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Faculteit Revalidatiewetenschappen

master in de revalidatiewetenschappen en de kinesitherapie

Masterthesis

Comparison of postural sway parameters between pregnant and non-pregnant women

Jill Coolen
Bas Roeymans

Scriptie ingediend tot het behalen van de graad van master in de revalidatiewetenschappen en de kinesitherapie, afstudeerrichting revalidatiewetenschappen en kinesitherapie bij kinderen

PROMOTOR :
Prof. dr. Lotte JANSSENS

COPROMOTOR :
dr. Nina GOOSSENS

2023
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Content table

Research context

This thesis is situated within the 'Lumbopelvic Pain' laboratory of Prof. Dr. Janssens Lotte, the supervisor of the lab. The research context pertains to the domain of 'Gait and Balance.' The research question addressed in this thesis is: “What are the differences in postural sway parameters and proprioceptive reweighting between pregnant and non-pregnant women?”. This inquiry is part of an ongoing study by Dr. Goossens Nina, titled: “The Role of Lumbar Proprioceptive Deficits, Psychosocial Factors and Inflammation in Pregnancy-related Lumbopelvic Pain (PLPP): A Follow-up Study in Pregnant Women” also known as PROFit. Dr. Goossens serves as the co-supervisor of the laboratory, and consequently, she is also the co-supervisor for this thesis, as we are permitted to conduct our thesis within her project.

The relevance of this research lies in obtaining deeper insights into pregnant women and the impact of pregnancy on factors such as balance and static postural sway characteristics. It is acknowledged in the literature that pregnant women have not been extensively studied, leading to gaps in knowledge regarding this demographic of proprioceptive reweighting and centre of pressure parameters. While proprioceptive reweighting has been investigated in various research populations, such as those with non-specific low back pain (Claeys et al., 2011) and chronic obstructive pulmonary disease (Janssens et al., 2013), but not yet within the group of pregnant women. This topic holds clinical relevance as studies indicate that 27% of pregnant women experience a fall during pregnancy (Dunning et al., 2003). Consequently, it is pertinent to examine whether differences exist in COP parameters and proprioceptive reweighting between pregnant and non-pregnant women.

The PROFit study by dr. Goossens holds meaningful potential and can be of real added value in this field. It gives rise to future studies on the population of pregnant women. By conducting more research into the influence of pregnancy on balance, proprioceptive reweighting and static postural sway characteristics, the number of publications related to this subject will increase. In this way, the topic becomes more popular in the research community. As a result, more efforts will be made to further research on this topic, leading to new insights. Furthermore, gaining clearer insights into the distinctions between pregnant and non-pregnant women will facilitate improved prenatal and postnatal counselling and care. This, in turn, will enable healthcare providers to tailor their interventions more effectively to the individual needs of pregnant women. In today's healthcare landscape, where the focus is on optimising the quality of care, this represents a valuable contribution.

This comprehensive research was conducted both at the REVAL Rehabilitation Research Center in Diepenbeek and within the home environment of the pregnant women. The REVAL Rehabilitation Research Center has a room equipped with a six-channel force plate for measuring COP and Maxon Motors. These Maxon Motors serve as muscle vibrators, providing insights into proprioceptive reweighting.

This thesis was jointly authored by Roeymans Bas and Coolen Jill. The research question was selected by the master's students in consultation with Dr. Goossens. Each section of the thesis was collaboratively written by the students, and the statistical analyses and literature searches were conducted jointly as well. This approach ensures an equal division of work between both students, with each gaining a comprehensive understanding of all aspects of the research. The collaboration proceeded smoothly, with ideas often aligning seamlessly.

Abstract

Background: Pregnancy induces numerous physiological changes, potentially impacting postural control (PC) in pregnant women.

Objectives: This study aimed to investigate potential differences in static postural sway, centre of pressure (COP) parameters, and proprioceptive reweighting between pregnant and non-pregnant women.

Methods: Repeated measurements were performed on 19 multiparous pregnant women in their third trimester and 20 nulliparous non-pregnant women. Static postural sway was measured looking at 95% confidence area, mean velocity and, sample entropy (SampEn) during relaxed standing with eyes open and feet apart on a stable support surface, and eyes covered and feet together on an unstable support surface. Proprioceptive reweighting was examined during trials with local muscle vibration applied to the ankle or back muscles, while participants stood relaxed with feet apart on both stable and unstable surfaces, with eyes always covered.

Results: A significant group effect was observed during static postural sway measurements for SampEn in the mediolateral (ML) direction ($P = .044$). Additionally, a significant interaction effect between non-pregnant women and condition ($P = .002$) was observed during proprioceptive reweighting with vibration at the multifidus muscle.

Conclusion: This study revealed that pregnant women exhibited less complex and more regular COP displacement for SampEn, indicating a more rigid PC strategy during static postural sway measurements. During multifidus muscle vibration, non-pregnant women showed increased forward displacement, indicating more reliable proprioception of the back. Further research is necessary to gain more insights into potential differences and interactions between groups.

Keywords: pregnant women, static postural sway, centre of pressure, proprioceptive reweighting, vibration trials

Introduction

Throughout pregnancy, the female body undergoes a range of physiological changes (Soma-Pillay et al., 2016). These adaptations enable the body to accommodate the physical demands of pregnancy and create an environment conducive to optimal fetal development (Tan & Tan, 2013). Such changes include hormonal and biomechanical alterations, such as increased curvature of the thoracic and lumbar spine angles (Yoo et al., 2015), as well as a surge in body weight and abdominal expansion. The latter changes push the centre of mass (COM) forward (Jensen et al., 1996), which could reduce postural stability, potentially leading to postural instability (Whitcome et al., 2007) and falls (Dunning et al., 2003). Research indicates that approximately 27% of pregnant women experience a fall at some point during their pregnancy (Dunning et al., 2003).

The physiological adjustments associated with pregnancy impact women's postural balance (Sarkar et al., 2022). Maintaining optimal postural control (PC) is crucial to prevent falls (Horak, 2006). Palmieri et al. (2002) defined PC as "the task of controlling the body's position in space for the dual purposes of stability and orientation.". Preserving postural balance is a multifaceted undertaking involving a well-coordinated interaction among various motor, sensory, and biomechanical components (Palmieri et al., 2002).

The weighting of sensory inputs is regarded as crucial for maintaining a variable PC (Carver et al., 2006), which indicates easily adaptable. In the process known as sensory reweighting, the central nervous system (CNS) evaluates the reliability of the incoming signals from each sensory system, consisting of the visual, vestibular, and proprioceptive systems and prioritises more reliable sensory information over less reliable ones (Peterka, 2002). This prioritisation is especially crucial when sensory information is disrupted, such as when standing with closed eyes, where reliance on visual input is absent.

One aspect of sensory reweighting is proprioceptive reweighting, where the CNS prioritises the most reliable proprioceptive signals originating from muscles and joints throughout the body (Peterka, 2002). In simple postural conditions, such as standing on a stable support surface, the CNS predominantly depends on proprioceptive inputs from the muscles around the ankle. Meanwhile, in more challenging conditions, e.g., standing on an unstable support surface, the CNS primarily relies on proprioceptive inputs from the spinal muscles (Brumagne et al., 2008; Janssens et al., 2010). This shift to the more proximal muscles occurs because the muscles around the ankle joint become less reliable when the surface is unstable.

Previous research, such as that conducted by Ramachandra et al. (2023), compared static postural sway characteristics between pregnant and non-pregnant women. Their findings indicated that pregnant women in their third trimester exhibit significantly larger postural sway in conditions that challenge the visual system, proprioceptive system, or base of support (Ramachandra et al., 2023). Furthermore, Goossens et al. (2022) conducted a systematic review investigating changes in static balance during pregnancy and postpartum. They noted that some of the included studies found differences compared to others, but these differences should be interpreted with caution. Both similarities and differences between pregnant and postpartum compared to non-pregnant women were found in sway magnitude, velocity, and variability. This heterogeneity may be attributed to the limited scientific literature on the topic, methodological disparities, and heterogeneity in study protocols (Goossens et al., 2022).

As noted earlier, the findings regarding differences in COP parameters between pregnant and non-pregnant women in previous scientific literature are inconsistent. Several studies have examined variables such as COP variability, COP velocity, and COP sway amplitude (Goossens et al., 2022). However, a notable gap in the scientific literature is the scarcity of research investigating the role of proprioceptive reweighting in postural balance in pregnant women. In a study by Ramachandra et al. (2023), a comparable research design as in this current study was employed, with comparable test conditions and participant groups. They investigated the static postural sway characteristics between pregnant and non-pregnant women but did not delve into the aspect of proprioceptive reweighting in detail. This highlights a gap in the literature regarding proprioceptive reweighting in pregnant women, particularly during more complex conditions. Moreover, other scientific studies have compared pregnant and non-pregnant women without examining differences in proprioceptive reweighting such as Opala-Berdzik et al. (2015) and Oliveira et al. (2009). With this in mind and considering that the female body undergoes several physical changes during pregnancy (Soma-Pillay et al., 2016) that affect the PC, this research aims to investigate the effect these changes have on proprioceptive reweighting.

Our aim was to examine potential disparities in static postural sway parameters between pregnant and non-pregnant women, measured across various conditions. Additionally, we also wanted to investigate the difference in proprioceptive reweighting between the two groups, also assessed under different conditions. In this way we wanted to gain more insight into the differences in proprioceptive reweighting and into the differences in static postural sway parameters between pregnant and non-pregnant women.

We hypothesised that pregnant women may exhibit increased static postural sway parameters and encounter challenges in effectively implementing proprioceptive reweighting in more difficult conditions as their bodies undergo different biomechanical and physiological changes.

Methods

Study design

This study was an experimental study, comprising a group of multiparous pregnant women in the third trimester and a control group of nulliparous non-pregnant women. Both independent study samples underwent one measurement session with repeated measurements, allowing for a comparison between pregnant and non-pregnant women.
Ethical approval for the study was obtained from the relevant ethical committees including those of Hospital East-Limburg (ZOL), UHasselt, Sint-Franciscus Hospital, Jessa Hospital, AZ Vesalius, ZOL Maas en Kempen Hospital, and Noorderhart Mariaziekenhuis. This scientific study formed part of a broader comprehensive study conducted by Goossens et al. identified by reference number B371201942396.

Participants

The study population consisted of multiparous pregnant women. The women included in this scientific study were part of a larger comprehensive study conducted by Goossens et al. Recruitment of participants was carried out through various channels including referrals from relatives and acquaintances of the researchers, distribution of flyers, outreach through social media platforms, and collaboration with the Gynecological Department of six hospitals in Limburg. In total, the study contained 19 pregnant women and 20 non-pregnant women. In addition, the characteristics of the included participants are presented in Table 1.

Inclusion criteria

The inclusion criteria for multiparous women were as follows: (1) age between 18-40 years old, (2) carrying singleton pregnancy, (3) currently pregnant with their second or more child, (4) in the third trimester of pregnancy (32 - 36 weeks), and (5) willing to sign an informed consent form.
In addition, the inclusion criteria for the nulliparous women were: (1) age between 18-40 years old, (2) not pregnant, (3) no previous pregnancy, and (4) willing to sign an informed consent form.

Exclusion criteria

The exclusion criteria for pregnant women were: (1) being in the first or second trimester of pregnancy, (2) having a history of surgery or major trauma to the spine, pelvis and/or lower limbs, (3) diagnosed with specific balance or vestibular disorders, (4) having spinal deformities, (5) diagnosed with rheumatic disease, (6) having neurological abnormalities (e.g., peripheral neuropathy), (7) experiencing uncorrected visual problems, (8) diagnosed with hyperemesis gravidarum, (9) having acute ankle problems, (10) experiencing pre-existing disorders that could affect pregnancy (e.g., hypertension, kidney disease, coagulation disorders), (11) (a history of) psychiatric disorders (identified with the SCID-5), and (12) being non-Dutch speaking.

For nulliparous women, the exclusion criteria were similar, with the following exceptions: (1) they were not allowed to be pregnant or have been pregnant yet. (2) Additionally, they were not allowed to have lower back pain at the time of inclusion or within the six months preceding inclusion, (3) nor could they have had a history of chronic lower back or pelvic girdle pain.

Table 1
Characteristics of the Study Samples

	Pregnant (N = 19)		Non-pregnant (N = 20)		Group difference
	Mean*/ Median**	SD / [Q1;Q3]	Mean*/ Median**	SD/ [Q1;Q3]	p-value
Age (years)	31**	[34; 30]	28**	[30;26]	.001 (a)
Height (cm)	166* 164**	6 [173;162]	167* 166**	8 [171;61]	.697 (a)(b)
Weight (kg)	76**	[84;64]	62**	[65;56]	<.001 (a)
BMI (kg/m²)	28**	[30;24]	22**	[23;20]	<.001 (c)

Note. SD = standard deviation, BMI = body mass index, Q1 = quartile 1, Q3 = quartile 3. The p-values were calculated using the following tests: (a) Rank-sum test, (b) 2-sample t-test, and (c) Welch test. For all parametric tests, the mean and SD are given. For the non-parametric tests, the median and interquartile range are given. See Appendix A1 for the used statistical decision tree.

Procedure

Measurements

The study visit for the pregnant women occurred during the third trimester (between gestational weeks 32-36), while the visit for the control group, comprising non-pregnant women, took place at a moment the woman was available. Both visits took place in the REVAL Rehabilitation Research Center in Diepenbeek.

During the test procedure, both pregnant and non-pregnant women underwent several postural control trials. These trials comprised two test conditions, each with and without local muscle vibration, during which various COP parameters were measured.

Initially, looking at the static postural sway parameters, the women underwent measurements without the local muscle vibrations, in which measurements were taken in two different conditions. During these conditions, the women were instructed to maintain an upright posture in a relaxed stance for 60 seconds. The first condition was considered easier, wherein the women had to stand barefoot on a stable support surface with their heels spaced 20 cm apart and their eyes open. They were directed to stand in a relaxed manner, with their arms alongside their body and gaze fixed straight ahead. In contrast, the second condition, deemed the more difficult one, required the women to stand barefoot on an unstable support surface with their feet together and their eyes open, while wearing non-transparent goggles that blocked their view. An Airex balance pad (measuring 50 x 41 x 6 cm) was utilised to create an unstable support surface. For a more detailed summary, Table 2 offers an overview of test conditions.

After completing the measurements without muscle vibration, the women proceeded to undergo the measurements with muscle vibration to investigate proprioceptive reweighting. The vibration was applied either on the muscle-tendon junction of m. triceps surae or on the m. multifidus (the lumbar part, specifically at the level of vertebrae L4-L5). During these measurements, the women had to stand in a relaxed position for 60 seconds with their arms alongside their body, just as they did during the measurements without muscle vibration. These 60 seconds were divided into 15 seconds of standing without vibration, followed by 15 seconds of vibration, and then another 30 seconds without vibration. Measurements for both muscle groups, were taken both in easy and difficult conditions. During the easy condition, the women were asked to stand on a stable support surface, whereas in the difficult condition, they had to stand on an unstable support surface. The Airex balance pad was utilised to create an unstable support surface. In both conditions, the women had to stand barefoot with their heels spaced 20 cm apart and their eyes covered with non-transparent goggles. Table 3 provides an overview of these procedures. The sequence of muscle vibrations was pseudorandomised. Each woman underwent the muscle vibrations first on the stable and then on the unstable support surface. If the woman first received muscle vibration at the level of the m. multifidus on the stable support surface, then on the unstable support surface, she would first receive muscle vibration at the level of the m. triceps surae to minimize a possible learning effect.

Table 2

Postural Conditions to Assess Centre of Pressure Parameters

Trial	Postural condition
1	Stable support surface, eyes open, feet 20 cm apart
2	Unstable support surface, eyes covered, feet together

Note. Each trial lasts 60 seconds.

Table 3

Postural Conditions to Assess Proprioceptive Reweighting During Muscle Vibration

Trial	Postural condition
1	m. triceps surae, stable support surface
2	m. multifidus, stable support surface
3	m. multifidus, unstable support surface
4	m. triceps surae, unstable support surface

Note. The women had to keep their eyes open during the trial, but vision was taken away with the non-transparent goggles. In each trial, no vibration is administered in the first 15 seconds, followed by 15 seconds of muscle vibration. Afterward, they have to stand for another 30 seconds to evaluate COP displacement. This table shows an example of a possible sequence of the procedure.

Postural balance analysis

This study measured postural sway using a 6-channel force plate (manufactured by AMTI) with a sampling frequency set at 1000 Hz. The force plate measures forces and torques in three different directions, namely in the X, Y, and Z directions. Subsequently, using SIMI software, these data are converted into COP measurements in three directions. Afterwards, the COP data were imported into Matlab. At this point, in-house scripts were used to preprocess the data. During this process, the COP time series underwent filtering using a 4th-order Butterworth filter with a low-pass filter set at 6 Hz. Additionally, a correction was made for the COP baseline offset by subtracting the average COP position in anteroposterior (AP) and mediolateral (ML) directions from the COP time series in the corresponding directions. Finally, different COP parameters, i.e., 95% confidence area, mean velocity, and sample entropy were calculated from the filtered data. It is important to note that the first 5 seconds of each trial were discarded from the analysis.

95% confidence area

The 95% confidence area, also known as the sway area, represents the area wherein the average COP displacement is expected to fall within a probability of 95% (Quijoux et al., 2021). This parameter is widely used in the literature (Schubert & Kirchner, 2014) to describe the movement of the COP over a period of time. With previous information in mind, the analysis of the 95% confidence area provides added value when examining at pregnant women.

Mean velocity

Mean velocity was analysed in both ML and AP directions. This parameter represents the average speed at which the subject's COP travels over time (Palmieri et al., 2002). Mean velocity is selected because it is described in the literature as a reliable and widely used parameter (Low et al., 2017) (Quijoux et al., 2021).

Sample entropy (SampEn)

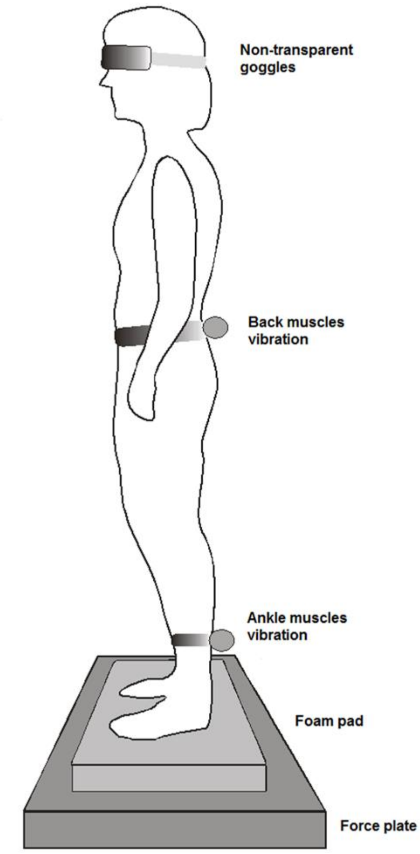
SampEn assesses the (ir)regularity of the COP displacement, aiming to describe the complexity of COP displacement. For calculation of SampEn, the parameters N, m, and r are set at N = 60 seconds, m = 2, and r = 0.2. Here, N represents the length of the trial, m indicates the length of the compared sequences, and r is the tolerance of accepting similarity (Richman & Moorman, 2000). In contrast to the two previous COP parameters, which are linear, this parameter is non-linear. SampEn does not examine continuous values of the COP displacement but looks at the direction in which the COP is moving. The parameter will, therefore, only be able to say something about the regularity or complexity of the COP but cannot assign a specific value (Clark et al., 2023). A value of 0.0 indicates a high regularity and low complexity, while a value of 2.0 indicates a high signal of complexity accompanied by little regularity in the displacement of the COP (Clark et al., 2023).

Muscle vibration

In this study, four trials were conducted using muscle vibration (Maxon Motors, Switzerland, 60 Hz, 0.5 mm) at the level of the m. triceps surae or the m. multifidus. The protocol we used for this study is similar to the protocol used in scientific research by Brumagne et al. (2008), which examined postural control strategies in individuals with recurrent low back pain. Using muscle vibration, we analysed the participants' proprioceptive reweighting, monitoring their response using a force plate. Local muscle vibration stimulates the muscle spindles of the Ia afferents, creating the illusion of muscle lengthening (Goodwin et al., 1972). This illusion will have to be corrected by the central nervous system. Therefore, with vibration at the level of the m. multifidus, a forward postural sway is expected, whereas with the vibration of the m. triceps surae, a backward postural sway is expected (Janssens et al., 2013). This allows us to estimate whether the test subject is ankle or lumbar proprioceptive dominant. This is done using the Relative Proprioceptive Weighting (RPW) ratio. The RPW ratio is calculated from the displacements made by the COP during vibration trials, by using the following formula RPW = (Abs ankle)/(Abs ankle+Abs back). The procedure reads 'Abs ankle' and 'Abs back,' meaning the absolute values of the displacement travelled by the COP. Those absolute values are measured with the formula "mean COP position during 15 seconds of vibration - mean COP position 15 seconds before the vibration". This is both for the trial during ankle muscle vibration and during back muscle vibration. A score corresponding to one indicates the use of input signals coming from the ankle. This is also called an ankle-controlled strategy in the literature. A score of zero suggests the use of input signals coming from the back. This is also described as the multisegmental strategy (Janssens et al., 2013).

Figure 1

Experimental Setup Vibration Trials



Note. This figure shows the setup for the vibration trials on an unstable support surface. While both the m. multifidus as the m. triceps surae are being vibrated in the image, it's important to note that in this experiment, these muscle groups were vibrated separately.
Janssens et al. (2013)
https://doi.org/10.1371/journal.pone.0057949.g001

Data analyses

Power analysis

The power analysis was performed by using "GPower 3.1". Power calculations were performed for each parameter under both difficult and easy conditions. The power was estimated by entering certain parameters. The 't-tests' are examined, whereby the statistical test 'Means: Difference between two independent means (two groups)' was chosen. In addition, the type of power analysis "Post hoc: Compute achieved power - given α, sample size, and effect size" was selected. Furthermore, the input parameters are two tails, effect size d (calculated), α error probability (0.05), sample size group 1 (19), and sample size group 2 (20). The effect size was calculated by using the "determine" function in the program, based on the means of the two groups and their standard deviations (SD). Based on these entered parameters, the calculated powers were provided.

Power can be interpreted as: "the higher the power, the lower the chance of a type II error". A type II error is the chance of a false negative result. No effect is detected, although an effect is actually present. In general, a power of 80% or more is considered acceptable.

Statistical analysis

Postural balance analysis without vibration

A statistical analysis was performed to verify the hypotheses for the postural balance analysis (without vibration) regarding the COP parameters in pregnant and non-pregnant women. The following hypotheses were formulated: as null hypothesis (H0), “There is no significant difference in the COP parameters between pregnant women and non-pregnant women.”, and as alternative hypothesis (HA), “There is a significant difference in the COP parameters between pregnant women and non-pregnant women.". In addition, pregnant women were expected to experience more difficulties during the more difficult conditions. This should translate into higher values of COP parameters. The statistical analyses were performed in the JMP Pro program (JMP Pro 17, SAS, Institute Inc, Cary, USA). Factors that had to be taken into account when analysing the data are the small sample sizes (19 pregnant women and 20 non-pregnant women), repeated measurements, and possible learning effects. As a result, the "Repeated Measures (Full Factorial Design)" model was used in JMP, which is a mixed model (see Appendix A2). This test is an extension of JMP, that is not contained in the basic package of JMP. However, before Full Factorial Design was used, the normality and variability from the residuals of the groups were tested. If both criteria were fulfilled, this test was applied. This test considered the interactions between the different condition properties and the repeated measurements. In this model, one within-subjects factor (namely the condition) and one between-subjects factor (namely group) were conducted. The condition factor consisted of two levels: easy and difficult condition, and the factor group also had two levels: pregnant and non-pregnant women. If significant p-values were observed with “Full Factorial Design”, the means (M) and SD were examined with 'Effect Details' to determine the direction of condition, group, or interaction the effect was the largest. When a significant interaction effect was found, further post-hoc tests, namely the Tukey Honestly Significant Difference (HSD), were performed to see exactly which interactions were significant. If the criteria for normality and variability were not fulfilled, the difference of group for the conditions or the difference of condition for the groups was analysed. This involved using the non-parametric Rank-Sum test (see Appendix A3) to examine the effect of the groups on the conditions, and by the non-parametric Signed-Rank test (see Appendix A4) to assess the effect of the condition for each group in JMP.

Postural balance analysis with vibration

To verify the hypotheses regarding movement analysis with vibration concerning COP displacement in pregnant and non-pregnant women, statistical analyses were conducted. The following hypotheses were formulated: the null hypothesis (H0), "There is no significant difference between pregnant women and non-pregnant women in the different vibration conditions.", and as alternative hypothesis (HA), "There is a significant difference between pregnant women and non-pregnant women in the different vibration conditions.". Normality and variability of the residuals were first assessed before conducting statistical analyses regarding these independent groups. If both criteria were fulfilled, "Repeated Measures (Full Factorial Design)" model was used (see Appendix A2). Similar to the non-vibration trials, when significant p-values were obtained with the "Full Factorial Design", the mean and SD were also examined using 'Effect Details' to ascertain the direction of the condition, group, or interaction. As with the non-vibration trials, if a significant interaction effect was observed, Tukey HSD post-hoc tests were conducted to determine which interactions were significant.

If the criteria of normality and variability were not fulfilled, the same non-parametric tests were conducted as in the analyses without vibration (see Appendices A3 and A4).

Results

Power Analysis

In this study, the power of each parameter (both in the trials with and without vibration) was exceedingly low. All of the powers were much lower than 80%. Consequently, the chance of similar results when upon retesting is minimal. This suggests a high probability of a type II error.

Postural balance analysis without vibration

For each COP parameter (as detailed above), the effect of the condition, the group, and the interaction between the condition and the group was investigated. These results found are summarised in Table 4. A significant main effect of 'condition' was observed for the following parameters: (1) net mean sway velocity, indicating higher velocity in the difficult condition compared to the easy condition, (2) sample entropy in AP direction, where the difficult condition provided higher complexity, while the easy condition provided more predictability or regularity, (3) sample entropy in ML direction, where higher complexity was present in the difficult condition, and higher regularity in the easy condition, and (4) area95, where a larger 95% confidence area in which the COP moved was observed during the difficult condition, and a smaller area during the easy condition. The difference in area95 between the conditions was examined separately for each group, revealing that within each group, the 95% confidence aera was larger for each difficult condition and was also larger in pregnant women compared to non-pregnant women. This analysis of the 95% confidence area was conducted using the non-parametric Signed-Rank test (Table 5).

One significant main effect of ‘group’ was found concerning sample entropy in the ML direction. The pregnant study sample exhibited more regularity and predictability, whereas more complexity was seen in the non-pregnant study sample. To ascertain whether there was a difference between the two groups for each condition, the Rank-Sum test was performed for the 95% confidence area. However, no statistically significant p-values were found (Table 6).

Table 4

Overview Statistical Parametric Analyses for the Trials Without Vibration

Parameter	Non-pregnant		Pregnant		Easy		Difficult		Main effect of condition		Main effect of group		Effect of the interaction	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	F-value (1, 36)	p-value	F-value (1, 36)	p-value	F-value (1, 36)	p-value
Mean sway velocity AP (cm/s)	.0028	.1984	.3074	.2091	.0002	.2038	.3100	.2038	1.15	.290	1.12	.298	1.13	.295
Mean sway velocity ML (cm/s)	.0046	.4249	.6574	.4479	.0009	.4366	.6612	.4366	1.14	.292	1.12	.297	1.12	.297
Mean net sway velocity (cm/s)	1.4681	.3921	1.9033	.4133	.2993	.4021	3.0722	.4021	23.87	**<.001**	.58	.450	.60	.443
Sample entropy AP	.0694	.0034	.0619	.0035	.0391	.0032	.0922	.0032	164.01	**<.001**	2.37	.132	.84	.365
Sample entropy ML	.0804	.0036	.0695	.0038	.0566	.0035	.0932	.0035	63.97	**<.001**	4.35	**.044**	1.30	.262

Note. All parametric statistical analyses are given in this table. The statistical test that was used is the "Repeated Measures (Full Factorial Design)". All the significant p-values are given in bold. The means and SD's show in which direction the effect goes. AP = antero-posterior, ML = medio-lateral, SD = standard deviation.

Table 5

Non-parametric Signed-Rank Test of 95% confidence area for Group

	Easy condition			Difficult condition		
Dependent variable	Median	IQR[Q1;Q3]	p-value easy condition	Median	IQR[Q1;Q3]	P-value difficult condition
Pregnant	.00002649	[.0000123145; .0000360578]	**<.001**	.00062074	[.0004705; .00079926]	**<.001**
Non-pregnant	.0000198415	[.0000124027; .0000314413]	**<.001**	.0005965	[.00049654; .00082505]	**<.001**

Note. This table shows whether there is a difference between the two postural conditions within each group. IQR = interquartile ratio, Q1 = quartile 1, Q3 = quartile 3.

Table 6

Non-parametric Rank-sum Test for difference between groups of 95% confidence area for Condition

Dependent variable	p-value influencing variable (NP-P)
Easy condition	.672
Difficult condition	.849

Note. The difference between groups for each condition was tested with the rank-sum test. NP = non-pregnant, P = pregnant.

Postural balance analysis with vibration

For the trials with vibration, the effect of condition, group and the interaction between condition and group on the displacement of the COP and the RPW ratio were investigated. The found results are summarised in Table 7.

A significant interaction effect was observed between group and condition regarding COP displacement during vibration at the m. multifidus. To identify the specific significant interactions, post-hoc tests were conducted (Table 8). The Tukey HSD test indicated that only the interaction between the non-pregnant women and the condition was significant. This means that within the non-pregnant group, there is a significant effect of condition on COP displacement during vibration of the m. multifidus, characterised by greater forward displacement during the difficult condition.

For all parameters, a significant main effect of condition was observed. This indicates that the COP displacement in backwards direction during vibration at the m. triceps surae was greater during the easy condition compared to the difficult condition. Moreover, the forward displacement during vibration of the m. multifidus was greater during the difficult condition compared to the easy condition. There was also an effect on RPW. In both the easy and difficult conditions, RPW values were closer to 100%, indicating a more likely ankle-steered strategy. During the easy condition, the ankle-steered strategy was more pronounced than during the difficult condition.

No significant main effect for group was found during the vibration trials.

Table 7
Overview Statistical Parametric Analyses for the Trials With Vibration

COP displacement	Non-pregnant		Pregnant		Easy		Difficult		Main effect of condition		Main effect of group		Effect of the interaction	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	F-value (1, 37)	p-value	F-value (1, 37	p-value	F-value (1, 37)	p-value
Vibtration m. triceps surae (m^2)	-1.2153	.1301	-1.0756	.1334	-1.3423	.1050	-.9486	.1050	16.54	**<.001**	.56	.458	.51	.479
Vibration m. multifidus (m^2)	.3572	.0680	.4261	.0698	.2655	.0605	.5178	.0605	12.39	**.001**	.50	.484	4.34	**.044**
RPW (%)	71.12	3.36	66.34	3.45	77.65	2.96	59.81	2.96	27.10	**<.001**	.99	.327	1.80	.188

Note. All parametric statistical analyses are given in this table. The statistical test that was used is the "Repeated Measures (Full Factorial Design)". All the significant p-values are given in bold. The means and SD's show in which direction the effect goes. SD = standard deviation.

Table 8

Post-Hoc HSD Tukey test p-values of the interaction effects for the Trials With Multifidus Vibration

		Left part of interaction		Right part of interaction	
Interaction	P-values	Mean	SD	Mean	SD
Non-pregnant*difficult vs. non-pregnant*easy	**.002**	.5580	.0845	.1564	.0845
Non-pregnant*difficult vs. pregnant*difficult	.910	.5580	.0845	.4776	.0867
Non-pregnant*difficult vs. pregnant*easy	.438	.5580	.0845	.3745	.0867
Non-pregnant*easy vs. pregnant*difficult	.054	.1564	.0845	.4776	.0867
Non-pregnant*easy vs. pregnant*easy	.288	.1564	.0845	.3745	.0867
Pregnant*difficult vs. Pregnant*easy	.748	.4776	.0867	.3745	.0867

Note. This table shows the interaction effects for group on condition during multifidus vibration tested with post-hoc HSD Tukey test. All the significant p-values are given in bold. SD = standard deviation.

Discussion

This study aimed to examine disparities in COP parameters and proprioceptive reweighting between pregnant and non-pregnant women. Trials were conducted with and without muscle vibration to gain insight into the differences between the two groups. It was hypothesised that there is a difference between the two groups, with pregnant women exhibiting higher postural sway parameters and experiencing greater difficulties in applying adequate proprioceptive reweighting in more difficult conditions.

With the main goal of identifying distinctions between the two groups, the p-values concerning the effect of group were first looked at after the statistical analyses were done. A significant effect for group was only observed in the trial without vibration, looking at static postural sway parameters, regarding sample entropy in the ML direction. According to this, non-pregnant women had a higher sample entropy in ML direction. They would exhibit a more irregular and complex COP displacement, indicating more variability of the COP. Previous scientific research has shown that a higher sample entropy would be important to have sufficient variability in the displacement of the COP, otherwise less effective postural control would be used (Kędziorek & Błażkiewicz, 2020) (Donker et al., 2007). From this, we can cautiously assume that pregnant women who had a lower sample entropy in the ML direction, will adopt a more rigid PC strategy and respond differently to perturbations. However, further research is warranted. With the exception of this parameter, no other significant results for group were observed during the trials with and without vibration. In research conducted by Dumke et al. (2024), sensory integration and segmental postural control during pregnancy were examined. The research found no significant differences in postural sway, sensory integration, or segmental balance control strategies between pregnant and non-pregnant women. Interestingly the authors hypothesised potential differences, which were not demonstrable due to the limited sample size and the postural position during the measurements of the women, which differed from other studies (standing with feet together and hands on the hips).

Furthermore, only one significant interaction effect was found in this study looking at proprioceptive reweighting during the trials with vibration, more specifically during the vibration at the m. multifidus. When conducting the Tukey HSD post-hoc tests, only the interaction between non-pregnant women and the condition proved significant. It was observed that non-pregnant women exhibited greater forward displacement of the COP during the difficult condition while undergoing vibration at the m. multifidus. The study of Claeys et al. (2011) found a similar result where their healthy control group demonstrated increased forward postural sway compared to individuals with non-specific low back pain during vibration at the m. multifidus when standing on an unstable support surface. Interestingly, no significant interactions were found for pregnant women, necessitating further research.

In general, significant effects were mainly found for condition, both in the trials with and without vibration. However, we did not observe a significant effect of condition for parameters such as mean sway velocity in the AP and ML directions and sample entropy in AP direction during the trials without vibration. In contrast to this current study, Opala-Berdzik et al. (2015) reported a significant increase in sway velocity in AP direction during advanced pregnancy when the women had to stand with their eyes closed. However, this difference was not significant in conditions with the eyes open. Notably, they only looked at this in 45 pregnant women and did not compare them with non-pregnant women. Given the relatively small sample size of 19 pregnant women in our study, the sample size can influence outcomes. As a result, the significant results should be viewed with a sufficiently critical view and interpretation should be made cautiously.

A significant effect of 'condition' was observed for the 95% confidence area. Both pregnant and non-pregnant women exhibited a larger area in the more difficult conditions, indicated by the means and SDs. Subsequently, it was observed that non-pregnant women had a significantly smaller 95% confidence area compared to pregnant women. This result aligns with the findings of a study by Oliveira et al. (2009), where a significant increase in the confidence area was observed during the second and third trimester of pregnancy. However, this increase was not significant for the condition with the eyes open and feet apart. Interpretation of findings in this current study should be cautious because this result is found with a nonparametric test with low power.

In contrast to the initial hypothesis, a significant effect for group was rarely observed across the investigated parameters. However, in the study by Ramachandra et al. (2023), a significant difference was found between the pregnant and non-pregnant study samples regarding the sway velocity in AP direction. They examined discrepancies in static postural sway characteristics, specifically average velocity in AP and ML directions, as well as the average velocity moment, between these two groups. The corresponding conditions in the study by Ramachandra et al. (2023) and our study are as follows: (1) standing on a stable support surface with feet apart and eyes open, and (2) standing on an unstable support surface with eyes closed and feet together. It is remarkable that they had a larger number of participants for both groups, with 40 participants in each group. This larger sample size ensures greater statistical power and a reduced chance of making a type 2 error (Ramachandra et al., 2023). Besides, their participants were, on average, slightly younger and had a somewhat lower body weight. However, the pregnant women in the study by Ramachandra et al. (2023) were primiparous, which is a major difference from our multiparous pregnant women. Calguneri et al. (1982) reported that multiparous women develop greater joint flexibility during pregnancy compared to nulliparous women. Considering this information, these changes could affect the static postural sway parameters. Although there are differences in certain characteristics of the participants in both studies, a larger sample size in our current study might facilitate the identification of differences between the groups.

When looking at the literature, significant changes in PC occur as women progress through pregnancy, especially in the third trimester. For instance, the 95% confidence area increases significantly during the second and third trimester of pregnancy compared to the early stages of pregnancy (Oliveira et al., 2009). Similarly, in our study, analysis of means and SDs also indicated increased COP values in pregnant women compared to non-pregnant women. Despite these increased COP values, this is not a significant effect in this study. Furthermore, Oliveira et al. (2009) observed greater COP sways in pregnant women throughout pregnancy when their eyes were closed, in both AP and ML directions, when the feet were apart. This observation is consistent with our results.

Throughout all vibration trials, a significant effect for condition is observed. The direction of COP displacement during these trials is consistent with scientific research by Janssens et al. (2013). Notably, the average COP distance travelled for the foam conditions is smaller than for the conditions with a stable support surface. This effect is seen only with muscle vibration at the level of the m. tricpes surae. The reduced backward displacement during difficult conditions could potentially be due to a decreased reliability of ankle proprioception. This was expected because, in difficult conditions, the proprioceptive signals from the ankle are likely to be less reliable. Additionally, these findings align with those of Ivanenko et al. (1999). A greater backwards displacement is observed during the analysis of triceps surae muscle vibration in the easy condition. This indicates an increased reliability of ankle proprioception, aligning with the expectations. On the other hand, during vibration at the level of the multifidus muscle, a greater forward displacement was observed during the difficult condition. This is due to an increased reliability of the proprioceptive signals coming from the lumbar muscles. During the easy condition, a smaller forward displacement was observed, meaning there was a decreased reliability of the proprioception coming from the back.

While analysing the effect of condition on the RPW ratio, a predominance 'ankle-steered strategy' during the easy condition is used within the study samples. In the difficult condition, while the proportion of 'multi-segmental strategy’ increases, the 'ankle-steered strategy' remains predominant. This can be assumed because the RPW value remains higher than 50% during the unstable condition, based on the mean values of our results. As previously mentioned, earlier scientific research confirms that an RPW ratio of one indicates the use of a 100% ankle-controlled strategy, while an RPW ratio of zero indicates a 100% multi-segmental strategy (Janssens et al., 2013). Prior research, such as that by Brumagne et al. (2008), has confirmed that on a stable support surface, an 'ankle-steered strategy' is more effective, whereas on an unstable support surface, a 'multi-segmental strategy' should be favoured due to less reliable proprioception at the ankles. A possible reason for observing a more dominant ankle-steered strategy in this study while standing on the unstable support surface is that the difficult condition may not have been challenging enough to elicit this dominance. This can be taken into further research by increasing the complexity of the difficult condition, for example, by introducing ballistic arm movements or utilising alternative unstable surfaces.

During the vibration trials, no significant effects for the parameter group were found. It is crucial to note that the sample sizes of 18 pregnant women and 20 non-pregnant women during the trials with vibration are small. This results in low statistical power and an increased chance of making a type two error. Remarkably, there is a scarcity of published scientific studies regarding the effect of pregnancy on proprioceptive reweighting with the integration of vibration trials. There have been other studies investigating proprioceptive reweighting using vibration trials in other populations. For instance, Claeys et al. (2011) did this in adolescents with non-specific low back pain and found significant differences. When critically examining the sample from the study by Claeys et al. (2011), differences are observed compared to our sample, but we also note several similarities. Pregnant women undergo physiological changes leading to alterations in the lumbar spine movement, specifically, there is reduced movement in the lumbar region, resulting in a more rigid strategy (Biviá-Roig et al., 2019). These rigid strategies are also found in adults with non-specific low back pain in the study by Claeys et al. (2011), where it is known that they rely less on proprioceptive signals from the back muscles but instead more frequently utilise an 'ankle-steered strategy'. Furthermore, it is crucial to continue investigating proprioceptive reweighting in future studies with a greater study sample to gain further insights into pregnant women as well.

Limitations

During this experimental study, several limitations were noted. For instance, the number of participating pregnant and non-pregnant women was not large enough to be able to speak with certainty about significant effects. Additionally, the power of each parameter, both in the trials with and without vibration, was extremely low likely due to the small groups. Consequently, the likelihood of observing similar results when the same tests are done is minimal, increasing the chance of a type II error. This may result in many false negative or false positive results. Besides the fact that the study samples were already small, the results during the trials without vibration of one pregnant woman were missing. As a result, the study sample for the non-vibration trials consisted of only 18 women. This was factored into the calculation of the powers.

Furthermore, there is a debate in the scientific literature regarding the interpretation of higher COP values. For instance, a higher mean velocity cannot immediately be equated to a poorer balance. Researchers could also interpret these higher values as individuals exhibiting an active postural sway, using it as a strategy to acquire more sensory information. According to this theory, individuals with an active sway would receive more information about the position of their body in space, aiding in achieving a safe upright posture (Carpenter et al., 2010). Given this perspective, the higher average velocities exhibited in pregnant women during the conditions would not necessarily be regarded negatively. These higher velocities were seen in the means of the pregnant women compared to the non-pregnant women, but this difference between the groups was not yet statistically significant. This could not mean with certainty that they have a poorer PC. Alternatively, it could also be viewed positively that they will make more corrections to maintain a safer stance. An additional limitation may be that the COP parameters were assessed during static conditions, precluding any statements about the differences between the two groups for these parameters during dynamic activities such as walking (Dunning et al., 2010). This needs to be further investigated in future studies.

Conclusion

The aim of this study was to investigate potential discrepancies in static postural balance and proprioceptive reweighting between pregnant and non-pregnant women. The hypothesis formulated for this purpose was that there is a difference between the groups for static postural balance and proprioceptive reweighting. Interestingly, only one significant difference between the groups for the COP parameter sample entropy in the mediolateral direction during upright standing was found. Here, pregnant women exhibited a reduced complex displacement of the COP. While the interaction effects between group and condition were the most interesting to look at, only one significant interaction effect was observed during the trials with vibration concerning the COP displacement during vibration of the m. multifidus. Surprisingly, this interaction was observed solely within the non-pregnant group with condition.

Since the differences between groups for various COP parameters and proprioceptive reweighting was our main objective to investigate, it is imperative that this research needs to be continued and expanded in order to be able to make statements with more certainty. As a result, we conclude that additional research is needed to gain more insights into the influence of pregnancy on postural balance, proprioceptive reweighting and COP parameters.

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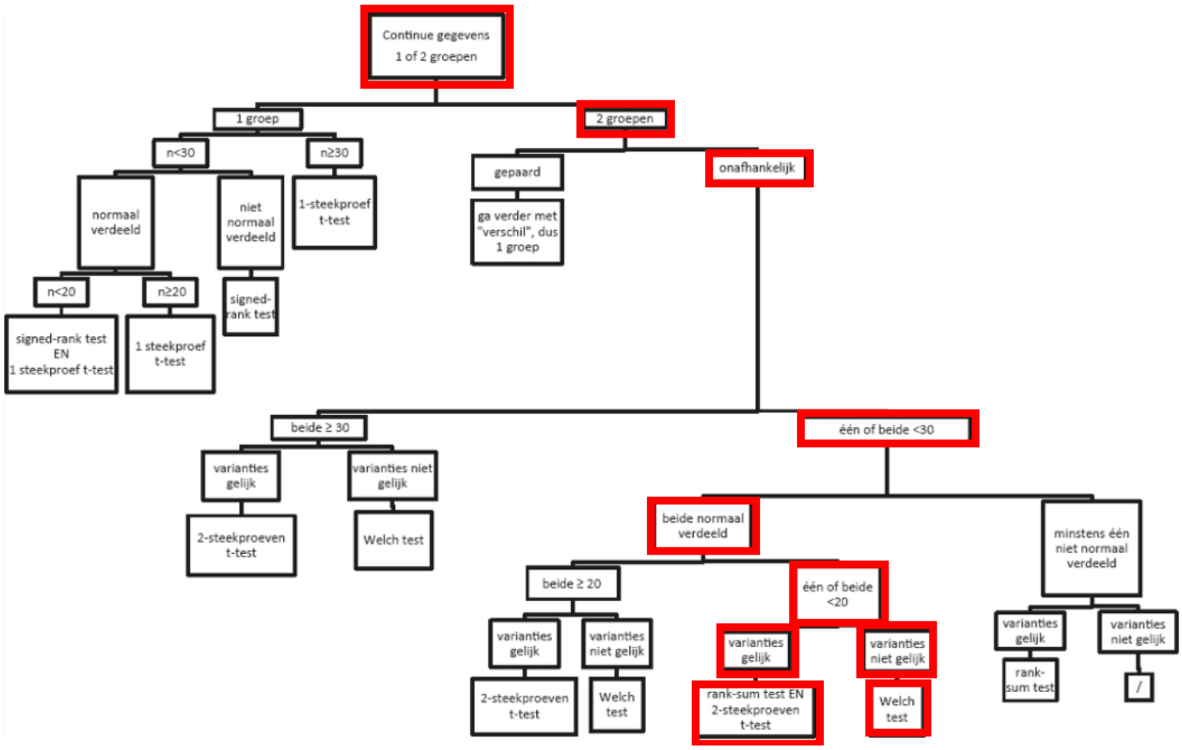
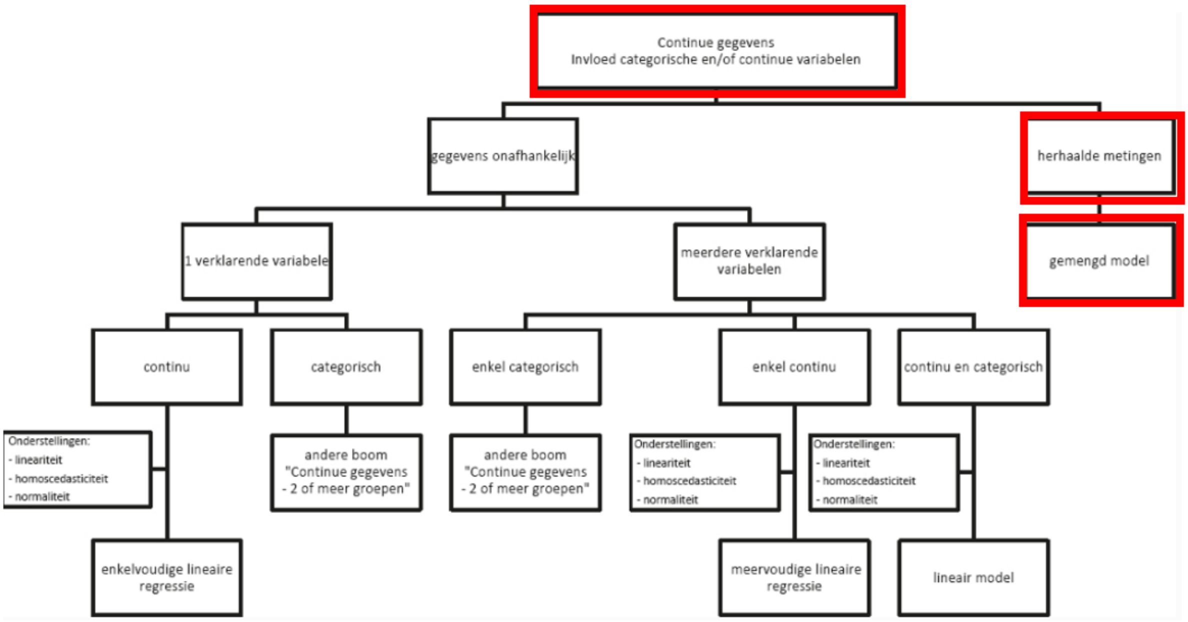
Appendix

Decision tree statistics

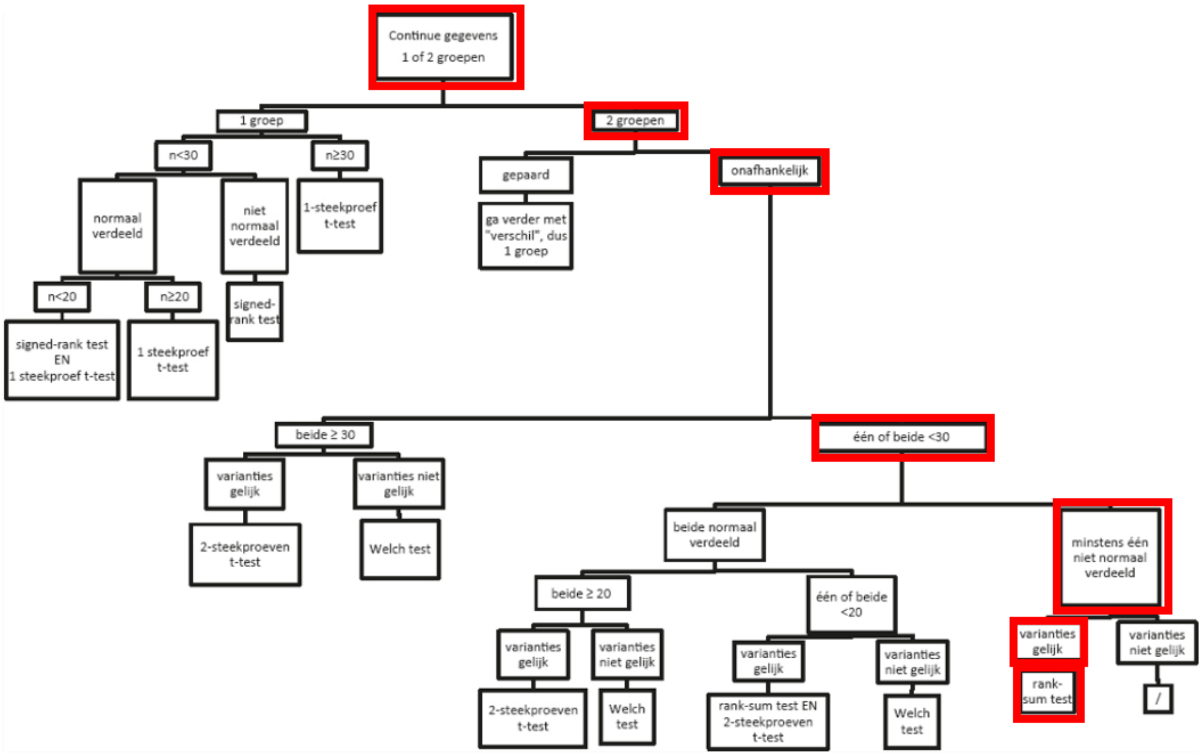
Appendix A1



Appendix A2



Appendix A3



Appendix A4