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Postural Balance Parameters as Objective Surgical Assessments in Low Back Disorders: A Systematic Review

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Abstract

Background: Postural balance assessments could render useful objective performance measures to evaluate the efficacy of low back disorder surgeries. Several studies utilized balance parameters but have not yet been collectively examined to determine an overall effect. Therefore, the purpose of the review is to investigate these measurements and determine their sensitivity for disparate spinal disorders after surgical intervention.

Methods: Articles were selected based on the following: 1) sample consisted of low back disorder individuals who underwent surgery; and 2) balance measurements were obtained both pre-surgery and at least at one time point post-surgery. Delphi consensus helped evaluate article quality and effect sizes were also determined for some studies.

Findings: Most of the articles addressed two specific low back disorders: 1) adolescent idiopathic scoliosis/spinal fusion; and 2) disc herniation/decompression surgery. For scoliosis patients, body sway seemed to increase (14–97%) immediately following surgery but gradually reduced (1–33%) approaching the one year post-spinal fusion assessment. For disc herniation patients, sway range, sway velocity, sway area, and sway variability all decreased (19–42%) immediately post-surgery.

Interpretation: Balance assessments for adolescent idiopathic scoliosis patients who underwent surgical intervention should be performed with visual occlusion, focus on time domain parameters,

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Author contributions

Tzu Chuan Yen wrote the manuscript and contributed to all aspects of the study, especially in search, analysis, interpretation of results; Nima Toosizadeh contributed in search, analysis and editing the manuscript; Carol Howe contributed in search, analysis and editing the manuscript; Michael Dohm contributed in developing the systematic review questions and design, and interpreting the findings; Jane Mohler contributed in editing the manuscript; and Bijan Najafi had a substantive role in the design of systematic review, study supervision and interpretation of results.

Conflict of interest

There is no conflict of interest for the current study.

and evaluated with longer follow-up times. Disc herniation patients who underwent decompression surgery should also have balance assessments with visual deprivation, test conditions specifically addressing hip strategy, and correlation with the pain level.

Keywords

Back pain; physical impairment; operation; functional disorder; outcome; evidence; balance

Introduction

In the United States, 149 million work days are currently lost annually because of low back disorders (LBD) [1]. Being the second most common cause for disability, LBD incurs costs of up to \$200 billion per year in the United States [1]. Based on both treatment and evaluation criteria by the US Food and Drug Administration, only about half of single level degenerative disc disease fusion and arthroplasty surgeries were deemed a success [2]. Lack of success in spine treatment, consequently, leads to secondary treatments. Martin et al. reported about 20% re-operation rates in an 11-year period for patients undergoing lumbar spinal fusion and/or decompression surgery [3]. With each study utilizing distinct evaluations, it is crucial to develop standard ways to assess LBD severity and its improvements following treatments in order to enhance surgical success rates. Although pain reduction is usually evaluated in clinical settings to assess improvements following low back surgeries, it may not be a reliable parameter due to physiological, psychological, and behavioral confounders [4]. Hence, objective physical impairment and disability measures should accompany LBD clinical evaluations [4, 5].

One such objective assessment of LBD physical impairment is related postural balance behaviors. Ruhe et al. performed a systematic review and demonstrated significantly greater postural sway during upright standing in non-specific LBD patients compared to healthy controls in 88% of the 16 analyzed studies [6]. Specifically, according to Byl et al., body sway increased up to 700% compared to healthy controls, and center of pressure (CoP) of the body moved posterior, during an eyes-closed one-foot balance task, indicating that patients with LBD rely more on hip strategy instead of the typical ankle strategy to maintain balance in an upright position [7]. Impaired performance in ankle strategy has been demonstrated as a reason for increased risk of fall [8]. In another study, Mientjes and Frank discovered a significant increase in anterior-posterior and medial-lateral root mean square (RMS) of the CoP in chronic LBD patients compared to healthy individuals in a leaned forward posture, suggesting that LBD patients exhibit increases in postural sway, relaxes trunk extensors, and decreases knee extension to compensate for pain [9].

Due to significant differences between healthy individuals and LBD patients, balance is a plausible method to objectively assess the efficacy of low back surgery. Previously we defined sensitive gait parameters for detecting LBD improvements following surgical procedures [1]. In continuation of our previous effort, summarizing studies that analyzed balance in LBD patients with different disorders and surgical interventions, the aim of this study was to identify the most sensitive balance parameters that correlate with physical improvements post-surgery in individuals with LBD.

Methods

Article selection

A systematic literature review was executed using methods specified in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [10]. Both controlled vocabulary terms (e.g., MeSH) and key words were utilized to search the following databases for articles focused on postural balance objective measures or instruments for assessing LBD pre- and post-surgery: PubMed/MEDLINE (1946–2015); Elsevier/Embase (1947–2015); Elsevier/Scopus (1823–2015); Wiley/Cochrane Library (1898–2015); Thomson-Reuters/Web of Science (1898–2015); and EBSCO/CINAHL (Plus with Full Text)(1981–2015). Literature searches were completed on May 29, 2015. The complete PubMed/MEDLINE search strategy, analogous to the other database searches, is available in Appendix. Reference lists of, and citations to, the articles eventually selected from the database searches were also screened.

Inclusion criteria stipulated that: 1) the population studied consisted of individuals with LBD requiring surgery; and 2) physical impairments due to LBD was measured objectively using balance assessment tests pre- and post-surgery. Balance measurements included one or more of the following: quantitative assessments of CoP, center of mass, and body weight distribution. No publication date or language limit was applied. Two independent reviewers performed the study selection (YHY, TY). In case of disagreements, a third reviewer (NT) cast the deciding vote. Titles and abstracts of retrieved references were originally screened for relevance. Subsequently, the full texts of the potential articles were analyzed to see if they met inclusion criteria. Letters, case studies, and systematic reviews/meta-analyses were excluded.

Quality assessment of selected studies

The Delphi Consensus was used to analyze the quality of the selected studies. Developed by three rounds of consensus among experts, the Delphi Consensus is a set of generic core items used to assess the quality of randomized clinical trials [11]. Criteria in the Delphi Consensus include: treatment allocation (randomization and treatment concealment); similarity of groups at baseline measurements; availability of eligibility criteria for participants; blindness of patient, caregiver, and outcome assessor to the study design; presenting point estimator and variability measures; and inclusion of an intention-to-treat analysis [11]. Four of the criteria, including randomization, concealing randomization, blinding of the care provider, and blinding of the patient, were not rated because of the impracticality, if not impossibility, of randomizing or blinding patients/care providers to surgical treatment assignments. Nonetheless, blinding of outcome assessors was included as one of the quality criteria. For our purposes, an additional score was added to the Delphi Criteria to account for the inclusion of a healthy participants control group when comparing pre- and post-surgery outcomes. This score was added because the normal ranges for objective balance parameters in the healthy population may not be obvious.

Results

We found 3977 articles through databases searches. Citation analysis of the most relevant articles revealed no additional articles. Of the 2026 articles that remained after duplicates were removed, 2012 were excluded because of irrelevance to the topic (Figure 1). Strict inclusion criteria, as outlined above were applied to the full text of 14 articles. Of these, 7 met the full set of criteria [12–18]. Aside from three studies [13, 14, 17], quantitative pre- and post-surgery measurements incorporated in the current review were stated rather than interpreted from graphs/tables for all objective balance parameters. Significance when comparing pre- and post-surgery measurements was unknown for two of these three articles [13, 14].

Quality assessment of selected studies

The average Delphi Consensus score for the selected studies was 1.9/6 (ranged 0–3, Table 3). None of these studies alluded to blinding of the outcome assessor, nor did they compare for significant differences during baseline measures for both the intervention and LBD control groups. LBD control groups who did not undergo surgical treatment were not included in any of the selected studies; only three of these studies included a healthy control group for pre- and post- surgery comparison analysis [13–15].

Participants, diagnosis, and surgical treatment

The mean (SD) sample size of participants who underwent surgery among all selected studies was 22 (12), ranging from 15 to 40 participants (Table 1). For healthy control groups, the mean (SD) sample size was 15 (0.6), varying from 15 to 16 participants. Using data from all but two studies that did not report a mean [16, 17], the mean (SD) age was 35 (22) years for the intervention group and 31 (27) years for the healthy control group (Table 1). Regarding the intervention sample, four (57%) of the studies recruited adolescents under the age of 18 [12–14, 16], one focused primarily on participants over the age of 50 [15], and two other samples consisted of mixed ages [17, 18].

Refraining from honing in on any particular surgery or disorder, the aim of this current review was to examine balance improvements in LBD patients post-surgery. Therefore, the selected papers concentrated on two specific types of LBD (including: scoliosis and disc herniation), and two surgical procedures (including: spinal fusion and decompression surgery) (Table 1). In one study, the type of LBD was not indicated [15].

Alterations in objective balance parameters pre- and post- spinal surgery

All studies assessed CoP using force plates during upright stance. Analysis of the data revealed that range/area, travelled distance, and velocity of CoP are most common parameters used for determining alterations in postural balance post spinal fusion in adolescent idiopathic scoliosis participants (Tables 1 and 2). One study showed that CoP location, travel distance, and sway radius remained relatively unchanged up to one year post-surgery [16]. Nonetheless, two studies suggested that the amount of body sway, measured by the area or velocity of CoP, increases immediately and up to three months after spinal fusion surgery [13, 14]. In the other study with longer follow up measurements, a significant

decrease in CoP velocity and sway area was determined at one year post spinal fusion in the eyes-open with visual feedback and eyes-closed conditions [12]. This same study at one year post spinal fusion also examined mean sway distance, sway range, and travel distance, all of which were significantly decreased by 1–16% under eyes open with visual feedback conditions [12]; however, significant increases by 5–23% were reported under eyes open conditions. To further measure underlying changes in swaying patterns, in one study, frequency dispersion, sway frequency, total power, centroidal frequency, and 95% power frequency were assessed one year post-fusion surgery and results revealed either significant mean value increases (2–16%) or decreases (1–33%) depending on the test condition [12]. Overall, although discrepancy exists, results from these studies suggest that body sway would increase immediately after spinal fusion and gradually subside.

During quiet standing, significant reduction in postural sway immediately post- surgery was determined in disc herniation participants who underwent decompression surgery; sway range, sway variability, and sway velocity was significantly reduced from 19% to 40% during an immediate follow-up under eyes-closed conditions [17]. Albeit insignificant, sway area was decreased by about 42% under these same conditions [17]. Interestingly, foot pressures on both the painful and non-painful sides of the body, being directly correlated with CoP, did not depict any significant alterations after decompression surgery in patients with disc herniation [18].

In participants with non-specific chronic low back pain (LBP) who also underwent spinal fusion, no significant change was observed in CoP displacement and CoP variation while performing a forward reaching task under normal stance [15].

Discussion

Balance assessment for adolescent idiopathic scoliosis/spinal fusion

Spine deformity in adolescents with idiopathic scoliosis causes asymmetrical posture development, which results in balance impairments [19]. Balance behavior can be quantified using either time domain (e.g., sway radius, sway range, travel distance, velocity, sway area, and sway distance of CoP movement in time) or frequency domain (e.g., sway frequency, total power, frequency dispersion, 95% power frequency, sway frequency, and centroidal frequency of CoP oscillation) parameters. Previous work demonstrated that patients with scoliosis have significantly greater amount of body sway than healthy individuals in a quiet upright standing test, measured by CoP velocity and sway area [19, 20]. Our findings here demonstrated sudden increases in body sway immediately following spinal fusion surgery in scoliosis patients, but improvements in postural balance began to appear one year post-surgery. Specifically, CoP sway and CoP velocity during quiet upright standing increased after spinal fusion and remained larger compared to pre-surgery values for up to three months. However, one year post-surgery, these parameters consistently decreased to values even smaller than pre-surgery measures, especially under eyes-open with feedback and eyes-closed conditions [12]. Accordingly, if changes remain undetected, longer recovery time, (longer than two years) may be necessary to better evaluate spinal fusion surgical efficacy. In agreement to our findings here, previous research highlighted that a long time of over three

years is required for all scoliosis participants after spinal fusion surgery to recover from the surgery and reach optimal truncal balance [21].

Time domain parameters effectively distinguish scoliosis participants from healthy ones, but frequency domain postural balance parameters are not as sensitive for distinguishing balance impairments in scoliosis patients [22]. Only a few frequency parameters were assessed to distinguish between scoliosis patients and healthy controls, but smaller differences were observed in these parameters compared to time domain parameters among these two groups. [22]. Hence time domain parameters such as travel distance, sway distance, and sway range, may be more sensitive for detecting balance improvements post-surgery in scoliosis patients during upright standing [22].

Overall among selected studies, the eyes-open condition within the upright quiet standing balance test was not as sensitive as the eyes-closed condition for identifying alterations in balance behaviors pre-and post-spinal fusion surgery; with vision, only sway distance, 95% power frequency, total power, and travel distance parameters were significantly changed following surgery [12]. On the other hand, within the same experimental setup and patient sample, within the eyes-closed condition and in addition to the above parameters, sway range, CoP velocity, sway frequency, sway area, centroidal frequency, and frequency dispersion were significantly altered. This observation is in agreement with previous studies that suggested visual occlusion instigated greater dependence on proprioception and the vestibular system, further disadvantaging LBD patients with a decreased low back position sense [23]. This theory was confirmed by previous reporting of a greater magnitude of CoP sway under eye-closed versus eyes-open conditions in adolescent idiopathic scoliosis patients [14, 24].

Balance assessment for disc herniation/decompression surgery

When examining pre- and post-decompression surgery changes, improvements in postural balance behavior were observed as a reduction in sway range, sway variability, sway velocity, and sway area during a forward-reaching task [17]. The reason behind this improvement is that patients were assumed to have immediately increased the role of hip strategy after decompression surgery, resulting in a better postural control while standing [17]. During easy tasks, LBD participants and healthy individuals rely more on the ankle strategy, where the trunk and head pivots uniformly around the ankle, as opposed to the hip strategy, where the hip acts as the fulcrum for the trunk [7]. Compared to healthy controls, LBD patients tend to avoid hip strategy, as it increases motion of the spine and its muscles, and consequently increases pain in the low back [25, 26].

Interestingly, similar to scoliosis/spinal fusion studies, eyes-closed condition appeared to be more sensitive in identifying balance improvements after spinal decompression surgery; no significant change in any of the sway parameters was observed within the eyes-open condition balance test within the disc herniation/decompression surgery [17]. Previous research showed that vision compensate for balance deficits in participants with disc herniation, where pain intensity correlated with reliance on vision while standing upright [27]. Accordingly, no noticeable differences were detected between participants with disc

herniation and healthy controls when measuring balance behaviors within the eyes-open condition [17].

LBD due to disc herniation commonly presents with unequal and asymmetrical pain in the legs and/or low back [28], and possible differences in muscle morphology between diseased and normal sides [29]; however, foot pressure distribution on both the painful and non-painful sides was not a sensitive parameter for detecting balance deficits in these adult patients [18]. Facet joint asymmetry, hypothesized to be the driving force of disc herniation due to uneven distribution of intervertebral shear force, is more sensitive in adolescents and children [30]. Hence, as it confirmed with the findings of the current review, asymmetry balance measurements may not be suitable for detecting balance improvements in adults with disc herniation.

Research limitations in objective balance assessment methodology

According to Table 3, the Delphi scores for the selected papers varied; none of the included studies provided baseline assessments of the measured outcome within the intervention and control groups. Further blindness of the outcome assessor was not indicated in any of these studies. Aside from the Delphi criteria, several other limitations are present. First, control for age or gender is lacking for some of the selected samples regarding alteration in balance behaviors post-surgery. Gender is especially important in four (57%) of the selected papers regarding adolescent idiopathic scoliosis, where mostly females are affected [12–14, 16]. Balance deterioration is also detected in the elderly due to many other disorders rather than LBD [31]. Hence, assessing samples from a variety of age groups, which was the case for only two (29%) studies, would increase the reliability of incorporating balance parameters as an objective assessment for LBD.

Second, none of the selected studies included subjective assessments of pain, disability, and physical performance to provide more insights into the underlying causes of disturbances in balance and its effects on daily activities.

Third, certain balance deficiencies may only be revealed under more taxing conditions. Even when detecting postural differences between young adults with older healthy adults, postural sway was significantly greater in the older healthy adults only on a dynamic platform [32]. Therefore, adding a cognitive task, tilting the platform, or standing on one leg, may assist in identifying the more indiscernible balance alterations that are more similar to daily living conditions. Only one (14%) of the studies involved simultaneous cognitive assessment within balance test by providing visual feedback during quiet standing [12], and another one involved a forward reaching task [15]. In the other five (71%) studies normal Romberg upright standing tests were performed to measure balance behaviors of LBD patients.

Conclusions

Limitations and summary

Ideally, similar studies examining multiple confounders under more challenging conditions would possibly unveil additional sensitive balance parameters. Although meta-analysis could not be performed due to inherent patient sample and treatment type disparities, valuable

information was gleaned from these studies regarding not only the usefulness of postural balance, but also how it can assess spinal fusion and decompression surgery success. With systematic use of the most sensitive parameters, the most effective surgery for each disorder could be identified. This would increase both patients' quality of life and functional status.

Recommendations

From the findings of the current review, the following recommendations were suggested to determine postural balance improvements in adolescent with idiopathic scoliosis who undergo spinal fusion: 1) include balance measurements with vision deprivation; 2) include time-domain balance parameters (especially CoP velocity and sway area), since they provide better sensitivity for detecting balance impairments in scoliosis patients rather than frequency domain parameters; and 3) perform long-term prospective balance measurements (longer than one year follow up) to better assess improvement in balance after adaptation to the fusion surgery.

To assess balance for disc herniation adult patients after decompression surgery, the following methods are recommended: 1) include measurements with vision deprivation; 2) measure time-domain balance parameters especially those related to assessing hip strategy balance mechanism (or parameters representing hip versus ankle strategy performance) during upright standing; and 3) separate participants into high versus low pain groups, since improvements in balance is suggested to be augmented with pain.

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Appendix

((((((((((("Back Pain"[Mesh]) OR "Sacroiliitis"[Mesh]) OR "Back Injuries"[Mesh]) OR "Sciatica"[Mesh]) OR "Spinal Diseases"[Mesh]))) OR (((((((((((spinal OR spine OR spines OR back OR backs OR vertebra* OR disc OR discs OR disk OR disks[Text Word])) AND arthrit*[Text Word])) OR sacroiliitis[Text Word]) OR (((curve OR curves OR curves OR curving[Text Word])) AND (spine OR spines OR spinal[Text Word]))) OR ((kyphosis[Text Word]) OR scoliosis[Text Word]))) OR (((vertebral OR compressure[Text Word])) AND (fracture OR fractures OR fracturing OR fractured[Text Word]))) OR sciatica[Text Word]) OR spinal stenosis[Text Word]) OR (((herniat* OR ruptur* OR prolapse OR prolapses OR prolapse OR prolapsing OR degenerative OR tear OR tears OR torn OR slipped OR slip[Text Word])) AND ((disc OR discs OR disk OR disks[Text Word])))) OR "back pain"[Text Word]))

AND

((((((("Postural Balance"[Mesh]) OR balance[Text Word]) OR "postural equilibrium"))

AND

(((((((((surgery[Text Word]) OR (((decompression OR fusion OR replacement OR injection[Text Word])) AND (spine OR spinal OR disc OR disk OR vertebra* OR back[Text Word]))) OR ((laser*[Text Word])) OR ((discectomy OR diskectomy[Text Word])) OR (((((((laminectomy[Text Word]) OR nucleoplasty[Text Word]) OR verterbroplasty[Text Word]) OR kyphoplasty[Text Word]) OR rhizotomy[Text Word]) OR cordotomy[Text Word]) OR foraminectomy[Text Word])) OR ((intradiscal electrothermal therapy OR IDET[Text Word])) OR (((radiofrequency lesioning[Text Word]) OR (percutaneous vertebral augmentation OR PVA[Text Word])) OR dorsal root entry[Text Word]) OR “interbody fusion” OR “interbody fusions”[Text Word]) OR (botox OR botulinum[Text Word])) OR (“General Surgery”[Mesh] OR “Surgical Procedures, Operative”[Mesh] OR “surgery”[Subheading] OR “lasers”[MeSH Terms] OR “diskectomy”[MeSH] OR “laminectomy”[MeSH Terms] OR “vertebroplasty”[MeSH Terms] OR “kyphoplasty”[MeSH Terms] OR “rhizotomy”[MeSH Terms] OR “cordotomy”[MeSH Terms] OR “Decompression, Surgical”[Mesh] OR “Spinal Fusion”[Mesh] OR “Total Disc Replacement”[Mesh] OR “Foraminotomy”[Mesh] OR “Pulsed Radiofrequency Treatment”[Mesh] OR “Injections, Spinal”[Mesh] OR “Botulinum Toxins, Type A”[Mesh])))))))

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Figure 1. Flowchart illustrating the process of literature search and extraction of studies meeting the inclusion criteria.

Table 1:

Changes in standing balance parameters pre- and post-surgery. Participants' information, diagnosis, and treatment are included for each study. See Table 2 for parameter definitions and measurement methods.

Reference	Participants	Surgery	Mean age (SD or range)	Significantly altered balance parameters based on effect size (ES)
Bustamante Valles [12]	Scoliosis; n=15	Spinal Fusion	Scoliosis: 15.5 (1.6)	Pre vs one-year post: Under the eyes-open with CoP visual feedback, reduction in CoP velocity, frequency dispersion, sway area, sway distance, sway range, total power, and travel distance (ES=0.13–0.33); increase in centroidal frequency, 95% power frequency, and sway frequency (ES=0.06–0.21). Under the eyes-open condition without CoP visual feedback, increase in 95% power frequency, sway distance, total power, and travel distance (ES=0.10–0.16). Under the eyes-closed condition, reduction in CoP velocity, centroidal frequency, 95% power frequency, sway area, sway frequency, total power, and travel distance (ES=0.10–0.27); increase in frequency dispersion, sway distance, and sway range (ES=0.01–0.67).
de Santiago [14]	Scoliosis; n=15 Healthy; n=15	Spinal Fusion	Scoliosis: 15.0 (1.6) Healthy: 15.1 (1.5)	Pre vs one-week to three-month post: With feet shoulder width apart, increase in CoP area under eyes-closed (ES=0.97–1.00) and eyes-open conditions (ES=0.99–1.00). With feet together, increase in CoP area under eyes-closed (ES=0.96) and eyes-open conditions (ES=0.63–0.98).
de Aubreu [13]	Scoliosis; n=15 Healthy; n=15	Spinal Fusion	Scoliosis: 15.0 (1.6) Healthy: 15.1 (1.5)	Pre vs one-week to three-month post: Increase in anterior-posterior (ES=0.13–0.99) and medial-lateral (ES=0.83–0.97) CoP sway under the eyes-open condition. Increase in anterior-posterior (ES=0.15–0.97) and medial-lateral (ES=0.88–0.98) CoP velocity under the eyes-open condition.
Pao [15]	Chronic LBP; n=16 Healthy; n=16	Spinal Fusion	Chronic LBP: 61.9 (11.3) Healthy: 62.0 (10.2)	Pre vs one-month post: No significant change in CoP displacement and CoP variation under eyes-open with forward reaching task conditions.
Sawatzky [16]	Scoliosis; n=12	Spinal Fusion	Scoliosis: unknown *	Pre vs immediate to one-year post: No significant changes in sway radius, CoP and travel distance, or shifts in CoP location under eyes-closed conditions.
Sipko [18]	Disc Herniation; n=40	Decompression Surgery	Disc Herniation: 46 (26–70)	Pre vs immediate post: No significant difference in foot pressures between painful and non-painful sides under the eyes-open condition with feet hip-width apart.
Sipko [17]	Disc Herniation; n=39	Decompression Surgery	Disc Herniation: (26–70)	Pre vs immediate post **: Significant reduction in anterior-posterior (ES=0.66) and medial-lateral (ES=0.54) sway range, anterior-posterior sway variability (ES=0.73), and anterior-posterior (ES=0.61) and medial-lateral (ES=0.61) sway velocity under the eyes-closed condition. Reduction in sway area (ES=0.54) under the eyes-closed condition.

* no information regarding age of recruited sample was provided in the article or from corresponding author

** effect size estimated from sample size and *p*-value

Table 2:

Objective balance parameter definitions. References and methods for measuring each parameter are specified.

Balance Parameters	Definition	Reference
95% power frequency	95 th percentile of power frequency for the center of pressure signal	Bustamante Valles [22]
Centroidal frequency	Zero crossing frequency representing location of the center of mass in the frequency domain for the center of pressure signal; higher values mean more spontaneous body sway	Bustamante Valles [22] Vette [33]
CoP area or sway area	Area that encloses approximately 95% of the points on the CoP plot in the anterior-posterior or medial-lateral directions	de Santiago [14] Bustamante Valles [22] Sipko [17]
CoP displacement	Weight shifting in the anterior-posterior direction during a forward reaching task normalized to participant foot length	Pao [15]
CoP location	Coordinate location of the point at which all body weight vectors result in one ground reaction force vector	Sawatzky [16]
CoP sway	Mean amplitude of CoP sway in the anterior-posterior or medial-lateral direction	de Aubreu [13]
CoP variation	Changes in CoP in the medial-lateral direction that quantifies smoothness of movement during a forward reaching task	Pao [15]
CoP velocity or sway velocity	Velocity of CoP movement in the anterior-posterior and medial-lateral directions	de Aubreu [13] Bustamante Valles [22] Sipko [17]
Foot Pressure	Mean pressure per foot calculated from the distribution of pressure forces on the ground	Sipko [18]
Frequency dispersion	Variability in frequency when comparing different group velocity versus frequency of the center of pressure signal; higher values mean more variability from the periodic sinusoidal graph	Bustamante Valles [22] Huisinga [34]
Sway distance	Mean distance from the mean CoP location in the anterior-posterior or medial-lateral directions	Bustamante Valles [22]
Sway radius	Mean radius of a circle to represent sway pattern, where all CoP trajectory falls within that circle	Sawatzky [16]
Sway frequency	Mean frequency of body sway signal	Bustamante Valles [22]
Sway range	Maximum CoP distance minus minimum CoP distance in the anterior-posterior or medial-lateral directions	Bustamante Valles [22] Sipko [17]
Sway variability	Standard deviation of sway magnitude in the anterior-posterior or medial-lateral directions	Sipko [17]
Total power	Integral of the square of the frequency domain CoP signal that represents the mean square value of the time series	Bustamante Valles [22]
Travel distance	Total CoP travel distance	Bustamante Valles [22] Sawatzky [16]

CoP: center of pressure

Table 3:

Quality assessment of selected papers using Delphi criteria.

	Bustamante Valles [12]	de Santiago [14]	de Aubreu [13]	Pao [15]	Sawatzky [16]	Sipko [18]	Sipko [17]
Include healthy control group							
No significant difference at baseline							
Indicate eligibility criteria							
Blinding of the outcome assessor							
Provide point estimates and measure of variability							
Include an intention-to-treat analysis							
Score	2	3	3	3	1	0	1