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Changes in static balance during pregnancy and postpartum: a systematic review

Authors:

Nina Goossens[1], Hugo Massé-Alarie[2], Daniela Aldabe[3], Jonas Verbrugghe[1], Lotte Janssens[1]

Affiliations:

1 UHasselt - Hasselt University, REVAL Rehabilitation Research Center, Agoralaan Building A, 3590 Diepenbeek, Belgium

2 Université Laval, Centre Interdisciplinaire de Recherche en Réadaptation et Intégration Sociale (CIRRIS), 525 Wilfrid-Hamel Blvd, Quebec City, Quebec G1M 2S8, Canada

3 Centre for Health, Activity and Rehabilitation Research, School of Physiotherapy, University of Otago, PO Box 56, Dunedin, New Zealand

Corresponding author:

Goossens Nina

Nina.Goossens@uhasselt.be

Agoralaan Building A

3590 Diepenbeek

Belgium

Email addresses of all authors:

Nina Goossens: nina.goossens@uhasselt.be

Hugo Massé-Alarie: hugo.masse-alarie@fmed.ulaval.ca

Daniela Aldabe: daniela.aldabe@otago.ac.nz

Jonas Verbrugghe: jonas.verbrugghe@uhasselt.be

Lotte Janssens: lotte.janssens@uhasselt.be

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Structured abstract:

Background: Because pregnant women show a high risk of falling, some researchers examined their balance during static standing. This systematic review summarized the findings from all studies evaluating static balance in women during pregnancy and postpartum.

Research question: Do pregnant and postpartum women show differences in static balance compared to non-pregnant women, and does static balance change during pregnancy and postpartum?

Methods: Pubmed, Embase, CINAHL, and Web of Science databases were searched systematically from inception until Feb 23, 2022. Studies were eligible for inclusion if they measured COP sway with a force plate during bipedal static standing, and compared COP outcomes between healthy pregnant or postpartum women and non-pregnant women, and/or during different stages of pregnancy and the postpartum period. Methodological quality was assessed overall with a modified version of the Downs and Black checklist, and specifically related to COP measurement by using recommendations of Ruhe et al. (2010). The protocol was registered in PROSPERO (CRD42020166302).

Results: Thirteen studies were included. Because methodological approaches varied greatly between studies, results were summarized descriptively. Studies reported either greater overall and anteroposterior COP sway magnitude, velocity and variability in women from the second half of pregnancy until six months postpartum compared to non-pregnant controls, or no differences in static balance. Changes in static balance throughout pregnancy were generally not found. Finally, there was no clear consensus on the influence of pregnancy on the reliance on visual inputs for balance control, and on whether differences in balance in pregnant and postpartum women reflect poorer balance or positive adaptations to the physical changes experienced during pregnancy.

Significance: Methodological heterogeneity between studies prevented us from drawing strong conclusions regarding the effect of pregnancy on static balance. Assessing the methodological quality of the studies revealed weaknesses that should be taken into account in future studies.

Introduction

Falling during pregnancy can lead to severe injuries and negative pregnancy outcomes [1-3]. About 27% of pregnant women report falling [2, 3], with more than a third of them sustaining two or more falls [3]. Pregnant women who fall are twice as likely to be hospitalized than non-pregnant women who fall [4], and those hospitalized for a fall have a higher risk of placental abruption, preterm delivery, labor induction, and cesarean section [5]. In addition, their unborn children are at a greater risk of experiencing distress and hypoxia than pregnant women hospitalized for other reasons than falling [5].

Optimal postural balance is essential to prevent falling [6]. It is achieved by keeping the vertical projection of the body's center of mass within the base of support. Maintaining balance is a complex process involving coordinated activity of the sensory (i.e., visual, vestibular, proprioceptive) and motor systems. Proprioceptive, visual, and vestibular inputs that signal changes in body position and movement (e.g., due to self-initiated or external perturbations) are sent to the central nervous system, which interprets and integrates them. Based on this integration, the central nervous system generates corrective motor outputs that are executed by the neuromuscular system to maintain or restore balance [6, 7]. Deficits in one or more of these systems can impair balance and increase the risk of falling, if not adequately compensated for [6].

During pregnancy, women's bodies undergo numerous, profound adaptations to cope with the physical and metabolic demands of pregnancy, and to ensure proper fetal development [8]. These adaptations are, for instance, an increased joint laxity [9], uterine growth [10], and weight gain in the abdominal region driving the maternal center of mass forward [11]. Progression of these changes throughout pregnancy may increase stress on the spine and abdominal muscles, potentially leading to lumbopelvic pain [12], but also forces women to constantly adapt to new postural requirements. To cope with this, women (compared to men) have for instance evolved an increased lumbar lordosis with a distinct dorsal wedging pattern and reinforcement of the lumbar vertebrae [13]. This allows them to adjust their center of mass, which moves anteriorly as pregnancy advances, above the hips and base of support [13]. If the sensory and motor systems involved in balance cannot adequately adapt to the physical adaptations during pregnancy, the risk of falling may increase. Moreover, a lack of sleep during pregnancy and postpartum [14, 15] could affect balance by interfering with the vestibular system, the perception of the subjective visual vertical, and vigilant attention [16-19].

Balance is commonly evaluated by measuring the movement of the body's center of mass relative to the base of support during standing. The movement of the center of mass during static standing (called "postural sway") can be seen as the movement of a single inverted pendulum that rotates around the ankles. During static standing, the movement of the center of mass relates strongly to the trajectory of the center of pressure (COP) [20, 21], the point of application of the ground reaction force under the feet. The movement of the COP can be measured with a force plate, and is usually expressed in spatial and temporal measures, such as sway magnitude, velocity and variability. Previous studies investigating static balance in pregnant women by measuring COP with a force plate reported conflicting results [22-25]. While Butler et al. [22] and Danna-Dos-Santos et al. [23] observed a greater sway magnitude in pregnant women compared to non-pregnant controls, Bey et al. [24] and Fontana Carvalho et al. [25] found no between-group differences. This could be due to methodological differences between studies, differences in the stage of pregnancy participants were in, or in the conditions used when evaluating balance (e.g., availability of visual inputs, size of the base of support).

So far, the evidence regarding differences in static balance (as assessed by measuring COP with a force plate) between pregnant or postpartum women and non-pregnant women, and during pregnancy and the postpartum period, has not been reviewed. Additionally, better insight into the effect of changing the postural condition during balance assessment may help clarify the underlying mechanisms of changes in static balance, and potential interventions to prevent falls, during pregnancy and postpartum. For instance, if closing the eyes highlighted differences in static balance between pregnant and non-pregnant women, this would emphasize the importance of visual inputs. If reducing the size of the base of support in particular affects balance during pregnancy, recommending a wider stance could help to prevent falling.

This systematic review therefore aimed to summarize the findings from studies examining (1) differences in static balance between pregnant and postpartum women, and non-pregnant controls, and (2) changes in static balance throughout pregnancy and postpartum. The results were categorized according to the postural condition used, i.e., eyes open versus closed, and a wider versus narrower stance. Furthermore, correlations between COP outcomes and factors such as sleep quality and weight gain were explored to gain insight into potential underlying mechanisms of changes in static balance during pregnancy and postpartum.

Methods

This systematic review was registered in the International Prospective Register of Systematic Reviews (PROSPERO, CRD42020166302), and was reported by using the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines [26] (Appendix 1).

1. Search strategy

PubMed, Web of Science, CINAHL, and Embase databases were systematically searched from inception onwards, with the latest search performed on Feb 23, 2022. The research questions were: “Do pregnant and postpartum women show differences in static balance, as assessed by measuring COP sway with a force plate, compared to non-pregnant women?”, and “Does static balance, as assessed by measuring COP sway with a force plate, change during pregnancy and postpartum?” MeSH terms (in PubMed) and free text words for pregnancy, postpartum, postural stability, postural control, postural balance, postural sway, body sway, center of pressure, and center of mass were combined (see Appendix 2 for detailed search strategies). Limitations for article type, language, or time of publication were not applied. The electronic search was supplemented by hand-searching the reference lists of the included articles.

2. Study selection

After discarding all duplicates, two reviewers (NG, PQ) independently screened all titles and abstracts for eligibility. Then, they reviewed the full-texts of the remaining articles. Disagreement between reviewers was resolved through open discussion and input from a third reviewer (LJ) if needed.

Studies were included if they:

1. Included healthy pregnant or postpartum women.
2. Measured COP with a force plate during bipedal static standing with or without sensory manipulations (e.g., closing the eyes, applying local muscle vibration).
3. Compared static balance between (1) pregnant or postpartum women and non-pregnant controls, and/or (2) during multiple stages of pregnancy and the postpartum period. No specific study types were excluded if the other inclusion criteria were met.
4. Were published in English, Dutch, German, or French in a peer-reviewed journal.

Studies were excluded if they:

1. Included women with reported complications or health conditions that could interfere with pregnancy (e.g., pre-eclampsia), or women with gestational diabetes mellitus or severe morning sickness, as this might affect balance [27, 28].
2. Evaluated balance during external perturbations (e.g., platform translations) or dynamic activities (e.g., gait).
3. Assessed the effect of an intervention (e.g., epidural analgesia) on static balance. However, if baseline measures comparing static balance between pregnant/postpartum, and non-pregnant women were available, or if the study evaluated static balance over time in a group of women that did not receive any experimental intervention, these data only were included.
4. Were case studies, non-original studies (e.g., reviews), conferences abstracts, or posters.
5. Were published in a language other than English, Dutch, German, or French.

3. Quality assessment

Three reviewers (NG, LV, LM) independently assessed methodological quality of each study with the validated Downs and Black checklist [29], as recommended by the Cochrane Collaboration [30]. Discrepancies were resolved by a fourth reviewer (LJ). The original Downs and Black checklist contains 27 questions related to reporting bias, internal and external validity, and statistical power, and demonstrates high internal consistency and reliability [29]. Because some questions were irrelevant for the type of studies included, we used a modified version of the checklist, similar to that employed in previous reviews [31, 32]. Questions related to the validity of the methodological design associated with an intervention study were removed (i.e., questions 4, 8, 13-15, 19, 23, 24), and only the longitudinal cohort studies were evaluated on questions concerning loss to follow-up (i.e., 9, 17 and 26) (See Appendix 3). Consequently, the maximum score was not equal for all study designs, and total scores on the Downs and Black checklist were reported as percentages. The quality of each study was categorized as "excellent" (86-100%), "good" (68-85%), "fair" (68-85%), or "poor" (< 50%), as proposed by O'Connor et al. [33].

Methodological aspects of measuring COP with a force plate were additionally assessed by using the recommendations from Ruhe et al. [34]: a sampling frequency of 100 Hz and cut-off frequency of 10 Hz, ≥90 s trial duration, three to five repetitions per condition, explicit instruction ("stand quietly"), and standardization of foot position. The percentage of studies that met each criterion, and the percentage of criteria met by each study were calculated.

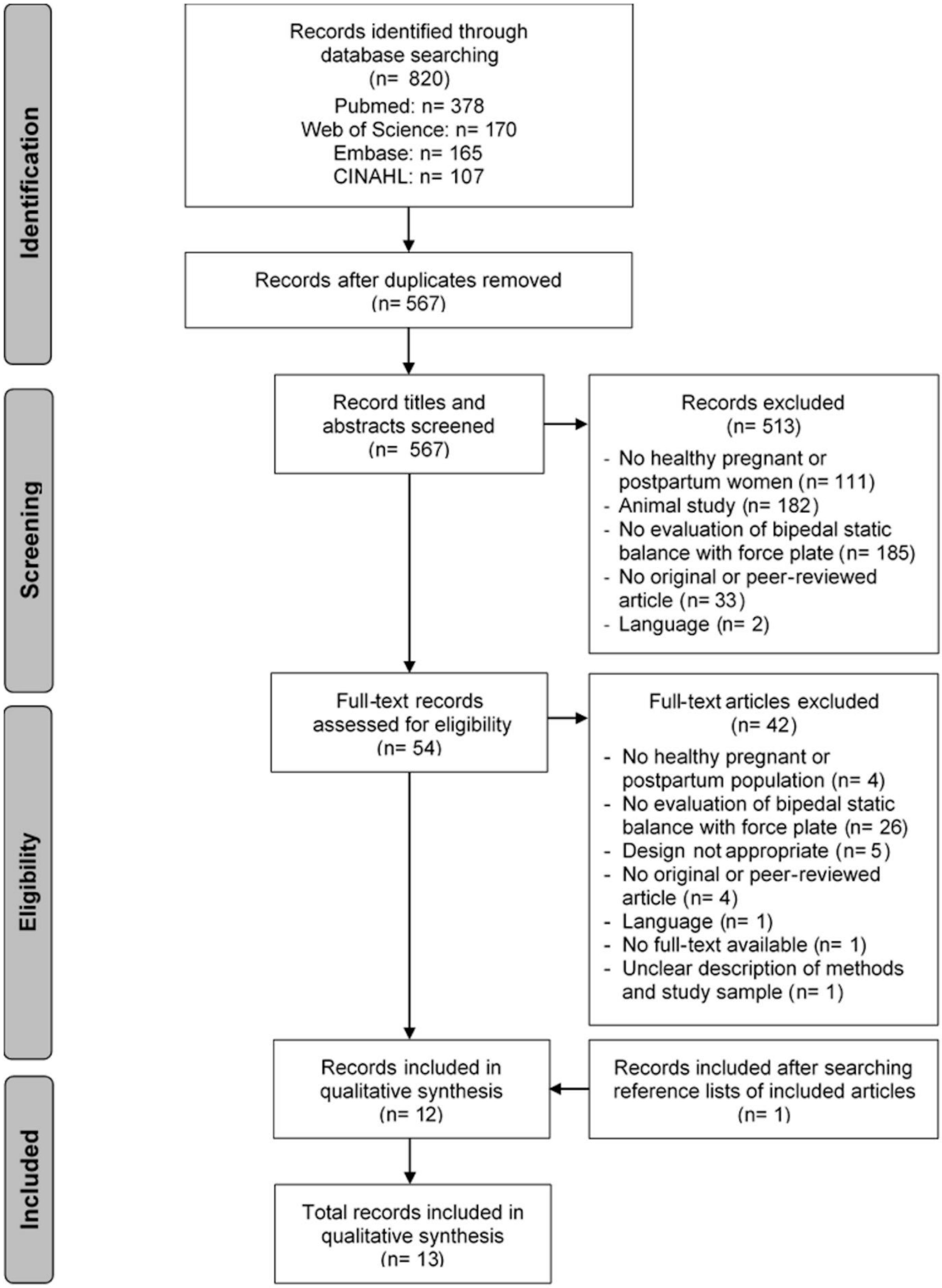
4. Data extraction

The same three reviewers independently extracted the following information from the articles by using a piloted computer form: (a) study design and timing of balance assessment; (b) characteristics of pregnant/postpartum sample (size, age, parity/gravidity); (c) characteristics of non-pregnant sample (size, age, parity/gravidity); (d) COP outcome measures (i.e., only linear outcomes were extracted); (e) postural conditions; (f) key findings; and (g) correlations between COP outcomes and other factors. If needed, discrepancies were resolved through input from a fourth reviewer (LJ).

Results

1. Study selection

The electronic search resulted in 820 records, of which 567 were unique. After screening title and abstract, 513 articles were excluded. Reviewing the 54 remaining full-texts led to the exclusion of 41 studies. Hand-searching the reference lists of the remaining 13 studies yielded nine potentially relevant articles, of which one was included after screening the full-text. Finally, the study of Wada et al. [35] was excluded due to an unclear description of the pregnant sample (e.g., COP data were collected during each pregnancy month, but the number of women per month was not reported) and methods (e.g., the authors did not describe which statistical tests were used). Thus, 13 studies were included (see Fig. 1).


Identification
Screening
Eligibility
Included
Records identified through database searching (n= 820)
Pubmed: n= 378
Web of Science: n= 170
Embase: n= 165
CINAHL: n= 107
Records after duplicates removed (n= 567)
Record titles and abstracts screened (n= 567)
Records excluded (n= 513)
- No healthy pregnant or postpartum women (n= 111)
- Animal study (n= 182)
- No evaluation of bipedal static balance with force plate (n= 185)
- No original or peer-reviewed article (n= 33)
- Language (n= 2)
Full-text records assessed for eligibility (n= 54)
Full-text articles excluded (n= 42)
- No healthy pregnant or postpartum population (n= 4)
- No evaluation of bipedal static balance with force plate (n= 26)
- Design not appropriate (n= 5)
- No original or peer-reviewed article (n= 4)
- Language (n= 1)
- No full-text available (n= 1)
- Unclear description of methods and study sample (n= 1)
Records included in qualitative synthesis (n= 12)
Records included after searching reference lists of included articles (n= 1)
Total records included in qualitative synthesis (n= 13)

2. Characteristics of the included studies

2.1. Methodological quality

Scores on the Downs and Black checklist ranged from 50 to 79% (See Appendix 4). Most studies (9/13, 69%) were of good quality (score between 68-85%), the remaining four studies showed fair quality (score between 50-67%).

Table 1 shows whether the methodology of each study met the recommendations of Ruhe et al. [34] to acquire reliable COP data. Seven studies (54%) used a sampling frequency of 100 Hz [23, 25, 36-40], while only one (8%) used a cut-off frequency of 10 Hz [23]. Five studies (38%) recorded COP during at least three trials [22, 25, 36, 37, 40], and one study (8%) used a sampling duration of at least 90 s [23]. About half of the studies (54%) reported the instructions, i.e. "to stand quietly or motionless", or "to maintain a stationary standing position" [24, 36, 38-42]. Finally, four studies (31%) described standardizing the position of the feet between trials [23-25, 40]. Out of six specific recommendations for COP measurement, the included studies reported/used zero to four criteria (median: two).

2.2. Study design and sample characteristics

The studies included a total of 368 pregnant and/or postpartum women (sample size: mean= 23, range= 10-72) and 124 non-pregnant controls (sample size: mean= 16, range= 8-30) (Table 2). Eight studies compared pregnant and/or postpartum women to non-pregnant controls [22-25, 36, 37, 40, 43], nine cohort studies followed the same sample of women over time [22, 36-42, 44], and two cross-sectional studies compared different samples of women at varying stages of pregnancy and the postpartum period [23, 24].

The reported mean or median age of participants ranged between 23 and 35 years, and was comparable between groups in all studies. For the pregnant/postpartum groups, five studies included primigravida and multigravida [22, 25, 36, 38, 39], one study included only primigravida [40], and seven studies did not specify gravidity [23, 24, 37, 41-44]. For the non-pregnant controls, three studies exclusively included nulligravida [22, 37, 40], and five did not report gravidity [23-25, 36, 43].

Table 1. Methodological aspects of COP measurement, in comparison to recommendations by Ruhe et al. [34].

	Sampling frequency	Cut-off frequency	Trial duration	Repetitions per condition	Instruction	Standardization of foot position	% criteria used/reported
Recommendation [34]	*100 Hz*	*10 Hz*	*≥ 90s*	*3-5*	*Stand quietly*	*Yes*	
Butler [22]	/	/	30 s	3	/	/	17%
Jang [36]	100 Hz	7 Hz	30 s	10	Stand quietly	/	33%
Nagai [43]	/	/	60 s	1	/	/	0%
Oliveira [44]	50 Hz	/	30 s	1	/	/	0%
Moccellin [37]	100 Hz	/	60 s	3	/	/	33%
Opala-Berdzik [38]	100 Hz	7 Hz	30 s	2	Stand quietly	/	33%
Moreira [40]	100 Hz	12.5 Hz	60 s	3	Stand quietly	Yes	66%
Bey [24]	200 Hz	7 Hz	7.5 s	2	Stand motionless	Yes	33%
Opala-Berdzik [39]	100 Hz	7 Hz	30 s	1	Stand quietly	/	33%
Danna-Dos-Santos [23]	100 Hz	10 Hz	120 s	1	/	Yes	66%
Takeda [41]	/	/	10 s	2	Stationary position	/	17%
Takeda [42]	/	/	10 s	2	Stationary position	/	17%
Fontana [25]	100 Hz	35 Hz	30 s	3	/	Yes	50%
% studies	54%	8%	8%	31%	54%	31%	

/ stands for "not reported". Green cells indicate that the recommendation was met, red cells indicate that the recommendation was not met.

2.3. Postural conditions during balance assessment

Table 2 presents the postural conditions used during COP recording. Most studies (12/13, 92%) measured COP sway during standing with eyes open and feet apart, though various stance widths were used: a self-selected stance width [22, 36, 38, 44], fixed stance width of 10 cm [23, 41, 42] or 20 cm [40], or feet placed hip-width apart [24]. Three studies did not specify stance width [25, 39, 43]. Seven studies (additionally) measured COP sway during standing with eyes closed [22, 25, 37, 38, 40, 43, 44], and in two studies, participants were (additionally) asked to place the feet together [37, 44], or in tandem stance [37].

2.4. COP outcome measures

Various traditional COP outcome measures were used (see Table 2): (a) *sway area* (area of the surface carried by the sway path; in mm^2 or cm^2) [23-25, 37, 40-44], (b) *mean COP velocity* or *path length per second* (in mm/s or cm/s, measured overall, in anteroposterior (AP), mediolateral (ML), and radial directions) [22-25, 36, 38-40], (c) *path length* (total path of COP excursion; in mm or cm; measured overall, in AP and ML direction) [24, 25, 38, 43], (d) *COP amplitude* or *range* (distance between the maximum and minimum COP displacement; in cm; measured in AP and ML direction) [23, 24], (e) *average radial displacement* (mean radial distance of COP from the centroid; in cm) [22], (f) *standard deviation (SD) of COP displacement* (in mm; in AP, ML, and radial direction) [36], and (g) *root mean square (RMS) of COP displacement* (in mm; in AP and ML direction) [40]. Because sway area, path length, COP amplitude, COP range, and average radial displacement provide information on the magnitude of sway, they were categorized as “sway magnitude” measures. SD and RMS of COP displacement were clustered as “sway variability” measures.

3. Main results from included studies

Heterogenous experimental set-ups, methodologies and study designs prevented us from performing a meta-analysis. The studies’ results were therefore summarized descriptively. Table 2 presents the key findings and the correlations between COP outcomes and other factors.

Table 2. Data extraction table

First author	Design, time points of balance assessment	Pregnant/ postpartum sample	Non-pregnant sample	COP outcome measures	Postural conditions	Key findings	Correlations between COP outcomes and other factors

Butler [22]	***Pregnant:***
	longitudinal, T1, T2, T3, 6-8 wks postpartum
	
	Non-pregnant:
	one time point
		N= 12
		32.8 ± 5 yrs
		92% primigravida
			N= 12
			31.1 ± 6 yrs
			100% nulligravida
				Magnitude:
				Average radial displacement (ARD)
				
				Velocity:
				Path length per second
					EO-SSSW
					EC-SSSW
						Compared to non-pregnant women:
						In EO-SSSW, ↑ ARD and path length per second at T2, T3 and 6-8 wks postpartum (not T1).
						
						In EC-SSSW, ↑ ARD at T1, T2, T3 and 6-8 wks postpartum, and ↑ path length per second at T2, T3 and 6-8 wks postpartum.
						
						During pregnancy and postpartum:
						The difference between EO-SSSW and EC-SSSW values for path length per second increased as pregnancy progressed.
							Pregnant/post-partum women:
							// weight gain during pregnancy: n.s.
							
							// weight lost in postpartum: n.s.

Jang [36]	***Pregnant:***
	longitudinal, every 4 wks from gestational week 16 to childbirth, and 6 wks, 12 wks and 6 mos postpartum
	
	Non-pregnant:
	longitudinal, every 4 wks for 40 wks, and 6 wks, 12 wks and 6 mos after 40th week
		N= 15
		31 ± 4 yrs
		33.3% primigravida
			N= 15
			31 ± 4 yrs
			Parity, gravidity: not specified
				Velocity:
				AP, ML and radial mean velocity
				
				Variability:
				SD of AP, ML and radial COP displacement
					EO-SSSW	***Compared to non-pregnant women:***
						In EO-SSSW, ↑ SD of AP and radial COP displacement. No differences in ML variability, or AP, ML and radial velocity.
						
						During pregnancy and postpartum:
						In EO-SSSW, ↓ in SD of AP COP displacement, ↓ in AP mean velocity, and ↑ in ML mean velocity from T3 to postpartum. No changes in ML and radial variability and radial velocity.
							Pregnant/post-partum women:
							Stance width:
							// SD of AP COP: (+)
							// ML mean velocity: (-)
							
							Sense of imbalance:
							// SD of AP COP: (+)
							// AP mean velocity: (+)
							// ML mean velocity: (-)

Nagai [43]	***Pregnant:*** one time point in T3 ***Non-pregnant:*** one time point	N= 35 30.6 ± 0.6 yrs Parity, gravidity: not specified	N= 8 35.4 ± 3.1 yrs Parity, gravidity: not specified	***Magnitude:*** Total, AP and ML path length; enveloped sway area	EO-SW NR EC-SW NR	***Compared to non-pregnant women:*** In EO-SW NR, ↑ area and AP path length at T3. No differences in total and ML path length. In EC-SW NR, ↑ area and AP path length, and ↓ ML path length at T3. No differences in total path length.	***Pregnant women with high anxiety:*** Only in pregnant women with high anxiety: sway area // state anxiety during EO (not EC): (+)
Oliveira [44]	***Pregnant:*** longitudinal, T1, T2, T3	N= 20 28.7 ± 6.2 yrs Parity, gravidity: not specified		***Magnitude:*** Ellipse area containing 85% of COP samples	EO-SSSW EC-SSSW EO-FT EC-FT	***During pregnancy:*** In EC-SSSW, ↑ area at T2 and T3 compared to T1. In EO-SSSW, EO-FT, EC-FT, no changes in sway magnitude.	N/A
Moccellin [37]	***Pregnant:*** longitudinal, T1, T2, T3 ***Non-pregnant:*** one time point	N= 13 29.2 ± 5.6 yrs Parity, gravidity: not specified	N= 20 26.1 ± 5.4 yrs 100% nulligravida	***Magnitude:*** Ellipse area containing 85.35% of COP data	EO-FT EC-FT EO-tandem	***Compared to non-pregnant women:*** In EO-FT, EC-FT and EO-tandem, no differences in sway magnitude at T1 (differences in T2 and T3 compared to non-pregnant women not investigated). ***During pregnancy:*** In EO-FT, EC-FT, EO-tandem, no changes in sway magnitude between T1, T2 and T3.	***Pregnant women:*** // quality of life: n.s.
Opala-Berdzik [38]	***Pregnant:*** longitudinal, T1, T3, 2 mos postpartum, 6 mos postpartum	N= 31 28.2 ± 3.6 yrs 84% primigravida		***Magnitude:*** Total, AP and ML path length ***Velocity:*** Total, AP and ML mean velocity	EO-SSSW EC-SSSW	***During pregnancy and postpartum:*** In EO-SSSW, no changes in sway magnitude and velocity between T1, T3, 2 mos postpartum and 6 mos postpartum. In EC-SSSW, AP path length and AP mean velocity ↓ from T3 to 2 mos postpartum and remained	***Pregnant women:*** EO: AP sway // stance width: (+) EC: AP sway // body mass (+) // amount of sleep 24 h before test: n.s.

						↓at 6 mos postpartum. No changes in total and ML magnitude, and total and ML velocity.	
Moreira [40]	***Pregnant:*** longitudinal, T1, T3 ***Non-pregnant:*** one time point	N= 13 25.8 ± 4.7 yrs 100% primigravida 23% had low back pain in T1, 54% in T3.	N= 15 27.7 ± 5.5 yrs 100% nulligravida	***Magnitude***: Ellipse area containing 85.4% of COP data ***Velocity:*** AP, ML mean velocity ***Variability:*** RMS of AP and ML amplitude	EO-FA (20 cm) EC-FA (20 cm)	***Compared to non-pregnant women:*** In EO-FA, EC-FA, no difference in sway magnitude, variability and velocity at T1. ↓ ML mean velocity and ↑ RMS of AP amplitude at T3. No difference in sway magnitude, AP velocity, and ML variability at T3. ***During pregnancy:*** In EO-FA and EC-FA, no changes in sway magnitude, variability and velocity between T1 and T3.	***Pregnant women:*** // disability due low back pain: n.s.
Bey [24]	***Pregnant:*** cross-sectional, T1, T2, T3 (3 different cohorts) ***Non-pregnant:*** one time point	N= 90 (30 in each trimester group) 30 ± 4 yrs Parity, gravidity: not specified	N= 30 28 ± 6 yrs Parity, gravidity: not specified	***Magnitude:*** Total path length; AP, ML COP amplitude; 95% confidence ellipse area ***Velocity:*** Overall mean velocity	EO-FA (hip-width)	***Compared to non-pregnant women:*** In EO-FA, no differences in sway magnitude and velocity in T1, T2 and T3. ***During pregnancy:*** In EO-FA, no changes in sway and velocity between T1, T2 and T3.	N/A
Opala-Berdzik [39]	***Pregnant:*** longitudinal, T1, 2 mos postpartum, 6 mos postpartum	N= 17 28.6 ± 4.4 yrs 76.5% primigravida		***Velocity:*** AP mean velocity	EO-SW NR	***During pregnancy and postpartum:*** In EO-SW NR, no changes in sway velocity between T1, 2 mos postpartum and 6 mos postpartum.	***Women 6 mos postpartum:*** AP velocity // trunk flexion mobility: (+)

Danna Dos Santos [23]	***Pregnant:*** cross-sectional: T1, T2, T3 (3 different cohorts) ***Non-pregnant:*** one time point	N= 30 (10 in each trimester group) T1: 28 (22-25) yrs, T2: 24.5 (22.2-27) yrs, T3: 25 (23.5-29.5) yrs Parity, gravidity: not specified	N= 10 23 (22-25) yrs Parity, gravidity: not specified	***Magnitude***: COP path area; AP, ML range ***Velocity:*** AP, ML mean velocity	EO-FA (10 cm)	***Compared to non-pregnant women:*** In EO-FA, ↑ area, and AP and ML range in T1, T2 and T3. No difference in sway velocity. ***During pregnancy:*** In EO-FA, no changes in sway magnitude and velocity between T1, T2 and T3.	N/A
Takeda [41]	***Pregnant:*** longitudinal, T2, T3	N= 72 32 yrs Parity, gravidity: not specified N= 10 fallers 32.8 yrs Parity, gravidity: not specified		***Magnitude:*** Rectangular area	EO-FA (10 cm)	***During pregnancy:*** Non-fallers: in EO-FA, no changes in sway magnitude between T2 and T3. Fallers: in EO-FA, no changes in sway magnitude between T2 and T3. No difference in sway magnitude between fallers and non-fallers.	N/A
Takeda [42]	**Pregnant:** longitudinal, T2, T3	N= 20 32.3 ± 3.2 yrs Parity, gravidity: not specified		***Magnitude:*** Rectangular area	EO-FA (10 cm)	***During pregnancy:*** In EO-FA, no changes in sway magnitude between T2 and T3.	N/A
Fontana Carvalho [25]	**Pregnant*:*** one time point in T2-3 ***Non-pregnant:*** one time point	N= 14 29 ± 6 yrs 85% primigravida	N= 14 30 ± 7 yrs Parity, gravidity: not specified	***Magnitude:*** 95% confidence ellipse area; total COP displacement ***Velocity:*** AP, ML mean velocity	EO-SW NR EC-SW NR	***Compared to non-pregnant women:*** In EO-SW NR, no difference in sway magnitude and velocity in T2-3. In EC-SW NR, no difference in sway magnitude and velocity in T2-3.	N/A

Abbreviations: COP= center of pressure; T1= first trimester; T2= second trimester; T3= third trimester; wks= weeks; yrs= years; EO= eyes open; EC= eyes closed; mos= months; AP= anteroposterior; ML= mediolateral; SSSW: self-selected stance width; SW NR: stance width not reported; FA: feet apart; FT: feet together; N/A: not applicable

3.1. Balance during standing with eyes open and feet apart

Table 3 shows the proportion of studies observing differences in balance between pregnant/postpartum and non-pregnant women, and changes in balance throughout pregnancy and postpartum, during standing with eyes open and feet apart.

3.1.1. Sway magnitude

Differences compared to non-pregnant controls: Greater overall sway magnitude was observed in the first trimester (T1) in one (n=10) out of four studies [23], in the second trimester (T2) in two (n= 10, 12) out of four studies [22, 23], in the third trimester (T3) in three (n= 10, 12, 35) out of six studies [22, 23, 43], and eight weeks postpartum in one study (n= 12) [22]. The remaining studies found no differences in overall sway magnitude at T1 (n= 12, 30, 14) [22, 24, 40], T2 (n=30, 14) [24, 25], and T3 (n= 30, 14, 13) [24, 25, 40]. One study reported larger AP and ML sway magnitude at T1 and T2 (n=10) [23], a second study found no differences at these timepoints (n= 30) [24]. At T3, two out of three studies observed a greater AP sway magnitude (n= 10, 35) [23, 43], and one out of three studies found a greater ML sway magnitude (n= 10) [23]. The other studies did not report differences in AP and ML sway magnitude at T3 (n=30, 35) [24, 43].

Changes over time: Five longitudinal cohort studies (n= 31, 13, 72, 20, 20) [38, 40-42, 44], and two cross-sectional studies (n= 10, 30) [23, 24] found no changes in sway magnitude across the three trimesters (overall: [23, 24, 38, 40-42, 44], AP: [23, 24, 40], ML: [23, 24, 40]), and postpartum (n= 31) (overall, AP, ML: [38]).

3.1.2. Sway velocity

Differences compared to non-pregnant controls: Two studies did not find a difference in overall sway velocity at T1 (n= 12, 30) [22, 24]. At T2 and T3, one study observed a greater overall sway velocity (n= 12) [22], while a second study found no differences (n=30) [24]. Finally, a greater overall sway velocity was found eight weeks postpartum in one study (n= 12) [22]. No differences in AP and ML sway velocity were observed at T1 in two studies (n= 10, 13) [23, 40], at T2 in three studies (n= 10, 14, 15) [23, 25, 36], and postpartum in one study (n= 15) [36]. At T3, one (n=13) out of four studies found smaller ML sway velocity [40], with the remaining three studies observing no difference in ML sway velocity (n= 10, 14, 15) [23, 25, 36]. AP sway velocity was found not to differ from non-pregnant controls at T3 in four studies (n= 10, 14, 15, 13) [23, 25, 36, 40].

Changes over time: No changes in overall (n= 30, 31) [24, 38], AP and ML sway velocity (n= 10, 31, 13) [23, 38, 40] as pregnancy progressed were found in two longitudinal studies (n= 31, 13) [38, 40], and two cross-sectional studies (n= 10, 30) [23, 24]. One longitudinal study reported that AP sway velocity decreased postpartum, while ML sway velocity increased (n= 15) [36]. In contrast, two other longitudinal studies found no changes in sway velocity between early pregnancy (n= 17) [39] or late pregnancy (n= 31) [38], and postpartum (n= 17, 31) (overall: [38], AP: [38, 39], ML: [38]).

3.1.3. Sway variability

Differences compared to non-pregnant controls: No differences in AP and ML variability were found at T1 in one study (n=13) [40]. Larger sway variability in AP and radial (but not ML) directions was observed at T2 in one study (n= 15) [36], at T3 in two studies (n= 15, 13) (AP: [36, 40], radial: [36]), and up to six months postpartum in one study (n= 15) [36].

Changes over time: One longitudinal study found no change in AP and ML sway variability as pregnancy advanced (n= 13) [40]. A second longitudinal study observed a decrease in AP sway variability postpartum, though it remained greater compared to non-pregnant women, suggesting an incomplete recovery (n= 15) [36]. In this study, ML and radial sway variability were not found to change after childbirth compared to during pregnancy [36].

3.1.4. Summary of results on balance during standing with eyes open and feet apart

About half of the studies reported greater overall, AP and ML sway magnitude, and overall sway velocity during pregnancy and postpartum. The remaining studies found no differences compared to non-pregnant controls. Moreover, sway magnitude and velocity during standing with eyes open and feet apart were consistently found not to change during pregnancy and postpartum. For sway variability, (only) one or two studies observed greater values in AP and radial direction during standing with eyes open, from T2 onwards with an incomplete recovery six months postpartum compared to non-pregnant women.

Table 3. Number of studies observing a difference in COP sway magnitude, velocity, and variability during standing with eyes open and feet apart.

		First trimester (T1)	Second trimester (T2)	Third trimester (T3)	Postpartum (PP)
Magnitude	Differences compared to non-pregnant controls	**Overall:** - 1/4 ↑ [23] - 3/4 = [22, 24, 40] **AP:** - 1/2 ↑ [23] - 1/2 = [24] **ML:** - 1/2 ↑ [23] - 1/2 = [24]	**Overall:** - 2/4 ↑ [22, 23] - 2/4 = [24, 25] **AP:** - 1/2 ↑ [23] - 1/2 = [24] **ML:** - 1/2 ↑ [23] - 1/2 = [24]	**Overall:** - 3/6 ↑ [22, 23, 43] - 3/6 = [24, 25, 40] **AP:** - 2/3 ↑ [23, 43] - 1/3 = [24] **ML** - 1/3 ↑ [23] - 2/3 = [24, 43]	**Overall:** - 1/1 ↑ [22]
	Changes over time		**Overall:** - 3/3 = versus T1 [23, 24, 44] **AP:** - 2/2 = versus T1 [23, 24] **ML:** - 2/2 = versus T1 [23, 24]	**Overall:** - 5/5 = versus T1 [23, 24, 38, 40, 44] - 5/5 = versus T2 [23, 24, 41, 42, 44] **AP:** - 3/3 = versus T1 [23, 24, 38] - 2/2 = versus T2 [23, 24] **ML:** - 3/3 = versus T1 [23, 24, 38] - 2/2 = versus T2 [23, 24]	**Overall:** - 1/1 = versus T1 [38] - 1/1 = versus T3 [38] **AP:** - 1/1 = versus T1 [38] - 1/1 = versus T3 [38] **ML:** - 1/1 = versus T1 [38] - 1/1 = versus T3 [38]
Velocity	Differences compared to non-pregnant controls	**Overall:** - 2/2 = [22, 24] **AP:** - 2/2 = [23, 40] **ML:** - 2/2 = [23, 40]	**Overall:** - 1/2 ↑ [22] - 1/2 = [24] **AP:** - 3/3 = [23, 25, 36] **ML:** - 3/3 = [23, 25, 36] **Radial:** - 1/1 = [36]	**Overall:** - 1/2 ↑ [22] - 1/2 = [24] **AP:** - 4/4 = [23, 25, 36, 40] **ML:** - 1/4 ↓ [40] - 3/4 = [23, 25, 36] **Radial:** - 1/1 = [36]	**Overall:** - 1/1 ↑ [22] **AP:** - 1/1 = [36] **ML:** - 1/1 = [36] **Radial:** - 1/1 = [36]
	Changes over time		**Overall:** - 1/1 = versus T1 [24] **AP:** - 1/1 = versus T1 [23] **ML:** - 1/1 = versus T1 [23]	**Overall:** - 2/2 = versus T1 [24, 38] - 1/1 = versus T2 [24] **AP:** - 3/3 = versus T1 [23, 38, 40] - 1/1 = versus T2 [23] **ML:** - 3/3 = versus T1 [23, 38, 40]	**Overall:** - 1/1 = versus T1 [38] - 1/1 = versus T3 [38] **AP:** - 2/2 = versus T1 [38, 39] - 1/2 ↓ versus T3 [36] - 1/2 = versus T3 [38] **ML:** - 1/1 = versus T1 [38]

				- 1/1 = versus T2 [23]	- 1/2 ↑ versus T3 [36] - 1/2 = versus T3 [38] **Radial:** - 1/1 = versus T3 [36]
Variability	Differences compared to non-pregnant controls	**AP:** - 1/1 = [40] **ML:** - 1/1 = [40]	**AP:** - 1/1 ↑ [36] **ML:** - 1/1 = [36] **Radial:** - 1/1 ↑ [36]	**AP:** - 2/2 ↑ [36, 39] **ML:** - 2/2 = [36, 40] **Radial:** - 1/1 ↑ [36]	**AP:** - 1/1 ↑ [36] **ML:** - 1/1 = [36] **Radial:** - 1/1 ↑ [36]
	Changes over time			**AP:** - 1/1 = versus T1 [40] **ML:** - 1/1 = versus T1 [40]	**AP:** - 1/1 ↓ versus T3 [36] **ML:** - 1/1 = versus T3 [36] **Radial:** - 1/1 = versus T3 [36]

Cells highlighted in green present findings of an increase in the variable of interest, cells highlighted in red indicate a decrease in the variable of interest. COP= center of pressure; T1= first trimester; T2= second trimester; T3= third trimester; AP= anteroposterior; ML= mediolateral.

3.2. Balance during standing with eyes closed and feet apart

Table 4 shows the proportion of studies observing differences in static balance between pregnant/postpartum and non-pregnant women, and changes in static balance across pregnancy and postpartum, during standing with eyes closed and feet apart.

3.2.1. Sway magnitude

Differences compared to non-pregnant controls: Greater overall sway magnitude was found in one out of two studies at T1 (n= 12) [22], in one out of two studies at T2 (n= 12) [22], in two out of four studies at T3 (n= 12, 35) [22, 43], and in one study eight weeks postpartum (n= 12) [22]. The remaining studies did not observe between-group differences in overall sway magnitude at T1 (n= 13) [40], T2 (n= 14) [25], and T3 (n= 14, 13) [25, 40]. One study found greater AP and smaller ML sway magnitude at T3 (n= 35) [43].

Changes over time: One out of three longitudinal studies observed an increased overall sway magnitude at T2 and T3 compared to T1 (n= 20) [44]. However, two other longitudinal studies found no change in overall sway magnitude as pregnancy progressed (n=31, 13) [38, 40], nor after childbirth (n= 31) [38]. Regarding AP and ML sway magnitude, one study reported no changes during pregnancy, and a decrease in AP (but not ML) sway magnitude from late pregnancy to postpartum (n= 31) [38].

3.2.2. Sway velocity

Differences compared to non-pregnant controls: Regarding overall sway velocity, one study found no difference at T1, but greater values at T2, T3, and eight weeks postpartum, and a greater difference in sway velocity between eyes open and eyes closed conditions at T3 (n= 12) [22]. For AP and ML sway velocity, no between-group differences were reported at T1 in one study (n= 13) [40], and at T2 in one study (n= 14) [25]. At T3, two studies found no difference in AP velocity (n= 14, 13) [25, 40]. One out of two studies observed a smaller ML velocity at T3 compared to non-pregnant women (n= 14) [25], with the second study reporting no between-group difference (n= 13) [40].

Changes over time: Two longitudinal studies found no changes in AP and ML velocity as pregnancy progressed (n= 31, 13) [38, 40]. One longitudinal study observed a decrease in AP sway velocity (but not ML) from late pregnancy to postpartum (n= 31) [38].

3.2.3. Sway variability

Differences compared to non-pregnant controls: No differences in AP and ML sway variability were observed at T1 in one study (n= 13) [40]. At T3 however, this study found a greater AP sway variability (but not ML sway variability) compared to non-pregnant women (n= 13) [40].

Changes over time: One longitudinal study found no changes in AP and ML sway variability during pregnancy (n= 13) [40].

3.2.4. Summary of results on balance during standing with eyes closed and feet apart

For sway magnitude, half of the studies showed greater overall sway in pregnant and postpartum women compared to non-pregnant controls. Moreover, one study found greater AP and smaller ML sway magnitude during late pregnancy. Some longitudinal evidence suggests that overall sway increases as pregnancy progresses, and that AP sway decreases postpartum. Regarding sway velocity, some cross-sectional studies showed greater overall and AP sway velocity from T2 onwards with an incomplete recovery after childbirth, and a smaller ML velocity at T3 compared to non-pregnant controls. However, sway velocity was not found to change during pregnancy in the longitudinal studies. For sway variability, one study reported greater values in AP (not ML) direction during late pregnancy compared to non-pregnant controls, but no changes during pregnancy.

Table 4 Number of studies observing a difference in COP sway magnitude, velocity, and variability during standing with eyes closed and feet apart.

		First trimester (T1)	Second trimester (T2)	Third trimester (T3)	Postpartum (PP)
Magnitude	Differences compared to non-pregnant controls	**Overall:** - 1/2 ↑ [22] - 1/2 = [40]	**Overall:** - 1/2 ↑ [22] - 1/2 = [25]	**Overall:** - 2/4 ↑ [22, 43] - 2/4 = [25, 40] **AP:** - 1/1 ↑ [43] **ML:** - 1/1 ↓ [43]	**Overall:** - 1/1 ↑ [22]
	Changes over time		**Overall:** - 1/1 ↑ versus T1 [44]	**Overall:** - 1/3 ↑ versus T1 [44] - 2/3 = versus T1 [38, 40] **AP:** - 1/1 = versus T1 [38] **ML:** - 1/1 = versus T1 [38]	**Overall:** - 1/1 = versus T3 [38] **AP:** - 1/1 ↓ versus T3 [38] **ML:** - 1/1 = versus T3 [38]
Velocity	Differences compared to non-pregnant controls	**Overall:** - 1/1 = [22] **AP:** - 1/1 = [40] **ML:** - 1/1 = [40]	**Overall:** - 1/1 ↑ [22] **AP:** - 1/1 = [25] **ML:** - 1/1 = [25]	**Overall:** - 1/1 ↑ [22] **AP:** - 2/2 = [25, 40] **ML:** - 1/2 ↓ [40] - 1/2 = [25]	**Overall:** - 1/1 ↑ [22]
	Differences compared to non-pregnant controls			**AP:** - 2/2 = versus T1 [38, 40] **ML**: - 1/1 = versus T1 [40]	**AP:** - 1/1 ↓ versus T3 [38] **ML:** - 1/1 = versus T3 [38]
Variability	Differences compared to non-pregnant controls	**AP:** - 1/1 = [40] **ML:** - 1/1 = [40]		**AP:** - 1/1 ↑ [40] **ML:** - 1/1 = [40]	
	Differences compared to non-pregnant controls			**AP:** - 1/1 = versus T1 [40] **ML:** - 1/1 = versus T1 [40]	

Cells highlighted in green present findings of an increase in the variable of interest, cells highlighted in red indicate a decrease in the variable of interest. COP= center of pressure; T1= first trimester; T2= second trimester; T3= third trimester; AP= anteroposterior; ML= mediolateral.

3.3. Balance during standing with a smaller base of support

3.3.1. Sway magnitude

Differences compared to non-pregnant controls: One study found no differences in overall sway magnitude at T1, regardless of eyes open or closed conditions (n= 13) [37].

Changes over time: Two studies observed no changes in overall sway magnitude as pregnancy progressed, regardless of eyes open or closed (n= 13, 20) [37, 44].

3.4. Correlations between COP outcomes and other factors

Seven studies investigated correlations between COP sway and factors hypothesized to influence balance, or to themselves be affected by an altered balance (See Table 2) [22, 36-40, 43].

One study observed a significant, weak correlation between body mass and AP path length and velocity during standing with eyes closed in pregnant/postpartum women ($r = 0.206$, $p < 0.05$) [38]. However, as only one correlation coefficient was reported, it is unclear whether body mass correlated with either COP path length or velocity. In a second study, no significant correlation between the change in body weight during pregnancy and postpartum, and the change in overall sway magnitude and velocity was found (exact p-values and correlation coefficients not reported) [22].

One study observed significant correlations between a greater self-selected stance width, and a greater AP sway variability ($r = 0.82$, $p < 0.01$) and smaller ML sway velocity ($r = -0.88$, $p < 0.01$) [36]. Moreover, stance width was found to increase during pregnancy, and to drop to pre-pregnancy levels after childbirth [36]. A second study found a significant, weak correlation between stance width, and AP path length and velocity during standing with eyes open (but not with eyes closed) ($r = 0.199$, $p<0.05$) [38]. However, because only one correlation coefficient was reported, it is unclear whether stance width correlated with either path length or velocity.

Feeling more unstable during standing correlated significantly with a greater AP COP variability ($r = 0.82$, $p < 0.01$) and velocity ($r = 0.72$, $p < 0.05$), and with a smaller ML sway velocity ($r = -0.80$, $p < 0.01$) in one study [36].

In pregnant women showing high anxiety (State-Trait Anxiety Inventory score> 35), state anxiety correlated with overall sway magnitude during standing with eyes open (r= 0.56, p= 0.020), but not with eyes closed[43].

Greater trunk forward flexion mobility was correlated with a greater AP sway velocity at six months postpartum (r= -0.6, p= 0.013), but not at T1 or two months postpartum (p> 0.05) [39].

Discussion

1. Summary of main findings

This review aimed to determine whether static balance changes during pregnancy, and if so, whether these changes recover after childbirth, and which mechanisms may be underlying. Altogether, studies observed either greater sway magnitude, velocity and variability in pregnant/postpartum compared to non-pregnant women, or no differences between groups. Differences were mostly found overall (i.e., in COP measures quantifying overall or total sway, rather than in AP and ML directions separately) and in AP direction, from T2 onwards, with an incomplete recovery six months postpartum. A few studies observed smaller ML sway velocity at T3. In general, balance was not found to change throughout pregnancy and postpartum, with the exception of two studies observing a decrease in AP sway velocity and variability, and an increase in ML sway velocity from late pregnancy to postpartum. Too few studies investigated the effect of reducing the base of support to draw conclusions. Finally, COP sway was found to correlate with stance width, feeling unstable during standing, trunk flexion flexibility, and anxiety in pregnant and postpartum women in a small number of studies.

2. Potential mechanisms explaining the results

In three longitudinal studies, removing visual inputs highlighted changes in balance over time. Oliveira et al. [44], and Opala-Berdzik et al. [38] only found changes in balance across pregnancy during standing with eyes closed, not with eyes open. Moreover, Butler et al. [22] reported that the difference in sway velocity between eyes open and closed conditions increased significantly as pregnancy progressed. These findings suggest that the reliance on visual inputs for balance increases throughout pregnancy, which (theoretically) could be due to (1) poorer vestibular and proprioceptive function, requiring an upweighing of visual inputs, or (2) to a lower capacity for sensory integration/reweighing during gestation [45]. The effect of pregnancy on vestibular and proprioceptive function and sensory integration has only rarely been studied. However, a high prevalence of dizziness symptoms (>50% of pregnant women), peripheral labyrinthine dysfunction [46], and poorer ankle joint position sense [47, 48] have been observed in pregnant women. The underlying mechanisms are not clear, but might relate to hormonal changes that alter homeostasis of labyrinthine fluids (for vestibular dysfunction) [46], increase joint laxity and cause edema around the ankles (for proprioceptive dysfunction) [47, 48]. However, in the other longitudinal [37, 40] and cross-sectional studies [25, 37, 40, 43] assessing static balance during standing with eyes open and closed, blocking visual inputs did not highlight differences in balance.

To elucidate potential underlying mechanisms of changes in static balance during pregnancy and postpartum, we extracted the correlations between COP outcomes and other factors such as sleep, weight gain, and stance width. Evidence from one study suggests that postural sway and anxiety are correlated, at least in pregnant women showing high levels of anxiety[43]. Moreover, correlations between postural sway and trunk flexibility were reported, though only six months postpartum when changes in sway were recovered [39]. Finally, pregnant women who perceived their balance to be poor exhibited greater AP sway velocity and variability, and adopted a wider stance, possibly to stabilize their posture, which only seemed to have the desired effect on ML postural stability [36]. There was no consensus regarding correlations with (changes in) body weight, even though it has been demonstrated that anthropometry might affect COP outcomes [49]. Yet, anthropometric changes during pregnancy have been found to explain only little (<5%) variance in dynamic balance control during gait [50]. Instead, the most important determinant of changes in gait stability during pregnancy appeared to be pre-pregnancy balance control. Women with poorer walking balance at the first testing showed the greatest decrease in balance throughout pregnancy [50].

3. Clinical implications and association with fall risk

Some consensus, albeit from a small number of studies, was found regarding greater sway variability during standing with eyes open, and greater sway velocity and variability during standing with eyes closed in women from the second half of pregnancy onwards until six months postpartum compared to non-pregnant women. In general, these differences were interpreted as reflecting poorer balance.

However, disagreement exists as to whether higher values of traditional COP outcomes during static standing reflect poorer or better balance. Indeed, greater COP velocity might indicate that subjects generate a normal, active sway to gain (more) sensory information about the body's position and movement in space and to explore the base of support, thus helping maintaining a stable posture [51]. Increasing postural sway may therefore be a strategy to generate useful information for the perceptual systems involved in balance, in case (reliable) sensory information is lost, or when the capacity for sensory integration is decreased [45, 52]. Moreover, it is increasingly recognized that sufficient variability is indispensable for healthy movement [53]. Hence, the clinical implications of the studies' results, such as the impact on fall risk, remain unclear. In line with this, Butler et al. [22] observed greater sway magnitude and velocity, as well as a higher fall prevalence in pregnant compared to non-pregnant women (i.e., 25% vs. 0%), while Jang et al. [36] observed a lower fall rate in pregnant compared to non-pregnant women (i.e., 13 vs. 47%), notwithstanding that the pregnant group exhibited a greater postural sway. Moreover, Takeda et al. [41] did not find any difference in postural sway between pregnant fallers and non-fallers. To note, in this latter study, pregnant fallers did exhibit smaller limits of stability (measured by leaning to the front, back, left and right as far as possible) compared to the non-fallers [41]. Thus, it remains unclear whether greater sway magnitude, velocity and variability during pregnancy and postpartum represent poorer balance, or a positive adaptation to compensate for the changes in the postural control system and postural demands during pregnancy.

Future prospective studies evaluating balance along with fall incidence throughout pregnancy and after childbirth, and using predictive modeling to determine whether COP outcomes can differentiate between fallers and non-fallers, or could predict falling, are needed. Moreover, as traditional COP outcomes neglect the spatial location of the COP relative to the boundaries of the base of support, novel multi-dimensional COP outcomes could be used. These outcomes employ information on instantaneous COP position, velocity and acceleration to predict how long it would take for the COP to reach the boundaries of the base of support [54]. Though these multi-dimensional COP outcomes have already been shown to provide a more sensitive measurement of balance impairments than traditional measures (e.g. in multiple sclerosis) [55], more studies are needed to evaluate their value in pregnant/postpartum populations.

4. Methodological issues of the included studies

Heterogeneity in experimental set-ups, methodologies and study designs may explain why some studies observed differences in balance during pregnancy and postpartum, while others did not. First, methodological aspects of COP measurement are known to affect (the reliability of) COP outcomes during bipedal static standing [34]. Many of the included studies failed to report which sampling and cut-off frequencies[22, 37, 41-44], instructions [22, 23, 25, 37, 43, 44] and stance widths [25, 39, 43] were used, and not one met both the recommended number and duration of balance trials. The studies that did describe the position of the feet used a variety of stance widths, which could impact the results. Adopting a wider stance has been shown to reduce ML (not AP) sway magnitude, assumed to reflect a more stable postural control [56]. The fact that some studies allowed women to select their own stance width, together with observing an increase in stance width as pregnancy progressed, could explain why these studies did not find increases in ML sway across pregnancy [36]. This is also reflected by the observed correlations between a wider stance and a smaller ML sway velocity and greater AP sway magnitude, velocity and variability during pregnancy [36, 38]. Finally, allowing participants to select their own foot position could have induced variability in foot angles and, hence, in balance. Indeed, subjects have been shown to rotate their feet outward when allowed to select the position of their feet, thereby increasing the size of the base of support and allowing the use of more effective synergies to control posture [57].

Second, considerable variability in when and how often balance was evaluated (e.g., during each trimester and postpartum vs. only once), study design (longitudinal vs. cross-sectional), and COP outcomes prevented us from drawing strong conclusions from studies using similar methodologies. Sway area was the most computed outcome, but various definitions were used, e.g., elliptical area containing 85% of COP data [37, 40, 44], 95% confidence ellipse [24, 25], rectangular area containing 100% of COP data [41, 42], enveloped sway area[43], and 30-sided polygon containing 100% of COP data [23]. Moreover, while some studies assessed sway magnitude and velocity in AP and ML directions separately (as recommended [58]), others only calculated “overall” or “total” velocity or magnitude. Finally, some studies only calculated one COP outcome[37, 39, 41, 42, 44], despite the advice to use both distance (e.g., sway area) and time-distance parameters (e.g. mean velocity) reflecting different aspects of balance [34, 58].

Third, most studies included heterogenous samples in terms of parity and gravidity, or failed to report parity/gravidity of the participants. Since greater sway magnitude, velocity and variability was observed at eight weeks postpartum [22], up to six months postpartum [36] compared to non-pregnant controls, future studies should only include nulligravida to rule out the potential influence of previous pregnancies on balance.

5. Limitations

A first limitation is that we only included studies assessing static balance. Most falls during pregnancy occur during dynamic activities, such as stair climbing, walking on slippery floors, and walking on uneven or sloped ground [3]. Nevertheless, we focused on static balance as sway parameters during static standing have been shown to correlate with fall risk factors and suboptimal postural strategies [59-62]. A second limitation is that we only extracted traditional COP outcomes. Some of the included studies also calculated frequency-domain parameters, e.g., percentile power in specific frequency bands [43], 95% and 80% power frequency [23, 36, 40], and total power in the 0-2 Hz frequency band [44], or used stabilogram diffusion analysis parameters [36]. However, since these specific parameters were only examined in one study each, we could not compare findings across studies. A third limitation is that authors of studies failing to report absolute p-values or correlation coefficients were not contacted to retrieve more information.

Statement of significance

We summarized the findings from studies using COP measures to investigate whether static balance changes during pregnancy and after delivery. The limited number of studies, heterogeneity in study protocols, and methodological limitations of the included studies compelled us to interpret the results with caution. Some studies observed greater sway magnitude, velocity and variability in pregnant and postpartum women compared to non-pregnant controls, while other studies found no differences. Whether the observed differences reflect either a poorer balance and increased fall risk, or an adaptation to compensate for the changes women's bodies undergo during pregnancy is not clear. Future studies using multi-dimensional COP outcomes and predictive modeling to predict falling are necessary.

Conflict of interest statement

The authors declare no conflict of interest.

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