Center of pressure excursion as a measure of balance performance in patients with non-specific low back pain compared to healthy controls - A systematic review of the literature

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Abstract

Background: Over the past 20 years, the center of pressure (COP) has been commonly used as an index of postural stability in standing. While many studies investigated COP excursions in low back pain patients and healthy individuals, no comprehensive analysis of the reported differences in postural sway pattern exist.

Search methods: Six online databases were systematically searched followed by a manual search of the retrieved papers.

Selection Criteria: Papers comparing COP measures derived from bipedal static task conditions on a force plate of non-specific low back pain (NSLBP) sufferers to those of healthy controls.

Results: Sixteen papers met the inclusion criteria. Heterogeneity in study designs prevented pooling of the data so only a qualitative data analysis was conducted. The majority of the papers (14/16, 88%) concluded that NSLBP patients have increased COP mean velocity and overall excursion compared to healthy individuals. This was statistically significant in the majority of studies (11/14, 79%). An increased sway in antero-posterior direction was also observed in NSLBP patients.

Conclusions: Patients with NSLBP exhibit greater postural instability than healthy controls, signified by greater COP excursions and a higher mean velocity. While the decreased postural stability in NSLBP sufferers further appears to be associated with the presence of pain, it seems unrelated to the exact location and pain duration. No correlation between the pain intensity and the magnitude of COP excursions could be identified.

Key Words: Balance, center of pressure, force-plate, low back pain, healthy controls, systematic review

Background

Body sway can be assessed by measuring the deviations in the location of the center of pressure (COP) on the supporting surface by means of a force platform. COP refers to the point at which the pressure of the body over the soles of the feet would be if it were concentrated in one spot. It is, however, not a true record of body sway but rather a measure of the activity of the motor system in moving the COP.

The cause of sway has been attributed to many factors such as inherent noise within the human neuro-motor system, as reflective of an active anticipatory search process, or as an output of a control process to maintain postural control [1-3]. Many uncontrollable factors may contribute to the degradation of the balance system such as decreased performance of the sensory-motor system with ageing, neurological or musculoskeletal disorders such as low back pain (LBP) [4].

Low back pain is a common condition with a reported 1-year prevalence ranging from 22% to 65% [5]. While the majority of these cases resolve within six weeks without medical intervention [6], a minority of around 20% may progress to become chronic and constitute the western world's most prevalent and costly health problem [7]. Recent evidence showed that while age is a major determinant for balance, low back pain may account for up to 9% of the variance in balance [8].

A variety of theories exist about the potential effect of NSLBP on postural stability. Ideally, the body should be able to generate quick COP transitions that just exceed the current position of the center of mass (COM) [3] and accelerate it into the opposite direction in order to maintain balance. On a basic level, (chronic) damage of sensory tissues in the lumbar spine, trunk [9] or lower extremities [10] may affect postural stability. Deterioration of this proprioceptive information from these areas may be the determining factor in reducing the accuracy in the sensory integration process. The resulting imprecise estimation of the COM position especially in chronic LBP sufferers may then lead to an increase in the safety margin of the adaptive COP shifts with regard to the predicted COM oscillations [11].

Another possible mechanism behind balance alterations is acute "pain inhibition" [12]. In this case, discharge from high-threshold nociceptive afferents interferes with spinal motor-pathways [13] as well as the motor cortex [14]. In addition it has been shown that pain may cause an increased pre-synaptic inhibition of muscle afferents [15] as well as affecting the central modulation of proprioceptive spindles of muscles [16], causing prolonged latencies by the decrease in muscle spindle feedback. These alterations may lead to decreased muscle control and result in increased postural sway.

This literature review will attempt to identify possible differences in COP pattern between NSLBP sufferers and healthy controls that may relate to the mechanisms described above. This step is fundamental before investigating whether a connection between the magnitude of these differences and the LBP intensity or location exists.

To our knowledge no systematic review has been conducted to investigate the possible impact of low back pain on COP pattern and the possible association of this effect with pain intensity or disability.

Aims

The aims of this systematic literature review were 1) to determine if there are significant differences in COP between LBP patients and healthy controls, 2) to investigate whether

the magnitude of these COP excursions are related to the level of pain perception or 3) to the perceived level of disability.

Methods

Search strategy

A comprehensive search strategy was developed by identifying all potentially relevant search terms, categorizing these terms into specific search phases and subsequently combining them by using Boolean terms. This search strategy was applied to six different electronic databases: PubMed, MEDLINE, EMBASE, Web of Science, ScienceDirect, Digital Dissertations and the Cochrane library. The detailed search strategy will be made available upon contacting the corresponding author.

Electronic searches

All databases were searched using the search strategy described above. Appropriate minor modifications to the basic search template were made to optimize the strategy in each of the six databases. Papers were limited to human studies published between January 1980 and July 2009.

Searching other resources

The hand search included analyzing references cited in studies selected from the original online search. Citation searches of relevant studies were conducted using the PubMed, MEDLINE and ScienceDirect databases.

Selection Criteria

Papers were limited to peer-reviewed journals and dissertations without restrictions regarding language. Wide inclusion and exclusion criteria for study designs were in order to avoid limitation of potentially relevant papers.

The inclusion criteria were: Papers in any language that were fully or partially concerned with COP measures of subjects with NSLBP derived from bipedal static tasks on a force plate, compared to measures of healthy controls. For the purpose of this review, NSLBP was broadly defined as pain of musculoskeletal etiology in the absence of any neurological symptomatology or structural damage due to trauma or serious pathology such as cancer or infection.

All COP measures, experimental setups and statistical models fitting these criteria were considered. No limitations of the type of patient demographics applied. We excluded studies with insufficient documentation of patient demographics or experimental setup where this rendered data extraction impossible. In addition, papers that were anecdotal, speculative or editorial in nature or studies that employed dynamic task conditions such as one-leg hopping, walking or some form of translation of the force platform were excluded.

Data extraction and management

For the purpose of this review AR acted as the principal reviewer. A colleague was involved independently in the process of identifying relevant studies and did not participate in further analysis of the finally included papers.

With regards to the research question, the data extraction consisted of five main areas regarding low back pain and disability: 1) location and origin of the pain, 2) LBP duration prior to the measurements, 3) number of previous painful episodes, 4) perceived pain intensity and 5) any reported disability level.

For the purpose of this review, a p-value at or below 0.05 ($p \leq 0.05$) was considered statistically significant.

Assessment of methodology

Recently it has been suggested that combined quality scores should not be incorporated into systematic reviews and instead the accuracy should be assessed by an investigation into individual quality scores [17].

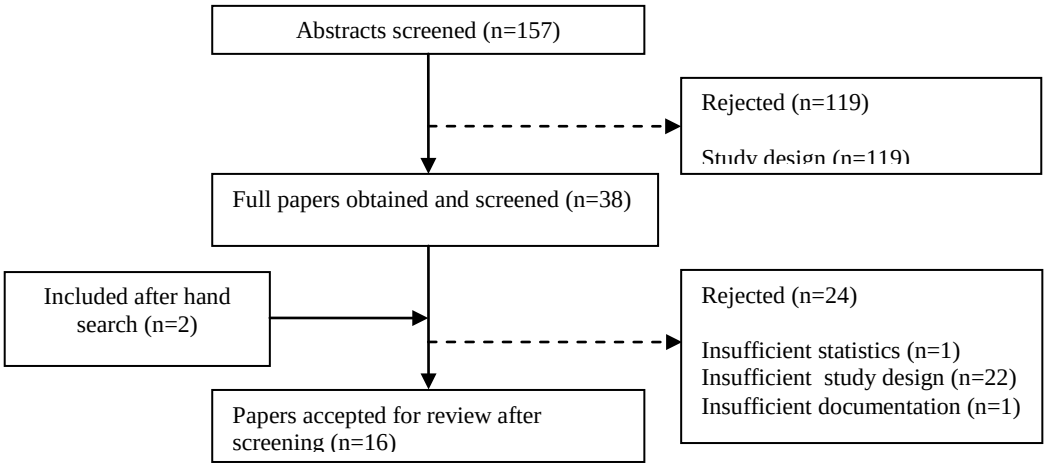
The reviewers specifically assessed the application, documentation and association of six individual items with regards to differences in COP measures between LBP patients and healthy controls. The reviewed criteria for experimental setups consisted of 1) subject demographics and morphology, 2) sample duration, 3) number of trial repetitions, 4) visual condition (eyes open or eyes closed), 5) stance, and 6) type of platform surface.

Results

Literature search results

Initially, the online search strategy identified 157 studies of which abstracts were screened individually by the reviewers. The application of inclusion/exclusion criteria and consensus by the reviewers on the titles and abstracts eliminated a further 119 papers. The most common reason for rejection was not meeting the selection criteria such as static or bipedal tasks. From the titles and abstracts of papers selected (n=38), full papers were reviewed and the same two reviewers (AR and TB) applied the inclusion criteria to the full text. Of these, 16 studies met the inclusion criteria and were included in this review. Two of these 16 were added after the hand search of reference lists of included papers (Figure 1).

Figure 1: Flowchart of papers



Study results

Characteristics of participants and methods
There was no blinding of the examiners to the participant's health status described. Most authors described the baseline demographics in appropriate detail by including weight, height, age and gender (12/16, 75%), eight studies (50%) included a physical examination in order to validate their health status prior to study enrollment. Only one of the included studies reported calibration procedures of the force-plate [18], another one described procedures to ensure that the participants resumed an identical foot position throughout the trials [19].

Both subject demographics and health status for all studies are shown in Table 1.With regard to patient demographics, less than half of the included studies (41%) enrolled mixed gender groups of healthy and NSLBP participants. The studies employed rather broad age ranges of participants, with the most commonly enrolled age range being 21-40 years (76%).

Table 1: Participant demographics and health status

Study	Healthy status and number of participants	Gender Female	Male	Age in years (SD)	Weight in kg (SD)	Height in cm (SD)
Luoto et al. [20]	moderate LBP: 68	35	33	20-60	-	-
	severe LBP: 31	18	13	20-60	-	-
	healthy: 61	29	32	20-60	-	-
Mientjes et al. [21]	LBP: 8	3	5	38.4	-	179
	healthy: 8	3	5	37.1	-	171
Kuukkanen et al. [22]	LBP: 90	-		39.9 (7.9)	-	-
Hamaoui et al. [23]	LBP: 10	0	10	33	77	181
	healthy: 10	0	10	31	69	178
Grimstone et al. [24]	LBP: 10	-		32 (8.3)	69 (14.7)	173 (10)
	healthy: 10	-		26 (5.4)	66 (15.1)	171 (10)
Brumagne et al.	LBP: 10	-		25	-	-

[25]	healthy: 10		-	25	-	-
	LBP: 10		-	63	-	-
	healthy: 10		-	63	-	-
Hamaoui et al. [26]	LBP: 10	0	10	33	77	181
	healthy: 10	0	10	31	69	178
Mok et al. [27]	LBP: 24		-	36.6 (10.)	71.2 (11.5)	171 (0.09)
	healthy: 24		-	36.9 (10.5)	65.3 (11.6)	169 (0.08)
Smith et al., [28]	healthy / Induced LBP: 12	4	8	26 (4)	71 (12)	176 (12)
della Volpe et al. [2]	LBP: 12	5	7	35.4	-	174.9
	healthy: 12		-	-	-	-
Popa et al. [29]	LBP: 13	6	7	35.1 (11.9)	76.5 (17.9)	174.3 (9.1)
	healthy: 13		-	32.2 (7.2)	69.5 (12.7)	174.4 (7.5)
Brumagne et al. [30]	LBP: 21	14	7	23.5 (1.0)	64.5 (12.9)	171.2 (10.2)
	healthy: 24	13	11	23.0 (1.6)	63.4 (10.1)	172.9 (9.5)
Lafond et al. [31]	LBP: 12		-	41.5	74.6	172.0
	healthy: 12		-	40.0	68.5	167.3
Harringe et al. [32]	LBP: 11	11	0	15.0	49.9	161
	healthy: 18	11	0	13.8	48.1	160
			0			
Mann et al. [19]	LBP: 10	10	0	57.6 (0.6)	57.6 (0.6)	165 (0.04)
	healthy: 10	10		20.27 (1.7)	56.7 (0.2)	166 (0.03)
Salavati et al. [33]	LBP: 22	9	13	26.1 (6.2)	67.1 (11.2)	172 (0.1)
	healthy: 22	9	13	25.0 (5.5)	66.5 (12.1)	173 (0.1)

LBP: low back pain

While the majority of studies defined neurological pathologies such as nerve root irritations in their exclusion criteria, few studies specifically addressed excluding vestibular conditions [21, 22, 26]. Other neurological conditions affecting balance were not addressed. Only one study investigated whether NSLBP sufferers were under the influence of pain medication [14] and consequently excluded those patients.

Table 2 shows the study characteristics and the results of the most commonly used COP parameters. There is a marked heterogeneity present in the in the included studies in terms of sample duration, number of trials or choice of COP parameters used.

About 53% of the trials were performed under both eyes closed (EC) and eyes open (EO) conditions. Most of the authors conducted less than three repetitions of postural sway recordings (9/16, 56%). Mean velocity (mVel), mean distance/displacement, root mean square (RMS) as well as sway area accounted for most of the COP parameters selected (Table 2).

Table 2: Study characteristics and selected COP parameters measured on a firm surface

Study	Condition	Duration (sec)	Number of trials	Parameter	Low back pain Result (SD)	Healthy controls Result (SD)	p-value
Luoto et al. [20]	normal stance, EO/F	25	1	mVel	male: A: 14mm/s B: 13mm/s	male: C: 12mm/s	p>0.05
					female:	female:	p<0.05

					A: 10mm/s B: 20mm/s	C: 11mm/s	
Mientjes et al. [21]	normal stance, EO/EC, F/C	unclear	3	mPos RMS (ML) RMS (AP)	- - -	- - -	p=0.099 p=0.016 p=0.031
Kuukkanen et al. [22]	unclear stance, EC/F	20 (40)	1	mVel (AP) mVel (ML)	17.1mm/s (3.7) 12.3mm/s (2.7)	- -	- -
Hamaoui et al. [23]	normal stance, EO/F	20	5	mPos (AP) mPos (ML)	2.9 mm (0.5) 1.6 mm (0.7)	1.9 mm (0.8) 1.1 mm (0.6)	p=0.002 p=0.032
Grimstone et al. [24]	normal stance, EO/F	120	1	mean dis-placement	3.2mm	2.4mm	-
Brumagne et al. [25] ∞	normal stance, unclear visual condition/ F	60	1	RMS (AP)	young: ~ 8mm elderly: ~7.5mm	young: ~5mm elderly: ~5mm	p<0.05 p<0.05
Hamaoui et al. [26]	normal stance, EC/F narrow stance, EC/F	20	5	mean dis-placement	AP 4.3 mm (1.6) ML 2.0 mm (1.2) AP 5.5 mm (1.5) ML 4.7 mm (1.6)	AP 2.7 mm (0.9) ML 1.3 mm (0.6) AP 3.0 mm (0.6) ML 3.7 mm (0.9)	p<0.05 p>0.05 p<0.001 p>0.05
Mok et al., [27] †	normal stance, EC/F	70	1	mVel	4.3mm/s (2.17)	5.03 mm/s (2.8)	p>0.05
Smith et al. [28] ∞	normal stance, EC/EO/F	120	1	mean dis-placement	EC: ~2,9 mm	EC: ~2.75 mm	-
della Volpe et al. [2]	normal stance, EO/F	20	3	mVel (AP) RMS length	12.18mm/s (1.2) 0.19mm (0.01)	10.32 mm/s (0.6) 0.16mm (0.01)	- -
Popa et al. [29]	normal stance, EC/F	20	3	mean dis-placement	2.85mm (0.024)	2.09mm (0.01)	p<0.05
Brumagne et al. [30]	normal stance, EO/EC, F/C	60	1	RMS (AP)	EC/F: 8,8 mm EO/F: 8,2 mm EC/C: 7,5 mm EO/C:.7,8 mm	EC/F: 5,4mm EO/F: 6,2mm EC/C: 8,7mm EO/C: 10,5mm	p>0.05 p>0.05 p>0.05 p<0.05
Lafond et al. [31] ∞	normal stance, EC/F	60	1	mVel (AP) RMS length Area	~5 mm/s ~1.3 mm ~8.0 cm²	~3 mm/s ~4.3 mm ~4.7 cm²	p<0.05 p<0.05 p<0.05
	normal stance, EC/F	1800		mVel (AP) RMS length Area	~13.5 mm/s ~11mm ~18.5 cm²	~17.5 mm/s ~17.5mm ~25.0 cm²	p>0.05 p<0.05 p>0.05
Harringe et al. [32]	normal stance, EC/F	120	2	RMS Vel Area	2.2 mm/s (0.59) 7.11cm² (3.04)	2.06 mm/s (0.6) 6.92 cm² (3.91)	p>0.05 p>0.05

Mann et al. [19] ∞	normal stance, EC/F	30	1-3	SD vel m displ AP m displ ML	~ 6.7 mm/s ~ 7.6 mm ~ 4.5 mm	~ 5 mm/s ~ 3.3 mm ~ 1.7mm	p=0.015 p<0.001 p=0.007
Salavati et al. [33]	normal stance, EC/F	30	3	SD vel mVel	AP: 13.0 mm/s ML: 15.2 mm/s 13.7mm/s (0.35)	AP: 14.8 mm/s ML: 17.2 mm/s 15.9 mm/s (0.33)	- - -

∞ The results presented have been extracted from bar-charts.
† The results from uni- and bilateral static task conditions were not differentiated.
AP: antero-posterior, BP: bipedal, displ: displacement, EC: eyes closed, EO: eyes open, F: firm surface, m displ: mean displacement; ML: medial-lateral, mPos: mean position, mVel: mean velocity, RMS: root mean square, SD vel: standard deviation of velocity

Although both height and weight have been shown to affect the reliability of COP measures [34, 35], none of the presented results was subject to a normalizing process for these factors. Normalizing refers to statistically removing the dependence of stabilometric parameters on biomechanical factors as originally proposed by O'Malley [27].

Reliability of COP data

Table 3 gives an overview of how the studies included meet the ideal experimental setup for reliable data. As a general rule, the most important factors for reliable data appear to be sampling duration, number of trials and visual condition. Irrespective of sampling frequency and cut-off frequency, a sufficient sampling duration (<90sec) in combination with the appropriate number of recordings (3-5) showed to yield reliable data for most COP parameters such as mean velocity (mVel) or area [32, 36, 37].

With few exceptions [2, 20, 23, 31], most of the studies conducted the trials under visual deprivation while only four [24, 28, 32, 38] applied a sampling duration that has shown sufficient reliability [37]. A minority used three or more trial repetitions [2, 19, 21, 26, 29, 33].

Table 3: Reliability criteria

Study	Sampling frequency	Cut-off frequency	Duration	Number of repetitions	Visual condition	Surface	
Recommended	~100Hz	10Hz	≥ 90sec	3-5	eyes closed	firm	Total
Luoto et al. [20]	0	0	0	0	0	+	+
Mientjes et al. [21]	0	0	unclear	+	+	+	+++
Kuukkanen et al. [22]	unclear	unclear	0	0	+	+	++
Hamaoui et al. [23]	0	unclear	0	0	0	+	++
Grimstone et al. [24]	0	unclear	+	0	0	+	++
Brumagne et al. [25]	0	0	0	0	unclear	+	+
Hamaoui et al. [26]	unclear	unclear	0	+	+	+	+++
Mok et al.,[27]	+	+	0	0	+	+	++++
Smith et al., [28]	+	unclear	+	0	+	+	++++
della Volpe et al. [2]	unclear	unclear	0	+	0	+	++
Popa et al. [29]	+	0	0	+	+	+	++++
Brumagne et al. [30]	+	0	0	0	+	+	+++
Lafond et al. [31]	+	+	+	0	0	+	++++
Harringe et al. [32]	0	+	+	0	+	+	++++
Mann et al. [19]	+	unclear	0	+	+	+	++++
Salavati et al. [33]	+	+	0	+	+	+	+++++

Pain characteristics

Only half the studies (8/16, 50%) stated the total low back pain duration prior to the test (ranging from 1 to 10.5 years); the long-term implications of this factor on COP excursions cannot be assessed. Of all the studies only, a minority (6/16, 38%) correlated this duration to pain intensity (Table 4).

Table 4: Pain definition, intensity and characteristics of included studies

Study	Physical examination	Low back pain *	Pain presence in years (SD)	Pain present at time of trial (n)	Pain intensity evaluation (pre-trial)	Score (SD)
Luoto et al. [20]	yes	chronic	-	yes (99/99)	VAS	unclear
Mientjes et al. [21]	-	chronic	10.9	yes (8/8)	VAS	2.6
Kuukkanen et al. [22]	yes	subacute	10 (8.4)	yes (58/58)	-	-
Hamaoui et al. [23]	-	chronic	-	yes (10/10)	-	-
Grimstone et al. [24]	-	chronic	3.54	yes (10/10)	VAS	<2
Brumagne et al. [25]	-	-	-	unclear	-	-
Hamaoui et al. [26]	yes	chronic	-	yes (10/10)	-	-
Mok et al.,[27]	-	chronic	10.5 (8)	yes (24/24)	VAS	2.0 (1.6)
Smith et al., [28]	-	acute	-	yes (12/12)	VAS	4.4 (1.9)
della Volpe et al. [2]	yes	chronic	5.2	yes (12/12)	NRS-11	2-5/10
Popa et al. [29]	yes	chronic	5.2 (3.3)	yes (13/13)	-	-
Brumagne et al. [30]	-	chronic	3.4 (2.5)	yes (21/21)	VAS	2.2 (1.5)
Lafond et al. [31]	yes	chronic	-	yes (10/10)	VAS	2.5
Harringe et al. [32]	-	-	-	mostly (7/11)	-	-
Mann et al. [19]	yes	chronic	-	yes (10/10)	VAS	6 (2)
Salavati et al. [33]	-	episodic	1.0	no (22/22)	VAS	<2.0

* Chronic pain is defined as pain presence for at least 3 months.
Visual analogue scale (VAS) ranging from 0-10: 0-2: light pain, 3-5: light to moderate pain, 6-7: moderate to intense pain, 8-10: unbearable pain

Pain assessment

Due to the described heterogeneity in the experimental setups, a direct comparison of data sets is problematic. Only about half of the studies described some form of physical examination prior to the recordings (9/16, 57%). While all investigated the effect of NSLBP on COP measures, not all studies (9/16, 57%) assessed the pain level in some form e.g. by means of a visual analogue scale (VAS). Luoto et al. [20] mentioned collecting VAS data of their participants but this data is missing in the published paper.

The participants of two studies did not experience any pain at the time of recording [24, 33, 39], neither were four individuals of another [32]. While Brumagne et al. [30] stated that their participants were not in an acute recurrence of NSLBP; they nevertheless reported VAS scores of 2.2±1.5 and were consequently counted as in pain. The perceived pain levels were similar throughout the studies at around 2.5 (VAS), indicating mild to moderate pain (Table 4).

Low back pain and postural sway

Generally there is a great variability in the reported COP measures. The results of the included studies indicate that patients suffering from NSLBP exhibited a greater postural instability than healthy controls. This difference was statistically significant in the majority of studies (14/16, 88%). Only two studies found significantly lesser COP excursions in patients suffering from low back pain.

The variation in results can be observed irrespective of the COP parameter chosen. Compared to healthy controls, participants with NSLBP exhibited a greater sway area [31, 32], which varied greatly between 7.11 cm^2 [32] and 18.5 cm^2 [31]. The NSLBP patients also showed an increased COP mean displacement [23, 24, 26, 28, 29].

This difference was significant in the AP direction [23, 26, 29]. The general trend towards an increased AP sway in pain sufferers was also present when considering the root mean square (RMS) for antero-posterior sway [30, 40], an effect that was found to increase with longer sampling durations [31]. Only two studies identified a decreased AP sway compared to healthy controls [27, 33].

Additionally, a higher COP sway velocity was found in non-specific LBP cases [2, 19, 20, 31, 32]. The mean velocities ranged from about 2.23mm/s [32] to 17.1mm/s [22] throughout the studies. For comparison, Table 5 shows the results for the parameter mean velocity.

Table 5: The effect of NSLBP on postural sway for the COP parameter mean velocity (mVel)

Study	Duration (sec)	Number of trials	Healthy controls Result (SD)	LBP patients (SD)	Pain severity (SD)
Luoto et al. [20]	15	1	male: 12mm/s	male: 14mm/s	moderate
				13mm/s	severe
	15	1	female: 11mm/s	female: 10mm/s	moderate
				20mm/s	severe
della Volpe et al. [2]	20	3	AP: 12.2 mm/s (1.2)	AP: 10.3 mm/s (0.6)	2-5 NRS-11
Lafond et al.[31] ∞	60	1	~3 mm/s	~5 mm/s	2.5 VAS
Mann et al. [19] ∞	30	1-3	~ 5 mm/s	~ 6.7 mm/s	6 (2) VAS
Salavati et al. [33]	30	3	15.9 mm/s (0.33)	13.7 mm/s (0.35)	< 2.0 VAS

Visual analogue scale (VAS) ranging from 0-10. 0-2: light pain, 3-5: light to moderate pain, 6-7: moderate to intense pain, 8-10: unbearable pain. NRS-11 ranging from 0 "no pain" to 10 "worst possible pain".
∞ The results presented have been extracted from bar-charts.

The contribution of visual information

The results show that the differences in COP pattern between LBP sufferers and healthy controls gain significance under visual deprivation. An increase in postural sway in the absence of visual input has been observed by numerous studies of healthy participants [19, 22, 29, 41]. In a study enrolling patients suffering from lumbar disc pathologies, the level of significance between those and healthy controls increased from $p<0.05$ (~12mm/s compared to ~8mm/s) under eyes open to $p<0.01$ (~23mm/s and ~13mm/s respectively) under eyes closed condition for COP mean velocity [41]. Mann et al. reported that the presence of visual input did not influence COP mean velocity in healthy subjects and no difference between healthy controls and LBP patients was observed under eyes open condition. With closed eyes, however, a significant difference became apparent (5mm/s compared to 6.7mm/s, $p=0.015$) [19].

Sampling duration

Most studies focused on investigating COP excursions of NSLBP sufferers during relatively short sampling durations of up to 120 seconds, observing the described increased postural instability. Only one study assessed body sway during prolonged standing of 30min [31].

Disability assessment

The study designs and variable participant's health characteristics render any direct comparison of results problematic (Table 6). The majority of the included studies (12/16, 75%) investigated the perceived level of disability of the participants. Two of the papers [20, 22] failed to document the results, another one only assessed post-trial disability levels [21]. In addition to the Roland Morris [42] questionnaire, the Oswestry [43] questionnaire was the most commonly used (8/12, 67%). The scores generally show great variability ranging from 1-32/50 (Oswestry) and 3.2-17/24 (Roland Morris).

Table 6: Disability definition and characteristics of included studies

Study	Disability assessed	Questionnaire	Score (SD)
Luoto et al. [20]	yes	Oswestry	unclear
Mientjes et al. [21]	yes	Oswestry (post-trial)	9-32 / 50 (mean 15.6)
		Roland Morris (post-trial)	3-17 / 24 (mean 7.5)
Kuukkanen et al. [22]	no	Oswestry	unclear
Hamaoui et al. [23]	no	-	-
Grimstone et al. [24]	no	-	-
Brumagne et al. [25]	yes	Oswestry	20/50
Hamaoui et al. [26]	no	-	-
Mok et al.,[27]	yes	Roland-Morris	3.2 (3.5) / 24
Smith et al., [28]	no	-	-
della Volpe et al. [2]	yes	Oswestry	1-24 / 50 (mean 7.8)
Popa et al. [29]	yes	Oswestry	0-24 / 50 (mean 7.08)
Brumagne et al. [30]	yes	Oswestry	7.3 (7.6) / 100
Lafond et al. [31]	yes	Oswestry	12.6 / 50 (7.3)
		FABQ	20.4 (16.2)
Harringe et al. [32]	no	-	-
Mann et al. [19]	no	-	-
Salavati et al. [33]	yes	Roland-Morris	3.4 / 24 (3.2)

Roland Morris Disability Questionnaire: 24 items, 0 (no disability) – 24 (severe disability).
Oswestry Disability Questionnaire: 50 points. 0-10: minimal disability, 11-20: mild disability, 21-30: severe disability, 31-40: crippling disability, 41-50: bed bound.
FABQ: Fear Avoidance Belief Questionnaire. 0-96, the higher the scale scores the greater the degree of fear and avoidance beliefs shown by the patient.

Discussion

Due to the heterogeneous study designs and experimental setups pooling of data was not possible. However, despite the great variability across the included studies our systematic review showed that patients suffering from NSLBP exhibit a significantly increased COP sway. Unfortunately, the magnitude of these differences in postural sway cannot be summarily expressed in terms of specific percentages or values. As a result, only a general trend is noted.

The reliability of COP measurements is determined by factors such as sampling duration, sampling frequency and number of trials [37]. In our critical review only about half the included studies fulfilled three or more of these recommended reliability criteria. However, there was a trend towards better methodological reporting in the more recent studies. Despite this it is worth bearing in mind that studies with less than all six criteria may still present fairly reliable results.

With regards to vision, an increase in COP excursions has been observed under visual deprivation compared to eyes open condition in patients suffering from NSLBP. This supports the previously mentioned proprioceptive deficits in NSLBP patients. An existing impaired sensory input from muscles and joints is more severely challenged with closed eyes. Vision is primarily used in controlling low frequency disturbances [44], as occurring during quiet stance. In conjunction with vestibular information, it is essential for stabilizing upright posture. In patients with a reduction in proprioceptive input, as seen in chronic NSLBP, it is therefore common to find a greater reliance on visual and vestibular cues to maintain postural stability. Visual obstruction will therefore exhibit a profound effect on balance as the system is deprived of two major contributors for postural control.

The pronounced antero-posterior sway with the resulting raised ankle stiffness [11] observed in NSLBP sufferers [23, 26, 29] may be seen as an compensatory mechanism to enhance sensory discrimination and thereby compensate for the deterioration of the feedback loop [29].

Interestingly, the magnitude of COP excursions varies depending on the location of the pain. Experimentally induced pain into the biceps muscle, for example, did not exhibit any significant effect on postural sway [2], while a similar injection of levo-ascorbic acid (L-AS) into the feet elicited the same basic COP pattern found in chronic LBP sufferers. As the pain level was increased, so did the COP mean velocity and range in anterior-posterior direction [45].

Clinical application of COP measures

While this literature review shows that statistically significant differences in postural sway are present, the clinical application of COP measurements still remains limited for five major reasons described below.

Firstly, the causative factor for the altered postural sway is still unknown. The question remains whether the increased COP excursions are related to the previously described physiological changes due to chronic pain perception or rather acute “pain inhibition” [12]. If the latter mechanism is mainly responsible, monitoring NSLBP sufferers during their treatment and rehabilitation process may aid as an objective tool in assessing the patient’s progress. If long-term neuro-physiological changes are primarily involved, individually varying recovery time frames may render such measurements less useful.

To address this question, future research is recommended to compare groups of participants suffering from a) acute LBP without previous pain history to b) those asymptomatic but with a long pain history to c) healthy controls. This way, the direct effect of acute pain on postural stability can be assessed in the absence of physiological and neurological changes postulated with chronicity.

Secondly, the data available is insufficient to determine whether some form of linear or non-linear correlation between the perceived pain intensity and the magnitude of postural sway exists. At similar VAS scores, the reported results for COP mean velocity vary

considerably. While one study reported a 100% increase in sway velocity with increasing pain perception [20], other studies showed no significant difference [19, 31].

Thirdly, the effect of pain duration, episodes of LBP and disability on COP excursions remain unclear. Due to the heterogeneous patient groups with a wide variety of pain durations and no information on the number of previous painful episodes being available, no conclusions can be drawn. Another contributing factor may be that self-reporting of LBP is prone to recall bias [46] and the definitions of NSLBP contained some variation throughout the studies. Both Oswestry and Roland-Morris results showed equally great variability which, in addition to the heterogeneous experimental setups, prevents interpretation. Further research is necessary to answer this question.

Fourthly, it has been shown that there is a steady natural increase in COP excursions with ageing [47]. The rather broad age-range of participants throughout the studies prevents an analysis of whether this also applies to pain-induced postural instability and how this magnitude correlates to specific age groups.

Finally, "normal" values are largely unknown and only one large-scale study offers reference values of healthy individuals for various COP parameters [47]. Similarly, reference data needs to be established for different LBP subgroups as a foundation for any intervention study. Until then, the identification of different COP patterns may be considered of academic rather than of clinical value at this time.

Conclusion

Patients with non-specific LBP exhibit greater postural instability than healthy controls. This difference is more pronounced under visual obstruction and can be attributed to either acute pain inhibition or diminished proprioceptive input from the lumbar spine and trunk muscles due to long-term neurological adaptations.

The decreased postural stability in NSLBP sufferers further appears to be associated with the acute presence of pain. There is insufficient data to suggest a relationship between pain intensity, previous pain duration or the level of perceived disability and the magnitude of COP excursions.

The clinical application of COP measures is limited by the unknown origin of the altered sway pattern, as well as a lack of COP reference values for different gender and age groups under both healthy and NSLBP. Further research is necessary to address these issues.

Limitations

A limitation of this literature review is the search strategy and its limitation to six databases which might not have identified all relevant papers. To overcome this, a dynamic search strategy was employed with selected hand searches of reference lists. Another limitation is the fact that only very few papers allowed for any direct inter-study comparison of results and many conclusions had to be drawn from those studies.

Competing interests

The author(s) declare that they have no competing interests. No funding was received for this review.

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