004).

Regarding acquisition speed, studies have indicated that for cutoff frequencies above 10 Hz, COP measured factors do not show significant variations, and a recommended sampling rate is 100 samples/s, to improve digital signal acquisition techniques and limited filter selectivity (SCHMID et al., 2002).

As technology and mathematical models advance, the possibilities of obtaining increasingly precise information make the logic of analyses more complicated, derived from the high complexity of the statistical models employed. An example is the analysis of time series, which examines the fluctuations and patterns in various physiological signals related to balance, such as body sway or center of pressure. These analyses provide insights into the stability and control of the body during static and dynamic tasks (MOE-NILSSEN, 1998).

SUBJETCS CHARACTERISTICS

Individual characteristics refer to morphological, physiological, and neurological attributes. Several studies aim to assess factors that can interfere with postural control, such as height, body mass, body mass index (BMI), age, gender, lower limb strength, injury history, neuromuscular impairments, foot morphology, gait type, fatigue, among others (AKIL et al., 2016; ASHKEZARI; SEIDI; ALIZADEH, 2017; CHIARI; ROCCHI; CAPELLO, 2002; KEJONEN; KAURANEN; VANHARANTA, 2003, TURKERI et al., 2019; TSAI; MERCER; GROSS, 2006). Injury histories and neuromuscular impairments are typically identified through questionnaires, while other variables are measured quantitatively. Concerning morphological aspects, authors have concluded that the most significant characteristics to consider in balance assessments are height and body mass (CHIARI 2000). Other research reports that BMI is a determining factor in postural control, predicting it from children to the elderly (KOLIC et al., 2020). Physical activity level is also a variable that can influence balance measurements, as several studies have presented similar conclusions in this regard (GENC; KIZAR, 2020; PIOTROWSKA et al., 2020; SLOANHOFFER et al., 2018; ZHU et al., 2021). Fatigue is another factor related to postural control performance, as indicated by the research of Ghram et al. (2018).

Furthermore, among subject-related factors, we can mention the sensory system, responsible for detecting information about body position and movement, and the motor system, responsible for coordinating and controlling the muscles involved in balance (HORAK; MACPHERSON, 1996; SHUMWAY-COOK; WOOLLACOTT, 2007). The vestibular system consists of the inner ear organs that detect linear and angular head movements. It plays a fundamental role in static balance by providing information about head position relative to gravity. Disorders in the vestibular system, such as labyrinthitis, can negatively affect static balance (BALOH; KERBER, 2010). The somatosensory system, which includes sensory receptors located in the skin, muscles, tendons, and joints, is crucial for maintaining static posture. Proprioception is a specific part of the somatosensory system that refers to conscious perception of body position, movement, and muscle tension (HORAK; MACPHERSON, 1996). Proprioception has a considerable role in maintaining body balance by providing sensory information to the central nervous system. Through proprioceptive receptors such as muscle spindles and Golgi tendon organs, information about muscle length and tension is conveyed, while joint receptors provide information about joint position and movement (PROSKE; GANDEVIA, 2012). Proprioceptive receptors continuously send signals to the CNS to maintain stability and proper alignment of the body relative to gravity and the environment. They help detect postural deviations and imbalances, allowing for rapid and precise muscle adjustments to restore an upright position (SHERRINGTON, 1906). The exchange of information between proprioceptive receptors, muscles, joints, and the CNS occurs through a complex neural pathway system. Ascending pathways transmit sensory signals from the body to CNS. Based on proprioceptive information, the CNS sends motor commands through descending neural pathways, enabling muscle and joint adjustments to maintain balance (PROSKE; GANDEVIA, 2012).

While observing fixed objects or the horizon, the visual system can help determine if the body is tilted, straight, or in other positions, providing a basis for appropriate postural adjustments. Visual processing disorders, such as visual acuity problems, depth perception issues, or restricted visual fields, can negatively affect static balance (GUERRAZ; BRONSTEIN, 2008). Cognition is also an important sense in processing and integrating information from sensory systems, such as the visual, vestibular, and somatosensory systems. Through perception, interpretation, and assessment of this information, cognition enables the brain to understand the body's position, movement, and relationship with the environment, contributing to appropriate postural adjustments (MIRELMAN et al., 2012).

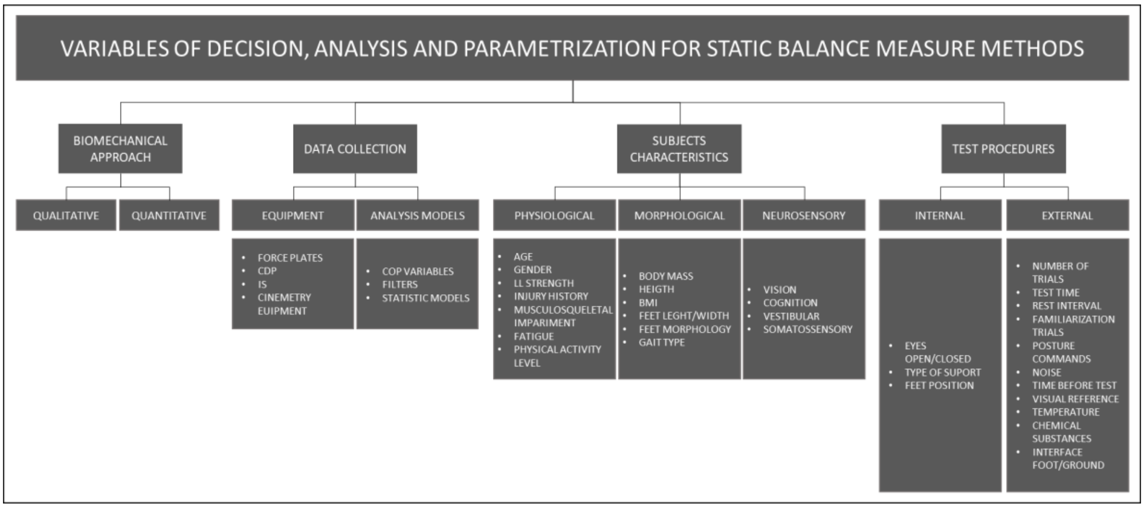
TEST PROCEDURES

The last group deals with procedural aspects or test protocols. Among the factors encompassed by the procedures, we can mention: postural standard, measurement time, rest interval between data collection, the number of trials under each condition, the number of trials for test familiarization, time of trials for familiarization, condition with eyes open, closed, or both, use of a visual reference point and its distance, unipodal or bipodal support, definition of foot positioning in terms of distance and angle, and interface between the feet and the supporting surface. Pinsault et al. (2008) mention that experimental parameters such as the number of trials used, collection time, and instructions given to each individual can have a significant impact on the results. The simple difference between an instruction to "stay still" and an instruction to "stay as still as possible" can have a considerable influence on the outcomes (ZOK; MAZZÀ; CAPPOZZO, 2008). Similarly, noise from conversations in the testing environment and the waiting time before starting the test itself can also affect balance performance (TAYLOR et al., 2015). Regarding the testing environment, the influence of temperature can alter the response of the body's balance system; its impact may vary among individuals and depend on factors such as adaptation to the environment, the level of physical activity, and general health (MAKINEN et al., 2005).

The importance of defining an appropriate interval between tests is related to fatigue, which can interfere with body control performance (SOSLU, 2019). Looking at the number of trials, studies with adults and the elderly suggest that a quantity of 3 to 5 tests can help reduce variability, considering measurements on bipodal support; for unipodal support, the result is not as consistent (LIN et al., 2008; PINSAULT; VUILLERME, 2009; RUHE; FEJER; WALKER, 2010; DA SILVA et al., 2014). On the other hand, other researchers, such as Lafond et al. (2004), concluded that 2 to 3 tests are sufficient for reliable results of COP parameters in measurements with bipodal support in the elderly. Corriveau et al. (2001) also recommend using an average of 4 attempts, also with bipodal support, for more accurate measures. In the same vein, the attempts for familiarization should also be considered in the procedures, as the total number of trials reflects the learning curve, resulting in a reduction of energy used to maintain the COM on the support base, as well as foot positioning, in addition to the interface between the feet and the supporting surface (CHIARI, ROCCHI, CAPPELLO, 2002).

Based on research evaluation, it is possible to synthesize the information as shown in Figure 2, which illustrates decision, parametrization and analysis variables broadly for the methodological design of static balance measurement. In Table 1, we can observe some characteristics of the most recent studies selected for the analysis. It is possible to identify, through the parameters extracted from the studies, some general characteristics concerning the methodology and the impact of the results on the analysis variables.

Figure 2 – Variables of decision, analysis and parametrization



Source: Elaborated by author (2023). Abbreviations: BMI= Body Mass Index; CDP= Computerized Dynamic Posturography; COP; Center of Pressure; IS= Inertial Sensors

Table 1 – Characteristics of the most recent studies

Author/ Year	Sample/ Gender/ Design	Objective	Biomechanical Approach	Groups	Results
Alqaraan et al. (2018)	Young collegiate athletes avg. 20 y/o (n=87)/ MF/ CS	Evaluate the impact of BMI on static and dynamic balance	Qualitative	FRG (n=39) SRG (n=48)	No significant differences between groups
Barbosa et al. (2017)	Elderly between 60 and 78 y/o (n=15)/ F/ CS	Evaluate the impact of physical activity level on balance	Quantitative	SEG (n=8) PAG (n=7)	No significant differences between groups
Baracks et at. (2018)	Collegiate athletes avg. 20 y/o (n=93)/ MF/ CO	To determine if group differences exist when using objective measures of balance with recent sport-related concussion and control group	Qualitative/ Quantitative	EG (n=48) CG (n=45)	Sport-related concussion can impact balance performance
Genc et al. (2020)	Children between 7 and 10 y/o (n=31)/ MF/ CO	Evaluate the effects of gymnastic exercises on static and dynamic balance	Qualitative	EMG (n=9) CMG (n=8) EFG (n=7) CFG (n=7)	Gymnastic exercises have a positive impact on postural control
Ghram et al. (2019)	Young athletes avg. 20 y/o (n=19)/ M/ EX	To compare ankle unilateral fatigue effects vs knee muscles	Quantitative	KG (n=10) AG (n=9)	No significant differences between groups

Michalack et al. (2019)	Elderly between 59 and 70 y/o (n=384)/ CS	Extract new parameters of posturography signals	Quantitative	GDG (n=54) HEG (n=98) HAG (n=193) HYG (n=39)	Most significant variables are average velocity and acceleration to determine COP variations
Oliveira et al. (2019)	Elderly avg. 68 y/o (n=90)/ M/ CS	To assess the effects of averaging trials of five different balance tasks	Quantitative	EG (n=90)	Coefficient of variation was lower for 3 trials
Piotrowska et al. (2020)	Elderly between 64 and 93 y/o (n=61)/ F/ EX	To compare the effect of regular NW and NW combined with CT on the ability to maintain static balance	Qualitative	NWCTG (n=20) NWG (n=20) CG (n=21)	NW significantly improved balance performance in closed eyes condition
Sadowska et al. (2019)	Young athletes avg. 18 y/o (n=53)/ MF/ CS	To examine the postural balance and to investigate the impact of footwear on the stability of the shooting position in pentathletes	Quantitative	ATG (n=27) CG (n=26)	Interface foot/ground was not significant in balance performance
Sloanhoffer et al. (2018)	Young (n=30)/ F/ CS	To investigate static and dynamic stability in collegiate gymnasts, non-gymnast athletes and non-athlete controls.	Quantitative	GG (n=10) OSG (n=10) CG (n=10)	Gymnastics training has a significant positive impact on balance performance
Soslu et al. (2019)	Atletas adultos (n=51)/ M/ EX	To investigate the effects of fatigue index on the static balance of sportsmen	Quantitative	FOG (n=19) VOG (n=13) SKG (n=10) ATG (n=9)	Fatigue has a negative impact on balance performance
Turkeri et al. (2019)	Adolescents athletes avg. 13 y/o (n=136)/ X/ CS	To investigate static and dynamic balance, reaction time, attention and BMI values	Qualitative	ISG (n=78) TSG (n=58)	Balance increase with age, training time has no impact on static balance
Zhu et al. (2021)	Individuals between 18 and 26 y/o (n=86)/ MF/ CS	To examine whether objectively measured physical activity and sedentary behaviors were related to static balance	Quantitative	MG (n=43) FG (n=43)	Physical activity level has impact on static balance

Source: Elaborated by author (2023). Abbreviations: AG=Ankle Group; ATG=Athletes Group; avg= average; BMI=Body Mass Index; CFG=Control Female Group; CG= Control Group; CMG= Control Male Group; CO= Cohort study; CS= cross section study; CT= Cognitive Training; EFG= Experimental Female Group; EG= Experimental Group; EMG= Experimental Male Group; EX= Experimental study; F= Female; FOG= Football Group; FRG= Freshman Group; GDG= Gait Disturbance Group; GG= Gymnasts Group; HAG= Healthy Adults Group; HEG=Healthy Elderly Group; HYG= Healthy Youngs Group; ISG= Individual Sports Group; KG= Knee Group; M=Male; MF= Male/Female; NW= Nordic Walk; NWCTG= Nordic Walk and Cognitive training; Group; NWG= Nordic Walk Group; OSG= Other Sports Group; PAG= Physical Active Group; SRG= Senior Group; SEG= Sedentary Group; SKG= Skiers Group; TSG= Team Sports Group; VOG= Volley Group

As studies on balance measurement progress, there is also an increase in the complexity of assessments in pursuit for more reliable and accurate results. The equipment itself, such as those of CDP, contributes to this complexity as data processing algorithms provide a balance index using a mathematical model based on COP variables defined by each supplier. Likewise, the data acquisition speed, which varies widely, is another source of deviations in measurements, with equipment differing by more than 20 times depending on manufacturer.

Despite the range of COP variables that can be measured, authors have concluded that acceleration and mean velocity are the most relevant for assessing balance performance (MICHALAK; PRZEKORACHA-KRAWCZYK; NASKRECKI, 2019). Studies utilizing statistical models of multivariate entropy considering time series have shown their advantages in terms of sensitivity in measuring body stability levels (MICHALAK; PRZEKORACHA-KRAWCZYK; NASKRECKI, 2019). Another study tested a model based on multivariate multiscale entropy and compared the results with traditional COP measurement models, presenting that entropy provides valuable information for generating more precise diagnoses (HANSEN et al., 2017).

Qualitative methods can be valuable for exploring participants' subjective experiences and providing insights into their perceptions and feelings regarding balance. However, they may not be suitable for objective evaluation purposes due to certain risks and limitations, particularly concerning the reliability and degree of result accuracy (SMITH, 2011). Qualitative assessment depends on researchers' subjective interpretation and analysis of data, which can lead to a lack of objectivity in results and challenging to compare different studies. This subjectivity complicates method replication and the attainment of consistent results across different contexts and with different researchers. Additionally, qualitative methods may be less sensitive in detecting minor changes or differences in body balance performance (CAMERINO; CASTAÑER; ANGUERA, 2012; MANCINI; HORAK, 2010).

The normalization of anthropometric measures such as body mass and height has been proposed in the literature to mitigate the impact of these variables on COP measurements (CHIARI; ROCCHI; CAPELLO, 2002). Similarly, applying an index that normalizes the body mass and height of subjects has been suggested when assessing data through CDP (CHAUDHRY et al., 2004). Regarding morphological variables, the correlation of BMI with static posture control is questionable, as the literature also presents results linking BMI to balance ability only in dynamic tests (ALQARAAN et al., 2018). Among physiological variables, despite fatigue being identified as a predictor of low performance in balance assessments, Barbosa et al. (2017) studied the influence of this variable and did not find a significant correlation.

One of the challenges of the methodology used in static balance assessments is precisely to minimize the impacts of subject-related parameters. Some patterns with this purpose can be observed in studies, such as the homogeneous formation of groups, with no significant differences in morphology, or the creation of correction formulas that would fit within the logic of the defined analysis models. PDC equipment, for instance, incorporates algorithms in their analysis models that consider the height, body mass, and BMI of each subject according to their stability index (ODA; GANAÇA, 2015). However, the evaluation of such methodological data and their relevance within the analysis models still falls to the discretion of each researcher.

Regarding procedural aspects, a comparative study identified differences in COP variable measurements in elderly women when comparing results from 1, 2, and 3 attempts, with the recommendation being to use an average of 2 measurements to ensure reliable results (OLIVEIRA et al., 2019). This finding aligns with Lafond et al. (2004), who concluded that 2 to 3 tests are sufficient for conscientious outcomes for bipodal support measurements in the elderly. However, other studies suggest using 3 to 5 attempts for static balance assessment (LIN et al., 2008; PINSAULT; VUILLERME, 2009; RUHE; FEJER; WALKER, 2010; DA SILVA et al., 2014). Corriveau et al. (2001) recommend using an average of 4 attempts with bipodal support for more accurate results.

FINAL CONSIDERATIONS

To explore aspects related to static balance assessment, with a primary focus on impactful variables and methodological parameters that can influence the results, it was possible to observe the existence of an extensive body of literature on this topic, given that over a century of research has been conducted. However, it can still be noted that, even today, there is a lack of a precise understanding of the mechanisms involved in this skill, related to the characteristics of the evaluated populations, data collection and analysis methods, and the parameters of the procedures established in the applied methodologies.

Therefore, the possibility of gaining an objective view of the analysis variables that can impact such a skill, related to the mentioned dimensions, is of great utility to researchers. This way, the margins for potential measurement deviations can be corrected or presented with the necessary caveats in the conclusions. According to the results and discussion of this research, the main impact factors for static balance measurements in the four stages of the method can be highlighted.

Regarding the biomechanical approach, quantitative methods should be used when a high sensitivity level to detect small skill deficits is required. Along the same lines of reasoning, control parameters for data collection and processing should be as comprehensive as the desired level of precision in the results. This includes considering the measurement of average velocity, displacement, perimeter, RMS (root mean square), elliptical surface area, and center of pressure (COP) acceleration. Additionally, using filters, defining segmentation, and employing more comprehensive statistical models are fundamental for result reliability.

Concerning the characteristics of the participants, notable variables include height, body mass, foot length, lower limb strength, age, gender, physical activity level, fatigue, history of lower limb injuries, deficits in vision, cognition, vestibular function, and proprioception.

Regarding procedure-related variables, it is recommended to consider the use of a visual reference (when testing with eyes open), precise definition of foot positioning (bipodal support), rest intervals based on the test duration, familiarization attempts when using predictive statistical models, standardization of communication and interface between the support base and equipment, temperature control, and assessing the intake of chemical substances that may interfere with balance ability.

It's important to note that some variables require further research for a better quantification of their impacts, obtaining the necessary scientific credibility for their relevance.

It is worth noting that, in addition to the need for the development of more robust standards for static balance measurement, they are also required in both qualitative and quantitative analyses to ensure the reliability of the results. These standards should take into account the level of precision required in relation to the assessment goal. In other words, the higher the precision needed, the more comprehensive the analysis models should be in terms of data extraction and processing. In this regard, the involvement of a multidisciplinary team is essential to ensure a comprehensive measurement process, considering a wide range of variables in the assessments.

Similarly, if high precision is not necessary, the number of variables can be reduced to simplify the method. It is important to emphasize that the defined standards should include clear and objective guidelines to minimize the dependence on experienced and highly trained individuals.

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