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Faculteit Revalidatiewetenschappen

master in de revalidatiewetenschappen en de kinesitherapie

Masterthesis

Influence of the sensory systems on postural control during pregnancy

Lauren Moors
Lotte Vranken

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

PROMOTOR :
Prof. dr. Lotte JANSSENS

COPROMOTOR :
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2020
2021

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Prof. dr. Lotte JANSSENS

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The influence of the sensory systems on postural control during pregnancy

Research question:
Which changes in postural stability occur as a result of an altered proprioceptive system and stance width?

Highlights:

- Falling is experienced by 30% of pregnant women.
- Postural control relies on the input of three sensory systems (visual, proprioceptive and vestibular system) and is controlled by the central nervous system.
- This study showed an increased postural instability in pregnant women influenced by manipulations of proprioceptive input, stance width and support surface.
- Future research needs to analyse the interaction between the different sensory systems and their effect on postural control.

Lotte Vranken & Lauren Moors
Promotor: Prof. Dr. Lotte Janssens
Copromotor: Dr. Nina Goossens

Woord vooraf

Twee jaar geleden zijn we begonnen aan de allereerste pagina dat we vandaag de dag onze masterproef kunnen noemen. Het was een lange weg met verschillende up’s en down’s die ons uiteindelijk tot hier heeft gebracht. Gedurende dit hele proces zijn we bijgestaan door verschillende personen die we graag zouden willen bedanken voor hun inzet en steun, zonder hen was dit niet mogelijk geweest.

In de eerste plaats zouden we onze oprechte dank willen betuigen aan onze promotor Dr. Prof. Lotte Janssens om ons de kans te geven ons te verdiepen in dit interessante onderwerp en ons elke stap van de weg bij te staan.
Daarnaast zouden we graag onze copromotor Dr. Nina Goossens bedanken voor het delen van haar uitgebreide expertise binnen dit vakdomein, voor grondig de tijd te nemen om dit onderzoek in goede banen te leiden en steeds bereikbaar te zijn voor al onze vragen.

Verder willen we onze familie en vrienden hartelijk danken voor hun steun en optimisme. Wanneer we er zelf even niet meer in geloofden, herinnerde ze ons eraan dat we goed bezig waren en we het tot een mooi einde zouden brengen.

Als laatste bedanken we mekaar voor de vriendschap en mooie samenwerking. We hebben plezier en leed met elkaar gedeeld, elkaar erdoor getrokken en samen doorgezet tot het bittere einde.

Riemst, 07/06/2021 L.V.
Bilzen, 07/06/2021 L.M.

Research context

This master thesis fits in the research domain of musculoskeletal rehabilitation. The research within this field of study aims to contribute to physiotherapeutic treatments of patients with musculoskeletal problems. With the use of a valid and reliable measure equipment, patients will be approached interdisciplinary to discover the mechanisms which lead to these musculoskeletal problems. Therefore, it is important to focus on the development of specific physiotherapeutic interventions which reduces the problems by solving the underlying mechanisms adjusted to every patient.

Many changes occur during pregnancy, especially in the musculoskeletal system (Smith, Marcus, & Wurtz, 2008). Namely; stretch of the abdominal muscles, displacement of the maternal center of gravity anteriorly, joint laxity, adaptations in lower extremity muscles and different input from the sensory system. These changes can lead to postural instability causing an increased fall risk in pregnant women. (Ribeiro, 2015; Nyska et al., 1997; Cogswell, Serdula, Hungerford, & Yip, 1995; Jensen, Doucet, & Treitz, 1996; Moccelin & Driusso, 2012; Cakmak, Ribeiro, & Inanir, 2015). Postural control relies on the input of three sensory systems (i.e., visual, proprioceptive and vestibular system) and is controlled by the central nervous system (CNS) (Ivanenko, Solopova, & Levik, 2000). During several static and dynamic conditions, internal or external perturbations can occur which lead to a sensory weighting between these three systems, whereby the focus will shift to the system with highest reliability in order to maintain postural stability (Carver, Kiemel, & Jeka, 2006; Brumagne, Cordo, & Verschueren, 2004).

The aim of this study was to investigate the role of the proprioceptive system on postural stability during pregnancy. Therefore, various base of support conditions were investigated. For example, participants had to stand on a stable and unstable surface support with vision occluded. Furthermore, muscle vibration was used to specify the role of proprioceptive inputs from the ankle and lower back muscles during postural control in pregnant women.

This master thesis is part of the postdoctoral project of Dr. Nina Goossens, namely: “Improving maternal health by identifying and tackling predictive factors for the development of low back pain during pregnancy and postpartum”. The research project is financed by AXA Research Fund. Last year, the first part of this duo-master thesis was completed. It consisted of a systematic review written by two students: Lotte Vranken and Lauren Moors, namely: “Postural control in pregnant women and after childbirth: a systematic review”. The second part took place in the research center REVAL at Hasselt University in Diepenbeek. The research protocol and method were provided by the promotor Prof. Dr. Janssens and copromotor Dr. Goossens. For the recruitment of the participants, flyers were distributed as well as emails, this was in cooperation with another master thesis duo who included the same subjects. The tests taken in the REVAL center were mostly conducted by the copromotor with the assistance of one student. The copromotor also pre-processed the obtained data by using Matlab software and a custom-made script to calculate specific COP outcome measures in AP and ML directions. Furthermore the data was categorized in an excel file under the respective outcome measure. Then both students processed the data independently, they entered the data into JMP and performed statistical tests on them. Finally, the description of the results was done by both students together. Likewise, the other parts of this master thesis which were also written in collaboration.

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1. Abstract

Background: During pregnancy, postural instability can occur which can lead to an increased fall risk. Postural stability control relies on three sensory systems (vision, proprioception, vestibular system) and is controlled by the central nervous system. For optimal postural control, the focus has to shift to inputs of the sensory system with the highest reliability given the environmental situations. This process is called sensory (re-)weighting.

Objectives: The aim of this study was to investigate postural instability in pregnant women through manipulating the support surface, stance width and proprioceptive input.

Participants: Eight pregnant women aged between 28-33 years old participated in our study. They were multiparous, had a singleton pregnancy and were in their third trimester of pregnancy.

Measurements: Postural stability during upright standing without vision was measured using a six-channel force plate and two local muscle vibrators. Our primary outcome measures were sway magnitude (standard deviation of COP) and sway variability (mean velocity of COP) in both anterior-posterior (AP) and medio-laterla (ML) directions. During the first four trials, several combinations between two factors: 'support surface' (stable or foam) and 'stance width' (feet apart or feet together) were investigated. During the last four trials, local muscle vibration was applied at ankle and back muscles. Both differences in COP outcomes (i.e., SD and mean velocity in AP/ML direction) and RPW ratio were determined with 2x2 repeated measure analysis of variance (ANOVA).

Results: A significant effect of the support surface ($p<0.0001$) was found for sway magnitude, whereby standing on a foam caused an increased sway magnitude in both AP and ML direction. While standing on a foam (AP and ML $p<0.0001$) as well as standing with feet together (AP: $p<0.0001$; ML: $p<0.0012$), an increased sway variability was visible in both directions. No significant effect of 'support surface' on relative proprioceptive weighting (RPW) ($p=0.178$) was found.

Conclusion: An increase in postural instability during pregnancy may occur as a result of changes in the proprioceptive input, support surface and stance width. However, future research needs to confirm these results.

Keywords: pregnancy, proprioception, stance width, postural stability, vibration

2. Introduction

During pregnancy, many changes occur, which might contribute to an increased risk of falling (Cakmak et al., 2015). Falling, a consequence of an impaired postural stability, is experienced by 30% of pregnant women (Dunning, Lemasters, & Bhattacharya, 2010). Postural instability is caused by several hormonal, physiological and anatomical adaptations during pregnancy, of which changes in the musculoskeletal system are important (E.K. Tan & E.L. Tan, 2013; Smith et al., 2008). Obviously, the uterus will expand through which the abdominal muscles are stretched and the maternal center of gravity is shifted more anteriorly. Consequently, postural instability will be more prominent in the third trimester of the pregnancy (Ritchie, 2003; Sneag & Bendo, 2007). Especially in the anterior-posterior (AP) direction body sway will increase as pregnancy progresses (Jang, Hsiao, & Hsiao-Wecksler, 2008; Nagai et al., 2009; Opala-Berdzik, Blaszczyk, Swider, & Cieslinska-Swideret, 2018).

Postural control, i.e. the maintenance of postural stability, relies on the input of three sensory systems (i.e., visual, proprioceptive and vestibular system) and is controlled by the central nervous system (CNS). The sensory inputs have to detect changes in body posture and locomotion during several static or dynamic conditions (Ivanenko et al., 2000; Sorensen, Hollands, & Patla, 2002). Throughout the conditions, these changes might be caused by internal and external perturbations. The input of the sensory systems allows the CNS to adjust the internal presentation of a person, position and orientation of body segments to the environment (Bloem, Allum, Carpenter, & Honegger, 2000; Carver et al., 2006; Sorensen et al., 2002).

To achieve this, there will occur a sensory weighting between the three sensory systems. Depending on a particular situation, the focus will be shifted to the sensory system with the most reliable input (Brumagne et al., 2004; Carver et al., 2006). For example, when someone has closed his/her eyes, the reliance on the vestibular and proprioceptive input will be increased because of limited visual feedback. Moreover, weighting can occur within one specific system, i.e., proprioceptive weighting. When a body part is experiencing an adaptation that leads to reduced proprioceptive signals due to fatigue, injury, pain or external factors (e.g., standing on a foam), the reliance on proprioceptive inputs from other body parts has to be increased (Brumagne et al. 2004; Carver et al., 2006; Claeys, Brumagne, Dankaerts, Kiers, & Janssens, 2011).

To measure proprioceptive weighting, local muscle vibration can be used (Claeys et al., 2011; Brumagne, Janssens, Knapen, Claeys, & Sudden-Johanson, 2008; Ito et al., 2018; Horak & Nashner, 1986). Muscle vibration executes a powerful stimulus to proprioceptors, i.e., it activates the muscle spindle Ia afferents. As a consequence, an illusion of muscle lengthening is created in upright standing, which will be interpreted as a joint displacement and followed by an excessive corrective body sway displacement in the opposite direction to avoid falling (Cordo, Gurfinkel, Brumagne, & Flores-Vieira, 2005; Roll & Veder, 1982). The amplitude of these unconscious corrective displacements in response to muscle vibration represents the amount of reliance of the CNS on the proprioceptive inputs from the vibrated muscles. For example, an excessive corrective sway after applying vibration to the lumbar muscles during standing indicates a dominant use of lumbar proprioception for maintaining postural stability (Brumagne et al., 2004). The vibration is mostly executed on the triceps surae muscles and lumbar multifidus muscles, because of their involvement in different postural strategies, respectively the ankle and multi-segmental strategy (Claeys et al., 2011; Brumagne et al., 2008; Horak et al., 1986). Although proprioception of the lumbar multifidus and triceps surae muscles is important to maintain a stable position, the role of proprioceptive input in postural stability in pregnant women has never been researched before. (Bloem et al., 2000; Sorensen et al., 2002)

This in contrast to other populations, e.g., persons with recurrent low back pain, where the reliance on the proprioceptive system was investigated with different methods, i.e., by observing postural sway during local muscle vibration, and by using two postural conditions in their trials, namely standing on a stable or unstable support surface/foam (Claeys et al., 2011). Moreover, in Oliveira et al. (2009) they used a protocol, which consisted of standing conditions where the pregnant subjects had their feet apart or together, to assess the role of stance width on postural control. Several studies observed an increased stance width during pregnancy. Since there is an increased postural instability with pregnancy progression, increasing stance width could be an adaptation to maintain balance (Jang et al., 2008; Opala-Berdzik et al., 2015; Ribas & Giurro, 2007).

However, to draw conclusions concerning postural instability in pregnant women, too few studies researched the reliance on proprioceptive input, support surface and stance width. Therefore, our current study did investigate the influence of these three factors on postural stability in pregnant women. This could be important to optimize physiotherapeutic treatments for reducing fall risk in the future.

3. Methods

3.1 Research question and hypothesis

3.1.1 Research question

Which changes in postural stability occur as a result of an altered proprioceptive system and stance width?

3.1.2 Hypothesis

We assume that differences in proprioceptive use occur during pregnancy and reduce postural stability. More specifically, we hypothesize that pregnant women rely less on proprioceptive inputs of the back muscles and more on proprioceptive inputs from the ankle muscles. During the vibration trials, we expect a higher RPW ratio when standing on a foam compared to standing on a firm support surface. Additionally, we assume that pregnant women stand with a wider base of support to maintain balance. Therefore, we expect an increase in postural instability in trials where the subjects need to stand with their feet together.

3.2 Study design

An exploratory cross-sectional design was used.

3.3 Participants

3.3.1 Inclusion criteria

The following inclusion criteria were applied to all pregnant participants: (1) aged between 18-40 years old, (2) singleton pregnancy, (3) multiparous (i.e., already given birth to at least one child) and (4) willing to sign informed consent form.

3.3.2 Exclusion criteria

The following exclusion criteria were applied to all participants: (1) history of surgery/major trauma to spine, pelvis and/or lower limbs, (2) specific balance or vestibular disorders, (3) spinal deformities, (4) rheumatic disease, (5) neurological abnormalities (e.g., peripheral neuropathy), (6) uncorrected visual problems, (7) hyperemesis gravidarum, (8) acute ankle problems, (9) pre-existing disorders that could interfere with the course of pregnancy (e.g., hypertension, kidney disease, coagulation disorders), (10) (a history of) psychiatric disorders (identified with the SCID-5), and (11) non-Dutch speaking.

3.4 Recruitment

Eight healthy, multiparous women who were in the third trimester of pregnancy were recruited. These eight women visited the REVAL Rehabilitation Research Center (UHasselt, Diepenbeek) for testing.

3.5 Baseline characteristics

Participants were asked about demographic and anthropometric data in the first session: Age, height, weight before pregnancy and current weight, BMI before pregnancy and current BMI, and gestational age. These data can be seen in Table 1.

Table 1

Participants' characteristics

	Pregnant women *n* = 8	**Range**
Age (years)	30.55 ± 1.71	28.61-33.86
Gestational age (days)	234.38 ± 9.16	224-247
Body height (cm)	168.13 ± 7.59	158-179
Pre-pregnancy body weight (kg)	66.88 ± 12.63	53-93
Pre-pregnancy BMI (kg/m²)	23.68 ± 4.32	20.20-31.80
Current body weight (kg)	79.3 ± 15.26	62-110
Current BMI (kg/m²)	28.04 ± 5	23.62-37.62
Gestational weight gain (kg)	12.43 ± 3.54	9-18

The values are means with standard deviations

BMI Body Mass Index

3.6 Medical ethics

All test procedures for this study were approved by the Medical Ethics Committee of the University of Hasselt (B371201942396).

3.7 Measurement

3.7.1 Study procedure

The test session took place during the third trimester of pregnancy. All tests were performed in the laboratory located in Diepenbeek. First, some anthropometric data were collected. Secondly, postural control during upright standing was measured during eight trials, by using a six-channel force plate (AMTI, Watertown USA). In total, we measured four postural control conditions during vision occluded with a duration of 60 seconds each, described in Table 1. During these conditions, several combinations were made between following characteristics; feet 20 cm apart/together and stable/unstable surface. Lastly, the use of ankle and lumbar proprioception during postural control was measured by using muscle vibration during four trials (Cordo et al., 2005; Goodwin, McCloskey, & Matthews, 1972; Roll et al., 1982; Roll, Vedel, & Ribot, 1989).

Table 2

Overview of trials

Trials to assess postural stability	
Trial number	**Postural condition**
1	20 cm between heels, stable support surface
2	Feet together, stable support surface
3	20 cm between heels, unstable support surface
4	Feet together, unstable support surface
Trials to assess proprioceptive use during postural control	
Trial number	**Postural condition and vibration of muscles**
5	Stable support surface, vibration of ankle muscles
6	Stable support surface, vibration of lumbar muscles
7	Unstable support surface, vibration of lumbar muscles
8	Unstable support surface, vibration of ankle muscles

3.7.2 Equipment

Based on previous studies, we selected the materials, procedure and outcome measures to assess proprioceptive use during postural control (Brumagne et al., 2004; Brumagne et al., 2008; Claeys et al., 2011; Kiers, Brumagne, van Dieën, & Vanhees, 2014; Pijnenburg et al., 2004).

First, a six-channel force plate (AMTI, Watertown USA) was used to measure center-of-pressure (COP) displacements during upright standing. This force plate served as the stable support surface, in contrary to the foam pad (Airex Balance Pad Elite, Airex Switzerland, 49.5 cm x 40.5 cm x 6.5 cm), which was placed on top of the force plate during some of the trials and was used as an unstable support surface. Second, during some of the trials, two muscle vibrators (Maxon Motors, Switzerland, 60 Hz, 0.5 mm) were applied bilaterally over the triceps surae ('ankle') muscles and lumbar paraspinal ('back') muscles. A vibration trial with a duration of 65 seconds; 20 seconds previbration, 15 seconds muscle vibration, and 30 seconds recovery, was given while standing on the six-channel force plate. Muscle vibration is a strong stimulus for muscle proprioceptors; it stimulates muscle spindle Ia afferents and induces an illusion of muscle lengthening. (Cordo et al., 2005; Goodwin et al., 1972; Roll et al., 1982; Roll et al., 1989). An unconscious corrective postural sway would occur if participants used proprioceptive inputs from the vibrated muscle to maintain postural control (Barbieri et al., 2008; Eklund, 1972; Goossens, Janssens, Caeyenberghs, Albouy, & Brumagne, 2019). The differences in SD and mean velocity COP outcomes during the first four trials, and mean COP displacements induced by muscle vibration during the last four trials, were recorded while the participant stood on the force plate ('stable support surface') and on the foam ('unstable support surface') with occluded vision (Brumagne et al., 2004; Brumagne et al., 2008).

3.7.3 Standardization

The participants were asked to stand barefoot on the force plate, with the arms hanging relaxed along the body during all trials. Between trials, the participant had a pause of one minute. To standardize the foot position during all subsequent trials, the position of the feet was marked on a transparent sheet with 20 cm between the heels and with feet together. To occlude vision, participants were given goggles whose lenses were sealed with tape. Participants were asked to keep their eyes open underneath.

3.7.4 Trials

To research postural control, the participants underwent eight trials with various postural conditions (See Table 2). All trials were executed in standing position. For the first two trials, participants stood on the force plate (‘stable support surface’) and for next two trials on a foam pad (‘unstable support surface’). In both conditions patients stood one trial with feet apart and the second trial with feet together. Moreover, the use of ankle and lumbar proprioception during postural control was measured during trial 5-8. Fifteen seconds of local muscle vibration was applied at the ankle or back muscles after 20 seconds of standing. During two trials, the participants stood on the force plate, while for the remaining two trials, the foam pad was used, all with occluded vision. Moreover, a randomisation of vibration trials was applied to prevent a learning effect. From seven participants we measured all postural conditions, one participant could only execute the tests with muscle vibration due to varices, which prevented her from standing up for a long time. To guarantee the safety of the participants during the test, two research assistants stood close to the participants at all times. Additionally, all women wore a chest harness.

3.8 Outcome measures

3.8.1 Primary outcome measures

3.8.1.1 Trials without muscle vibration

Primary outcome measures were related to changes in postural stability after manipulation of the proprioceptive system and stance width. First, postural control was analyzed during upright standing where the COP displacements AP and ML direction were measured with the force plate. This force plate recorded the forces and moments in x, y and z directions at a rate of 1000 Hz. The software used for the calculations of the COP position in all three directions from raw force plate data is SIMI. Matlab software and a custom-made script was used to pre-process these COP signals and to calculate specific COP outcome measures in AP and ML directions.

First, the COP signals were filtered by using a lowpass 4th order Butterworth filter at 6 Hz. Second, the COP baseline offset was corrected by subtracting the mean COP position in AP and ML direction from all COP measurements in corresponding direction. Finally, the script then calculated: COP_max and COP_min in AP and ML direction equals the maximal COP position in every direction. These were used to calculate the standard deviation of COP in AP and ML direction (in m) and Mean COP velocity in AP and ML direction (in m/s). Because standard deviation (SD) of COP displacements provides information about the magnitude of sway, this is categorized under the label 'sway magnitude', mean velocity of COP displacement is referred to as a measure of 'sway variability'.

3.8.1.2 Trials with muscle vibration

The use of ankle and lumbar proprioception during postural control was evaluated by recording the mean COP displacements in response to muscle vibration with the force plate (Brumagne et al., 2004). Positive COP displacements indicate an anterior sway and negative COP displacements indicate a posterior sway. A Relative Proprioceptive Weighting ratio (RPW) was calculated to measure ankle versus lumbar proprioceptive dominance. The absolute value of the mean COP displacement during ankle muscle vibration was divided by the sum of the absolute COP displacements during ankle and back muscle vibration (Brumagne et al., 2008). Consequently, an RPW outcome of 1 corresponded to a total reliance on m. triceps surae proprioception and an outcome of 0 corresponds to a total reliance on m. lumbar multifidus proprioception. It has been shown that the quantification of the postural response to muscle vibration by COP displacement during muscle vibration and RPW rate is reliable (Kiers et al., 2014).

3.9 Data analysis

Data were statistically analyzed using JMP Pro 15, whereby an overall significance level of $p < 0.05$ was used. First, the baseline characteristics of all subjects were summarized of which the normality was tested. The zero hypothesis was that all baseline demographic characteristics were normally distributed ($H0$= data normally distributed). The alternative hypothesis was that all characteristics were not normally distributed ($H1$= data not normally distributed). To examine the normality of each characteristic separately the Shapiro-Wilk test was used. Data were not normally distributed if the P-value was <0.05, then the zero hypothesis was rejected. Consequently, the median and interquartile (IQR) distance were extracted from the data. When the zero hypothesis was not rejected (P-value > 0.05), the mean and standard deviation (SD) were extracted. Furthermore, the mean and standard deviation (SD) for every parameter were calculated. Differences in COP outcomes (i.e., SD and mean velocity in AP/ML direction) were determined with a 2x2 repeated measure analysis of variance (ANOVA) with within-subject factors 'support surface' (stable, unstable), fixed effect 'stance width' (feet together, feet apart) and repeated structure 'Person ID' (P1,P2,...P8). The differences in RPW ratio were also determined with a 2x2 repeated measure analysis of variance (ANOVA) with within-subject factors ‘support surface’ (stable, unstable) and ‘muscle’ (ankle, back).

4. Results

4.1 Baseline descriptive characteristics

All characteristics were normally distributed except for ‘pre-pregnancy BMI’. The pregnant women had a mean age of 31 ± 2 years, a mean body height of 168 ± 8 cm and a mean gestational weight gain of 12 ± 4 kg. Further details on baseline characteristics can be found in Table 3.

4.2 Effects of surface and stance width on COP variables during pregnancy

The factor ‘support surface’ (stable/foam) showed a significant effect on the SD outcomes of COP in both directions (AP/ML) while standing ($p<0.0001$) (See Fig. 1). More specifically, when standing on foam, the SD outcomes of COP in AP and ML directions were significantly increased compared to the stable condition. No significant difference in mean values of stance width were observed ($p= 0.1176$).

In terms of mean velocity outcomes of COP in AP and ML direction, significant effects from the ‘support surface’ (AP: $p<0.0001$; ML: $p<0.0001$) as well as ‘stance width’ (AP: $p<0.0001$; ML: $p<0.0012$) were demonstrated. More specifically, a higher mean velocity outcome of COP was visible while standing on a foam compared to a stable surface, as well as during feet together compared to feet separated (See Fig. 2). There were differences of standard deviation values of mean velocity outcomes of COP in AP and ML, of which the highest values were observed in the factors ‘foam’ and ‘feet together’.

In general, the trials with combined factors ‘unstable surface/feet together’ (US/FT) showed highest mean values and trials with combined factors ‘stable surface/feet apart’ (SS/FA) showed lowest. This was the case in all four COP outcome measurements (See figure 3,4,5 and 6)

4.3 Effects of local muscle vibration on COP variables during pregnancy

There was no significant effect of ‘support surface’ on RPW ($p=0.178$). Figure 7 illustrates the RPW during the vibration trials while standing on a stable support surface and standing on a foam. Where figure 8 illustrates the COP displacements during the different conditions of muscle vibration.

Table 3
Baseline characteristics tested on normality with Shapiro-Wilk test (p-value)

		p-value
Age (years): mean ± sd	31 ± 2	0.365
Gestational age (days): mean ± sd	234 ± 9	0.2
Body height (cm): mean ± sd	168 ± 8	0.481
Pre-pregnancy body weight (kg): mean ± sd	67 ± 13	0.27
Pre-pregnancy BMI (kg/m²): median ± IQR	22 ± 7	0.015*
Body weight (kg): mean ± sd	79 ± 15	0.362
BMI (kg/m²): mean ± sd	28 ± 5	0.075
Gestational weight gain (kg): mean ± sd	12 ± 3.5	0.086

The values are mean with standard deviations for normally distributed data. For not normally distributed data, the values are median with interquartile distance. *BMI* Body mass index, *p <0.05 means significant difference.

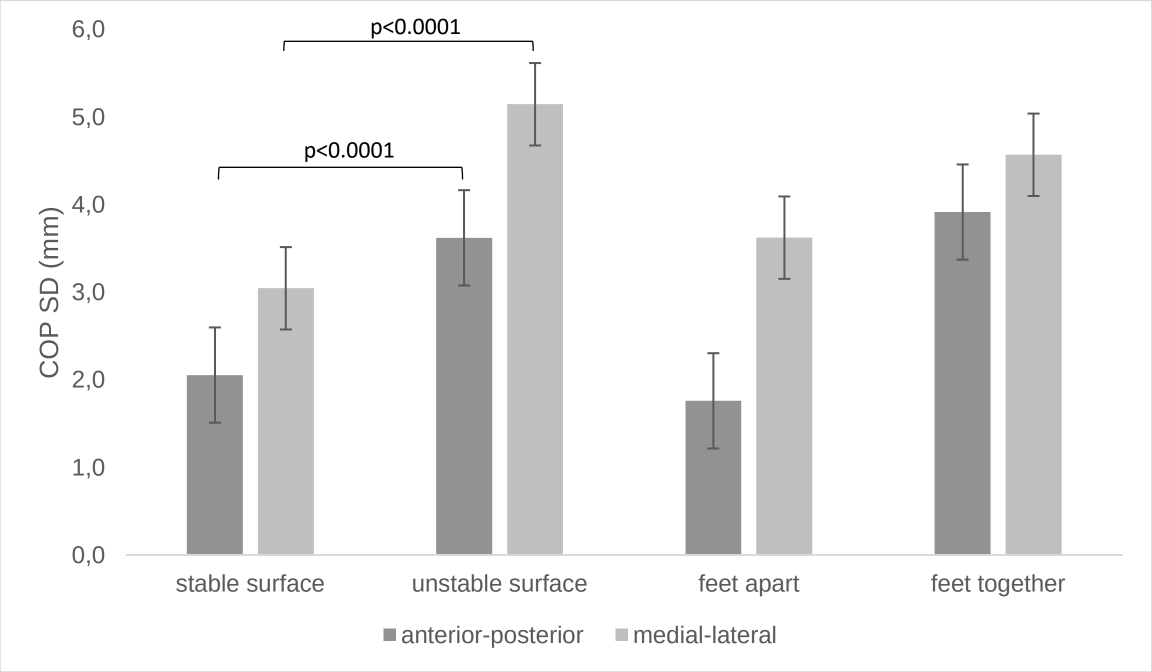

Fig. 1 Values of the standard deviations (SD) of the anteroposterior (AP) and mediolateral (ML) center of pressure (COP) displacements for the trials comparing the factors 'support surface' (stable/foam) and 'stance width' (feet apart/feet together) in pregnant women. Error bars present standard deviations of the mean values. P-values represent a significant effect.

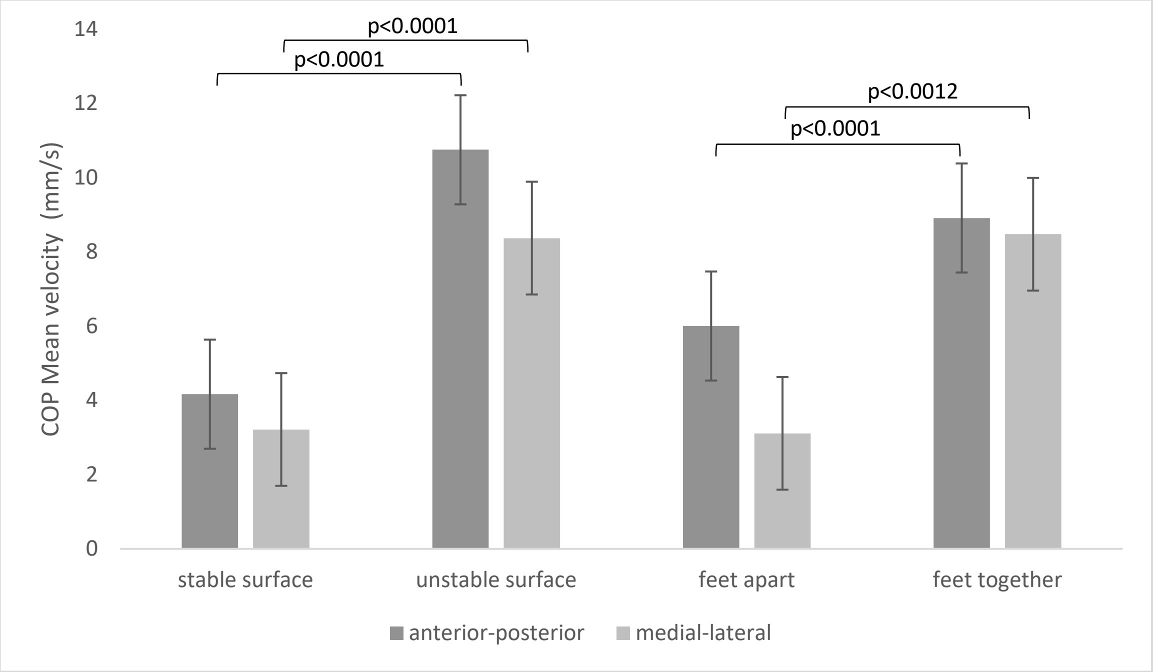

Fig. 2 Values of the mean velocity of the anteroposterior (AP) and mediolateral (ML) center of pressure (COP) displacements for the trials comparing the factors 'support surface' (stable/foam) and 'stance width' (feet apart/feet together) in pregnant women. Error bars present standard deviations of the mean values. P-values represent a significant effect.

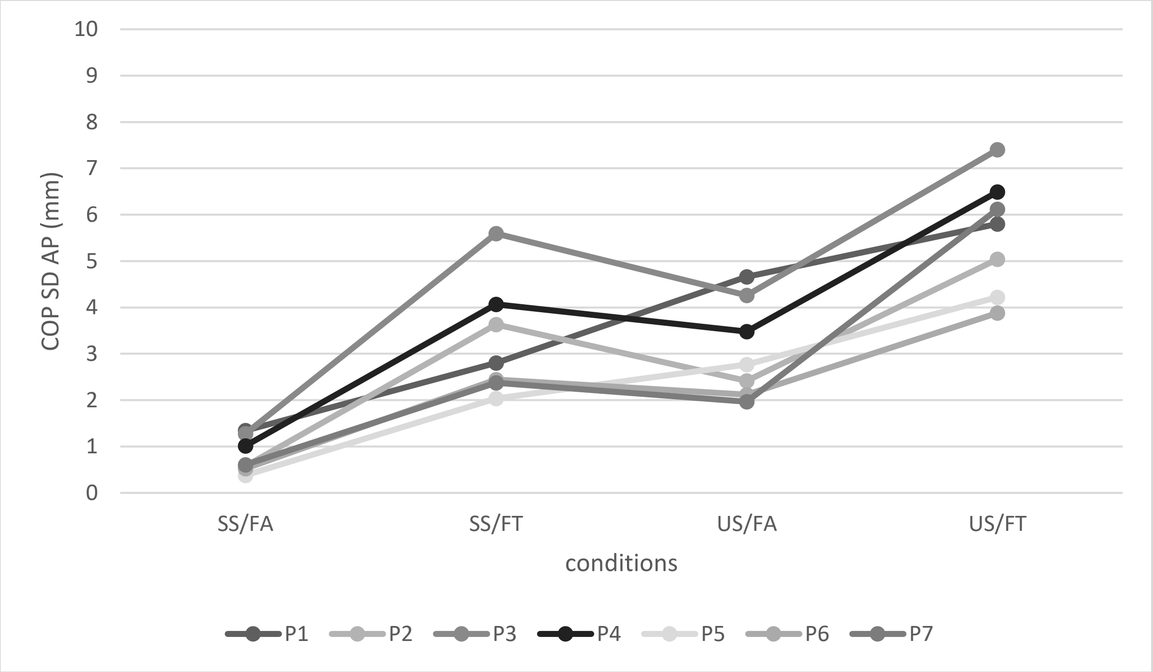

Fig. 3 Mean values of the standard deviations (SD) of the anteroposterior (AP) center of pressure (COP) displacements for each individual subject, for example person one defined by 'P1', during the trials: 'stable surface/feet apart (SS/FA)', 'stable surface/feet together (SS/FT)', 'unstable surface/feet apart (US/FA)' and 'unstable surface/feet together (US/FT)'.

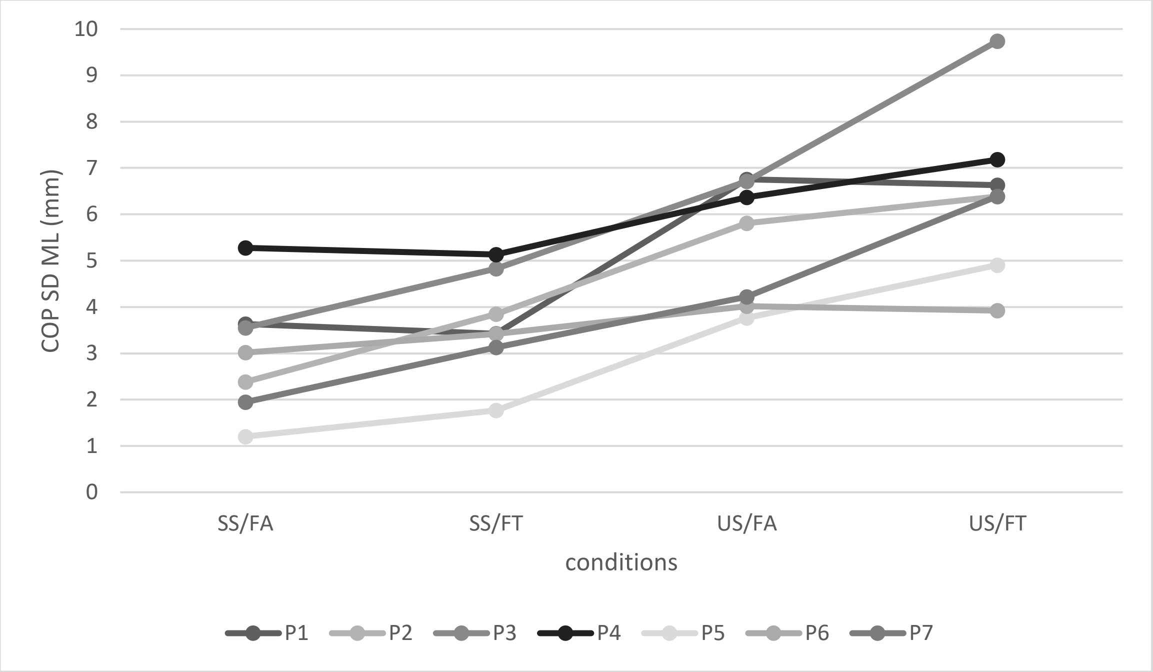

Fig. 4 Mean values of the standard deviations (SD) of the mediolateral (ML) center of pressure (COP) displacements for each individual subject, for example person one defined by 'P1', during the trials: 'stable surface/feet apart (SS/FA)', 'stable surface/feet together (SS/FT)', 'unstable surface/feet apart (US/FA)' and 'unstable surface/feet together (US/FT)'.

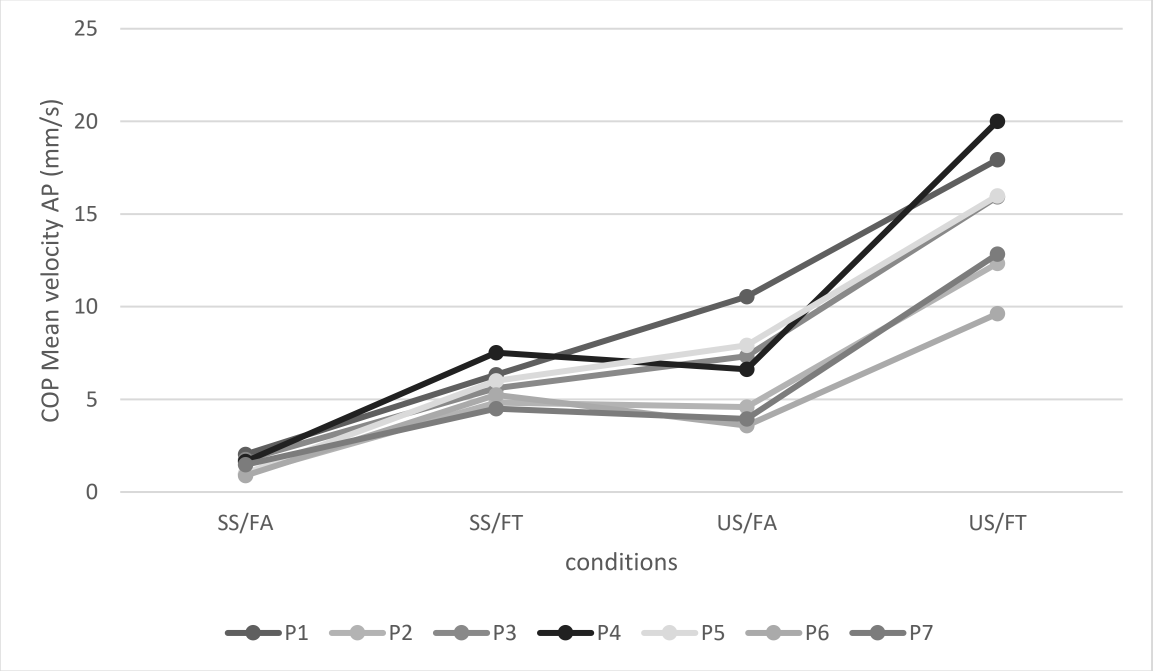

Fig. 5 Mean values of the mean velocity of the anteroposterior (AP) center of pressure (COP) displacements for each individual subject, for example person one defined by 'P1', during the trials: 'stable surface/feet apart (SS/FA)', 'stable surface/feet together (SS/FT)', 'unstable surface/feet apart (US/FA)' and 'unstable surface/feet together (US/FT)'.

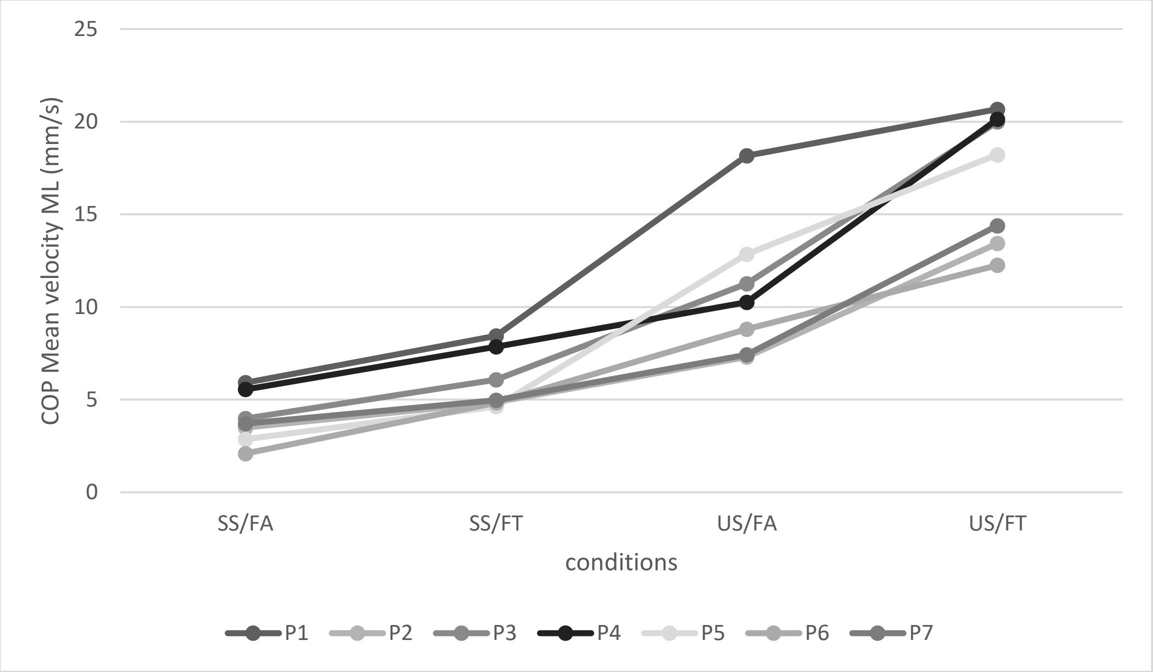

Fig. 6 Mean values of the mean velocity mediolateral (ML) center of pressure (COP) displacements for each individual subject, for example person one defined by ‘P1’, during the trials: ‘stable surface/feet apart (SS/FA)’, ‘stable surface/feet together (SS/FT)’, ‘unstable surface/feet apart (US/FA)’ and ‘unstable surface/feet together (US/FT)’.

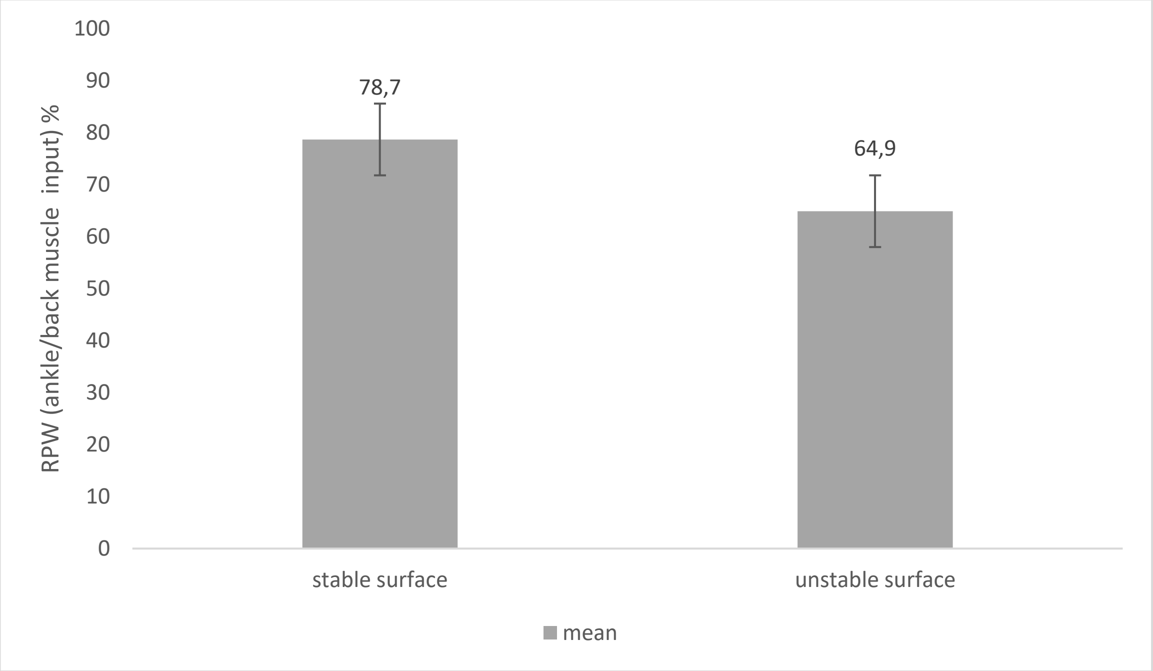

Fig. 7 Mean values of the relative proprioceptive weighting (RPW) during standing on stable surface and on unstable surface/foam. Higher RPW values mean more reliance on proprioceptive inputs of ankle muscles. Error bars present standard deviations of the mean values.

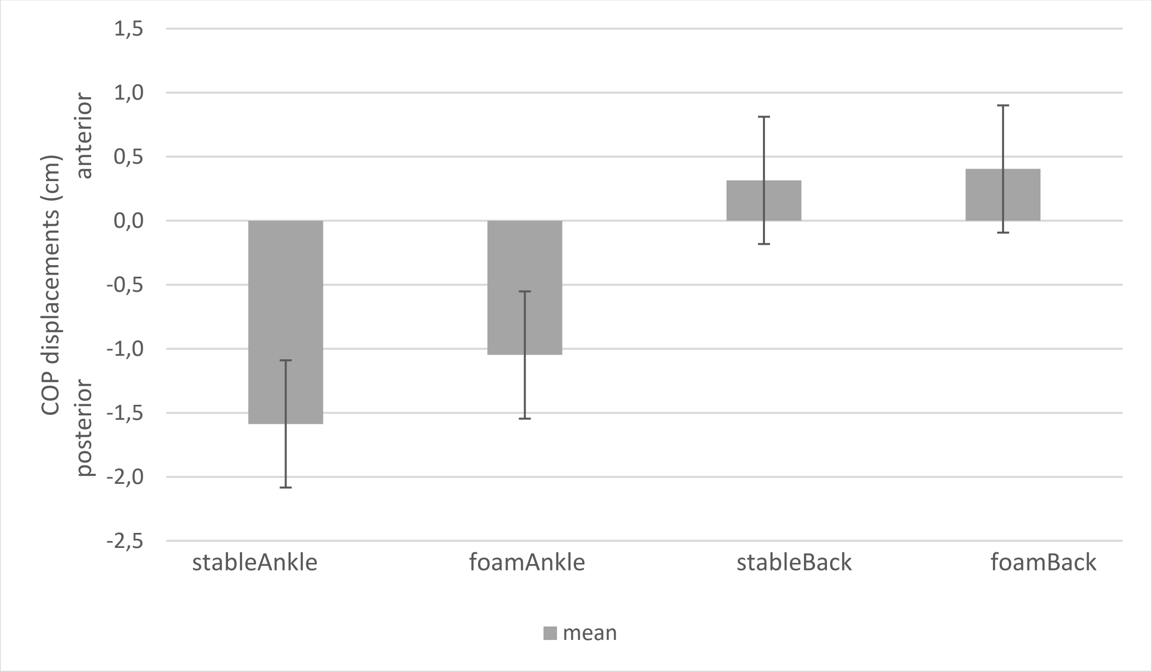

Fig. 8 Mean values of center of pressure (COP) displacements during muscle vibration of the ankles or the back when standing on a stable surface or an unstable surface/foam. Values > 0 represent anterior COP displacements, values < 0 represent posterior COP displacements. Error bars present standard deviations of the mean values.

5. Discussion

5.1 Main findings

We investigated postural stability in pregnant women through manipulating the support surface, stance width and proprioceptive input. First of all, an increased sway magnitude (COP SD) in both AP and ML directions was observed when subjects stood on a foam compared to a firm support surface. However, no significant effect on sway magnitude was found when standing with feet apart compared to feet together. Furthermore, when the task became more complex, i.e. standing on a foam with feet together, a significant increase of sway variability (mean velocity COP) was observed. These significant effects were found in both AP and ML directions. Finally, standing on foam caused no significant difference in relative proprioceptive weighting compared to standing on a stable support surface.

The increase in sway magnitude while participants stood on a foam was also found in a study which investigated elderly persons and persons with low back pain written by Brugmagne et al. (2004). A possible explanation could be that subjects rely mostly on ankle muscle proprioception while standing on a stable support surface. This statement could be confirmed by the results of muscle vibration, which represented dominance use of ankle proprioception (RPW ratio = 78.7). Consequently, standing on foam causes a reduced reliability of ankle muscle proprioception due to an imbalance between body movements, forward to backward, and ankle torques (Kiers, Brumagne, van Dieën, van der Wees, & Vanhees, 2012; Ivanenko, Talis & Kazennikov, 1999). However, this hypothesis needs to be interpreted with caution because of a different methodology, pregnant women were not part of the study population. Moreover, this increased sway magnitude was observed in both AP and ML directions. An increase in AP direction could be explained by abdominal weight gain which causes the maternal center of gravity to move anteriorly as the pregnancy progresses (Butler, Cozon, Druzin, & Rose, 2006; Cakmak et al., 2015; Ribas et al., 2007). Therefore, gestational weight gain could be a contributing factor leading to this postural instability (Roberts, Talbot, Kay, Price & Hill, 2018). However, in our current study postural instability could not be explained by this factor, as the within-group standard deviation of gestational weight gain was not remarkably large. For the sway magnitude in ML direction, several studies found a significant increase, though no clear explanations were mentioned (Nagai et al., 2009; Jang et al., 2008). A possible hypothesis could be a higher laxity of the ligaments, resulting in a more unstable position of the ankle joints which leads to an increased sway magnitude in both AP and ML directions (Marnach et al., 2003; Ritchie, 2003).

There was no significant effect of stance width on sway magnitude, despite the fact that pregnant women may increase their stance width as a result of increased postural instability (Jang et al., 2008). Consequently, it would be logical that a significant increase of sway magnitude would occur, when subjects needed to stand with feet together. This hypothesis is in agreement with findings from previous research (Mientjes & Frank 1999; Mok, Brauer, & Hodges, 2004; Henry, Hitt, Jones, & Bunn, 2006; Popa, Bonifazi, Volpe, Rossi, & Mazzocchio, 2006).

Moreover, our second outcome measure sway variability was significantly increased in trials with conditions using a foam. When non-pregnant subjects showed a lower sway variability, this reflected a good capacity of switching between different postural strategies; i.e. ankle and hip strategy, to maintain postural stability (Borzucka, Kręcisz, Rektor, & Kuczyński, 2020). However, as a result of the enlarging uterus, abdominal muscles are weaker causing lumbar muscles to overcompensate. We assume that pregnant women cannot rely on their back muscles due to this overactivity (Sneag et al., 2007). Additionally, this overactivity can be seen in persons with non-specific low back pain (Lima, Ferreira, Reis, Paes, & Meziat-Filho, 2018; Moreira, Elias, Gomide, Vieira, & Amaral, 2017). In this final group an increased body sway and a higher sway velocity were detected (Ruhe, Fejer, & Walker, 2010; Brumagne et al., 2004). We hypothesize that pregnant women, same as persons with non-specific low back pain, cannot switch their proprioceptive reliability from the input of ankle muscles to lumbar muscles when standing on a foam, which results in a higher sway variability. This is in contradiction to the results of Claeys et al. (2011) which found a decreased sway variability as a result of decreased proprioceptive input of the back muscles. Moreover, when a postural condition becomes more complex, subjects will have to increase the use of lumbar muscle proprioception because of proprioceptive weighting (Claeys et al., 2011). Mok et al. (2004) concluded that there was a decrease in sway velocity, though in two systematic reviews the majority (88%) of the included articles found an increased sway velocity in persons with non-specific low back pain compared with healthy individuals (Ruhe et al., 2010; Mazaheri, Coenen, Parnianpour, Kiers, & van Dieën, 2013). Therefore, we assume that a similar mechanism applies between pregnant women and persons with LBP, where the use of lumbar proprioception is compromised, by pregnancy or low back pain, and results in a negative effect on postural stability.

Despite the fact that there was a significant effect of stance width for outcome measure sway variability, no explanation could be given why no effect could be found for sway magnitude. We assume that if the sample size was larger, we would have observed a significant effect of stance width on both outcome measurements.

Furthermore, another factor which led to an increase in sway variability according to our results is stance width, more specifically during trials with feet together. In general, postural stability in pregnant women will decrease when visual input is suppressed (Butler et al., 2006; Oliveira, Vieira, Macedo, Simpson, & Nadal, 2009), whereby their base of support will expand to preserve balance (Jang et al., 2008; Ritchie et al., 2003). Consequently, when participants need to stand with feet together, other muscles would probably be provoked, such as those around the hip instead of the plantar flexors. Therefore, participants need to shift from ankle to hip strategy to stabilise their quiet standing posture (Mok et al., 2004; Oliveira et al., 2009). We assume that the unstable support surface along with the change in strategy provide an increase in the difficulty of the task, which in turn leads to an increase in sway variability.

During the muscle vibration trials we expected a significant higher RPW ratio in trials with an unstable support surface. However, our results showed no significant effect of 'support surface' on RPW (p=0.178). In both conditions, stable and unstable surface, an RPW ratio above 50% was visible, which indicates a higher reliability on the ankle proprioception (Brumagne et al., 2008; Ivanenko et al., 1999).

Moreover, pregnant women cannot adjust their proprioceptive weighting and rely more on ankle proprioception to maintain balance, irrespective of a stable or unstable surface (Pinto et al., 2020). In healthy subjects, COP displacements are larger when vibrating the lumbar muscles standing on a foam compared with ankle vibration, where COP displacements decreased (Brumagne et al., 2004; Ivanenko et al., 1999; Kiers et al., 2012). In contrast to our results, where COP displacements are higher when vibrating the ankle muscles compared to vibrating the lumbar muscles in subjects standing on an unstable support surface. Furthermore, these results are consistent with several studies on people with low back pain (Brumagne et al., 2004; Brumagne et al., 2008; Claeys et al., 2011; Kiers et al., 2014; Pinto et al., 2020). Therefore, we can conclude that our group of subjects was probably too small to find a significant difference.

5.2 Strengths and limitations

Some limitations of our study need to be discussed. First, the study population consisted of eight pregnant women, which is a small sample size. Although we expected more subjects, due to the current situation with Covid-19 many pregnant women did not want to take any risks by participating in our study. A non-participation bias can be present, as only pregnant women participated voluntarily by replying to our advertisements. However, the included multiparous women had a mean age of 31 years with a standard deviation of 2 years. Therefore, our group is homogeneous which leads to a high generalizability in this age range for multiparous women. Second limitation, pre-pregnancy weight and current body weight existed of a large variation between the women, through which some results need to be considered. For example when applying lumbar muscle vibration, variations in COP displacements could be attributed to a difference of lumbar skin thickness between the subjects.

Another limitation, there was only one test moment, better would be to measure subjects at different moments in time during pregnancy and after childbirth. Unfortunately due to Covid-19, a study procedure with four test moments during the different trimester and postpartum period was not feasible. Therefore, postural instability could not be compared between the trimesters of pregnancy and whether the results shown by this study were persistent after childbirth. Despite this limitation, the test moment was optimally standardized; an accurate determination of foot position by using a transparent sheet and the same pair of goggles with taped glasses. However, a randomisation of vibration trials was applied to prevent a learning effect. In a fixed sequence, muscles could adapt to the vibration leading to bias in outcome measures (Caudron, Langlois, Nougier, & Guerraz, 2010).

Nevertheless, during our test moment the factor fatigue was not taken into account. Fatigue could occur during the last trials which might lead to postural instability. In other words, when a subject experiences fatigue in a particular body part, the CNS needs to shift its reliability to proprioceptive inputs from other body parts (Brumagne et al., 2004).

To assess postural stability we used a force plate (AMTI, Watertown USA), one of the most commonly used measure equipment in several balance studies (Claeys et al., 2011; Jang et al., 2008; Oliveira et al., 2009; Opala-berdzik et al., 2014). However, force plates are costly and unmanageable, which makes them impractical in clinical settings (Seimetz, Tan, Katayama, & Lockhart, 2013). A strength of our study is the use of two local muscle vibrators (Maxon Motors, Switzerland, 60 Hz, 0.5 mm), to research the proprioceptive role in postural stability. These vibrators are widely used in proprioceptive studies (Brumagne et al., 2008; Claeys et al., 2011; Kiers et al., 2011; Pinto et al., 2020; Pollind & Soangra, 2020). Kiers et al. (2014) confirmed that displacements during vibration and proprioceptive weighting have the greatest reliability of all responses from parameters after applying muscle vibration.

Furthermore, due to a small sample we were limited in our statistical analysis, through which we could not investigate the interaction effects. It would have been statistically more correct to apply a non-parametric test in our data analysis because of this small sample size. However, multiple measurements were performed within the same group, therefore we assumed a 2x2 repeated measure analysis of variance (ANOVA) suited better to determine our results.

Finally, our initial study protocol implemented a control group of non-pregnant women. Therefore, we included SD outcomes, which offers a good reliability in discriminating between subjects and controls. Additionally, the effectiveness of the postural control system is reflected by velocity, the lower the velocity, the greater the postural control (Paillard & Noé, 2015). Furthermore, velocity can be considered as the measurement with the greatest reliability between trials (Duarte & De Freitas, 2010). Consequently, a qualitative measurement of postural control was applied leading to another strength of our research.

5.3 Future research and clinical implications

To confirm our findings, future studies with larger sample sizes and control groups of non-pregnant women are necessary. In this manner, it will be possible to make a statement about which sensory system will get disturbed during pregnancy and reduce postural stability. Additionally, it may be interesting in future research to include only the most effective trials, for example only the ones which showed significant effects in multiple studies. Therefore, the duration of test moments could be reduced which makes it possible to implement more test moments, more specifically during the different trimesters and after childbirth. Moreover, it can be investigated in which trimester postural instability, due to changes in sensory systems, increases the most. Hence, it will be possible to determine when to start intervention programs to restore postural balance and reduce risk of falling.

Moreover, future research will have to integrate a follow-up period to investigate if changes in sensory systems persist after childbirth or their eventual next pregnancy. Another factor which needs to be taken into account during this follow-up period is joint laxity. Cakmak et al. (2015) observed a significantly increased joint laxity during pregnancy, contributing to reduced postural stability. This joint laxity persists until twelve weeks after childbirth, though it remains unclear whether joint laxity might still be present in following pregnancies, leading to postural instability (Schauberger, Rooney, Goldsmith, Shenton, Silva, & Schaper, 1996; Smith et al., 2008). However, Calguneri et al. (1982) did report that during subsequent pregnancies joint laxity will remain unchanged. This could be an interesting interaction factor to research in further studies.

Furthermore, since the purpose of this study was to look primarily at the influence of the proprioceptive system on postural balance, we only extracted the data with vision occluded. Therefore, it would be better if future studies compared both conditions; eyes open and eyes closed. Consequently, a comparison between the different conditions of proprioception, vision and stance width can be made, investigating their influence on postural control.

Moreover, we instructed the participants to keep their arms hanging relaxed along the body. However, we observed that participants used their arms to restore balance during the vibration trials. We assume that arm swing can be used as a strategy to maintain postural stability. Hence, it could be interesting to measure the magnitude of this arm swing in future studies.

Moreover, dynamic tasks could be included in future study protocols because of a positive correlation between pregnant-fallers and a disturbed dynamic postural stability (McCrory, Chambers, Daftary, & Redfern, 2010).

According to our results, there were significant effects observed of stance width and support surface on postural stability. Therefore, it could be interesting to implement more low-cost and feasible measurement equipment in clinical practices, in order that physiotherapists can compose a specific exercise programme targething the deficits causing postural instability. A systematic review by Clark et al. (2018) evaluated the reliability and concurrent validity of a Wii Balance Board (WBB) as an alternative measurement tool in assessing standing balance. They concluded that the use of an WBB is similarly valid and reliable as force plates which makes it useful to implicate in clinical settings. Another recent study of Pollind et al. (2020) also investigated an alternative measurement tool, namely a “Mini Logger”. This wearable inertial measurement unit is easy, reliable and accurate to use for postural sway analysis in clinical environments.

6. Conclusion

The proprioceptive system has an important role on postural stability in pregnant women. Moreover, the results showed significant effects of support surface on both outcome measures, namely sway variability and sway magnitude. More specifically, standing on a foam caused more postural instability in both AP and ML direction.

Consequently, when the task became more difficult, like standing on a foam with feet together, an increase in sway variability was observed.

However, no significant effect of the support surface on RPW was visible. Due to a small sample size no conclusion can be drawn if pregnant women could shift from ankle to hip strategy to maintain balance. It could be possible that pregnant women rely more on proprioceptive input of ankle muscles during difficult tasks and cannot adjust their proprioceptive weighting. Nevertheless, these assumptions need to be investigated in future research with all limitations taken into account.

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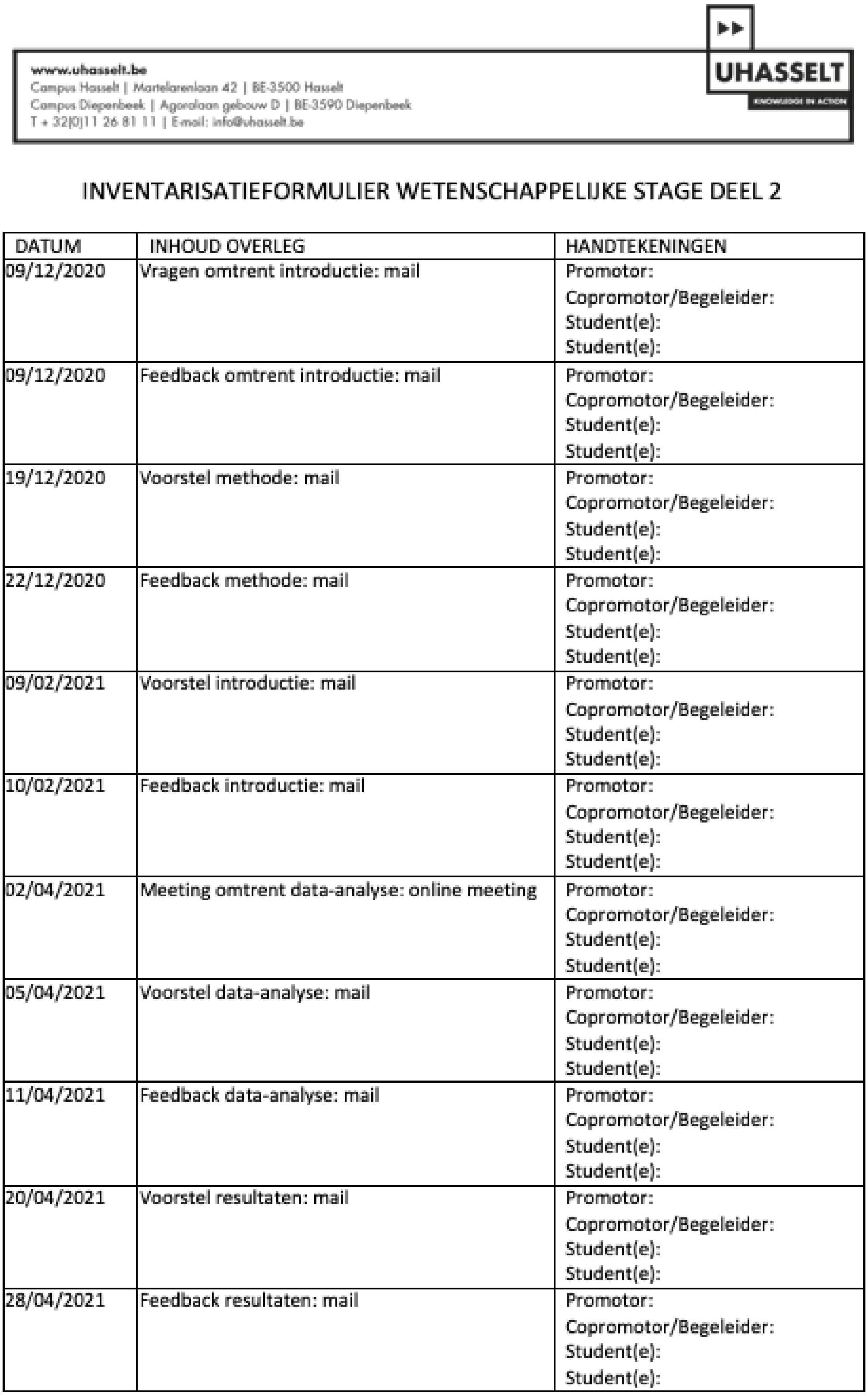
8. Appendix



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INVENTARISATIEFORMULIER WETENSCHAPPELIJKE STAGE DEEL 2

DATUM	INHOUD OVERLEG	HANDTEKENINGEN
09/12/2020	Vragen omtrent introductie: mail	Promotor: Copromotor/Begeleider: Student(e): Student(e):
09/12/2020	Feedback omtrent introductie: mail	Promotor: Copromotor/Begeleider: Student(e): Student(e):
19/12/2020	Voorstel methode: mail	Promotor: Copromotor/Begeleider: Student(e): Student(e):
22/12/2020	Feedback methode: mail	Promotor: Copromotor/Begeleider: Student(e): Student(e):
09/02/2021	Voorstel introductie: mail	Promotor: Copromotor/Begeleider: Student(e): Student(e):
10/02/2021	Feedback introductie: mail	Promotor: Copromotor/Begeleider: Student(e): Student(e):
02/04/2021	Meeting omtrent data-analyse: online meeting	Promotor: Copromotor/Begeleider: Student(e): Student(e):
05/04/2021	Voorstel data-analyse: mail	Promotor: Copromotor/Begeleider: Student(e): Student(e):
11/04/2021	Feedback data-analyse: mail	Promotor: Copromotor/Begeleider: Student(e): Student(e):
20/04/2021	Voorstel resultaten: mail	Promotor: Copromotor/Begeleider: Student(e): Student(e):
28/04/2021	Feedback resultaten: mail	Promotor: Copromotor/Begeleider: Student(e): Student(e):

Lotte JANSSENS

Inkomend - School Gisteren om 18:36

Antw: Discussie

Details

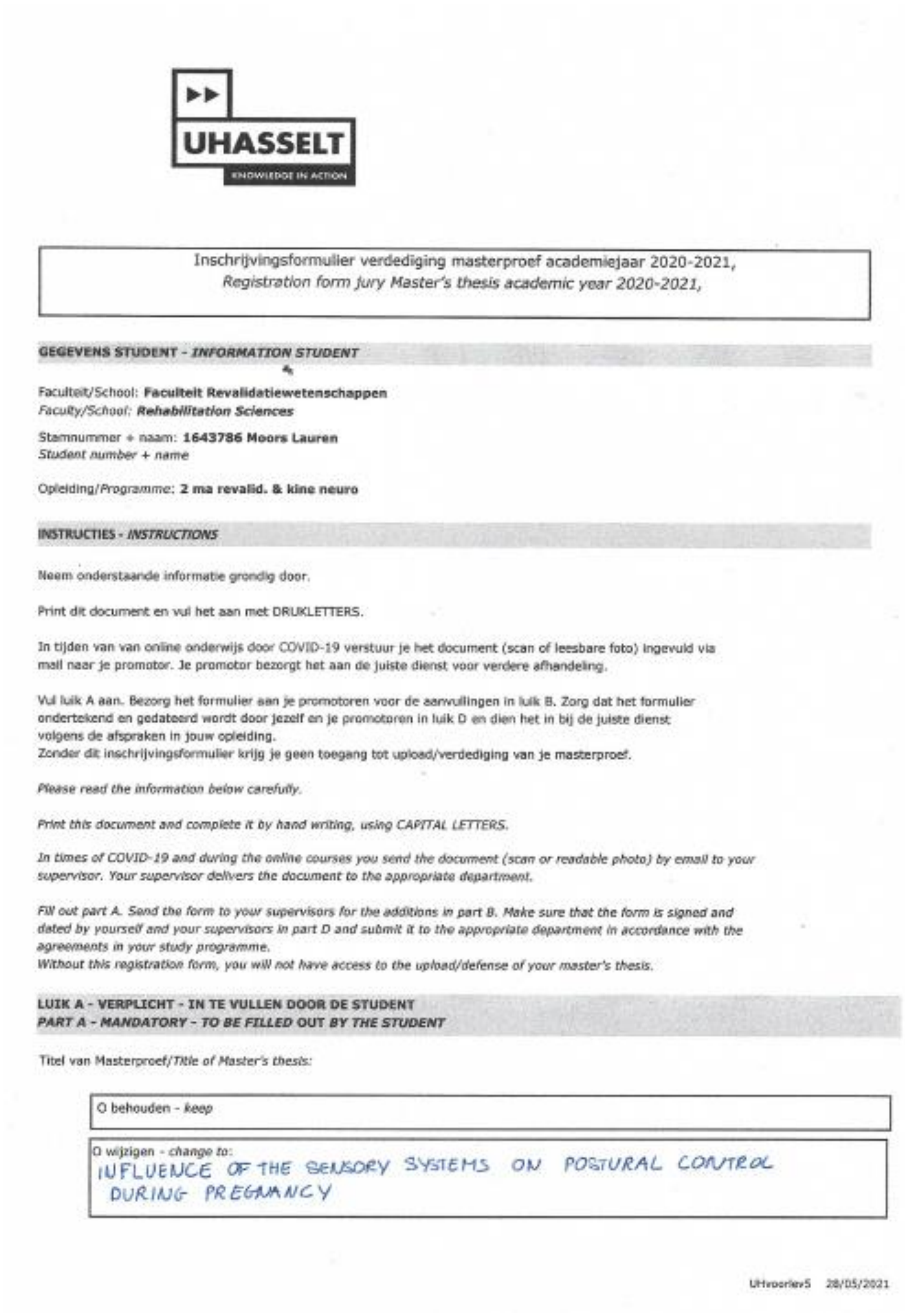
Aan: Lauren Moors, Kopie: Lotte Vranken

Beste Lotte en Lauren,

Hierbij de formele goedkeuring van jullie ingestuurde documenten: inventarisatieformulier en inschrijvingsformulier verdediging (akkoord met wijziging titel en niet-bindend advies om te verdedigen).

Mvg,

Lotte Janssens



Inschrijvingsformulier verdediging masterproef academiejaar 2020-2021,
Registration form jury Master's thesis academic year 2020-2021,

GEGEVENS STUDENT - ***INFORMATION STUDENT***

Faculteit/School: **Faculteit Revalidatiewetenschappen**
Faculty/School: ***Rehabilitation Sciences***

Stamnummer + naam: **1643786 Moors Lauren**
Student number + name

Opleiding/*Programme*: **2 ma revalid. & kine neuro**

INSTRUCTIES - ***INSTRUCTIONS***

Neem onderstaande informatie grondig door.

Print dit document en vul het aan met DRUKLETTERS.

In tijden van van online onderwijs door COVID-19 verstuur je het document (scan of leesbare foto) ingevuld via mail naar je promotor. Je promotor bezorgt het aan de juiste dienst voor verdere afhandeling.

Vul luik A aan. Bezorg het formulier aan je promotoren voor de aanvullingen in luik B. Zorg dat het formulier ondertekend en gedateerd wordt door jezelf en je promotoren in luik D en dien het in bij de juiste dienst volgens de afspraken in jouw opleiding.
Zonder dit inschrijvingsformulier krijg je geen toegang tot upload/verdediging van je masterproef.

Please read the information below carefully.

Print this document and complete it by hand writing, using CAPITAL LETTERS.

In times of COVID-19 and during the online courses you send the document (scan or readable photo) by email to your supervisor. Your supervisor delivers the document to the appropriate department.

Fill out part A. Send the form to your supervisors for the additions in part B. Make sure that the form is signed and dated by yourself and your supervisors in part D and submit it to the appropriate department in accordance with the agreements in your study programme.
Without this registration form, you will not have access to the upload/defense of your master's thesis.

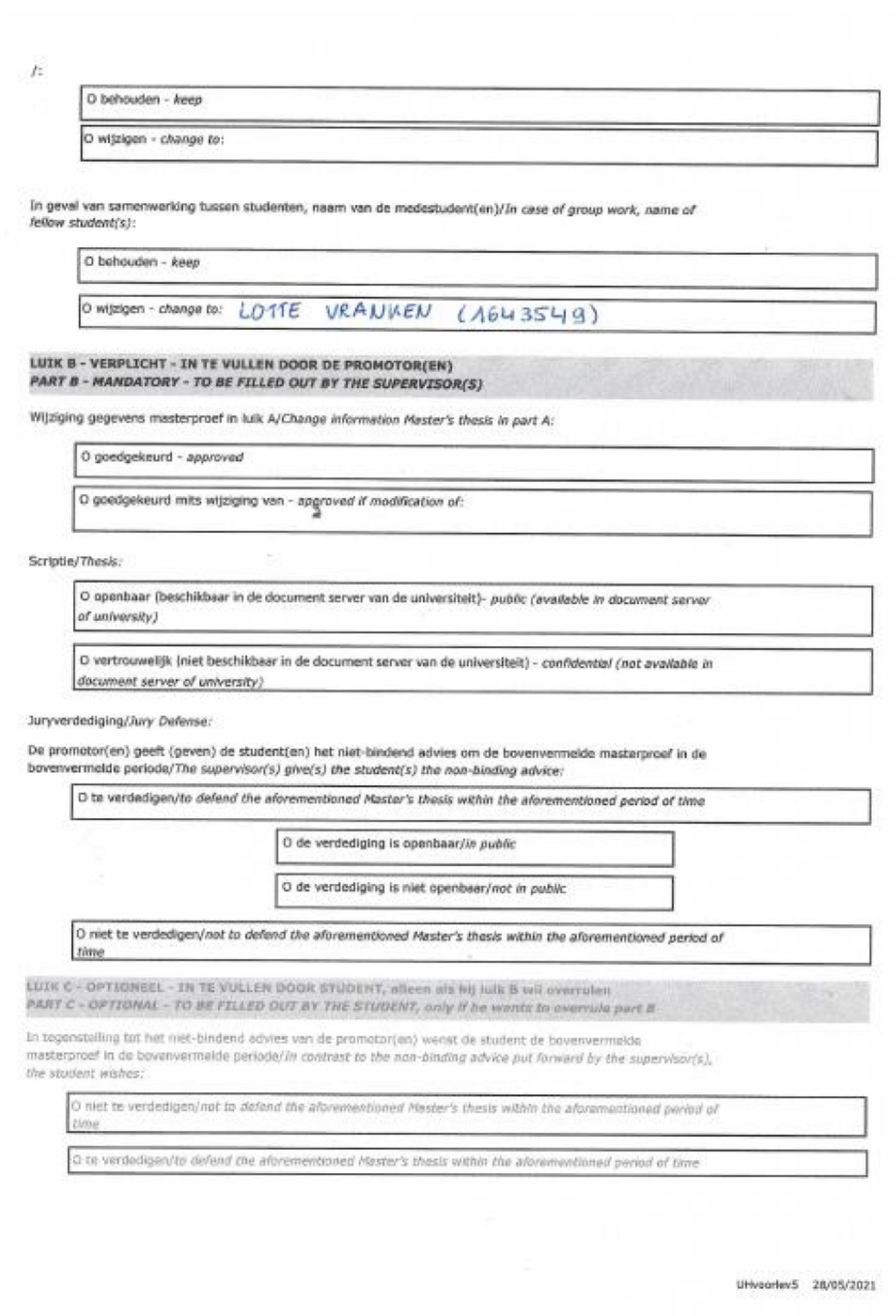
LUIK A - VERPLICHT - IN TE VULLEN DOOR DE STUDENT
PART A - MANDATORY - TO BE FILLED OUT BY THE STUDENT

Titel van Masterproef/*Title of Master's thesis:*

○ behouden - *keep*

○ wijzigen - *change to:*
INFLUENCE OF THE SENSORY SYSTEMS ON POSTURAL CONTROL
DURING PREGNANCY

UHvoorlev5 28/05/2021



/:

○ behouden - *keep*

○ wijzigen - *change to:*

In geval van samenwerking tussen studenten, naam van de medestudent(en)/*In case of group work, name of fellow student(s):*

○ behouden - *keep*

○ wijzigen - *change to:* LOTTE VRANKEN (1643549)

LUIK B - VERPLICHT - IN TE VULLEN DOOR DE PROMOTOR(EN)
PART B - MANDATORY - TO BE FILLED OUT BY THE SUPERVISOR(S)

Wijziging gegevens masterproef in luik A/*Change information Master's thesis in part A:*

○ goedgekeurd - *approved*

○ goedgekeurd mits wijziging van - *approved if modification of:*

Scriptie/*Thesis:*

○ openbaar (beschikbaar in de document server van de universiteit)- *public (available in document server of university)*

○ vertrouwelijk (niet beschikbaar in de document server van de universiteit) - *confidential (not available in document server of university)*

Juryverdediging/*Jury Defense:*

De promotor(en) geeft (geven) de student(en) het niet-bindend advies om de bovenvermelde masterproef in de bovenvermelde periode/*The supervisor(s) give(s) the student(s) the non-binding advice:*

○ te verdedigen/*to defend the aforementioned Master's thesis within the aforementioned period of time*

○ de verdediging is openbaar/*in public*

○ de verdediging is niet openbaar/*not in public*

○ niet te verdedigen/*not to defend the aforementioned Master's thesis within the aforementioned period of time*

LUIK C - OPTIONEEL - IN TE VULLEN DOOR STUDENT, alleen als hij luik B wil overrulen
PART C - OPTIONAL - TO BE FILLED OUT BY THE STUDENT, only if he wants to overrule part B

In tegenstelling tot het niet-bindend advies van de promotor(en) wenst de student de bovenvermelde masterproef in de bovenvermelde periode/*in contrast to the non-binding advice put forward by the supervisor(s), the student wishes:*

○ niet te verdedigen/*not to defend the aforementioned Master's thesis within the aforementioned period of time*

○ te verdedigen/*to defend the aforementioned Master's thesis within the aforementioned period of time*

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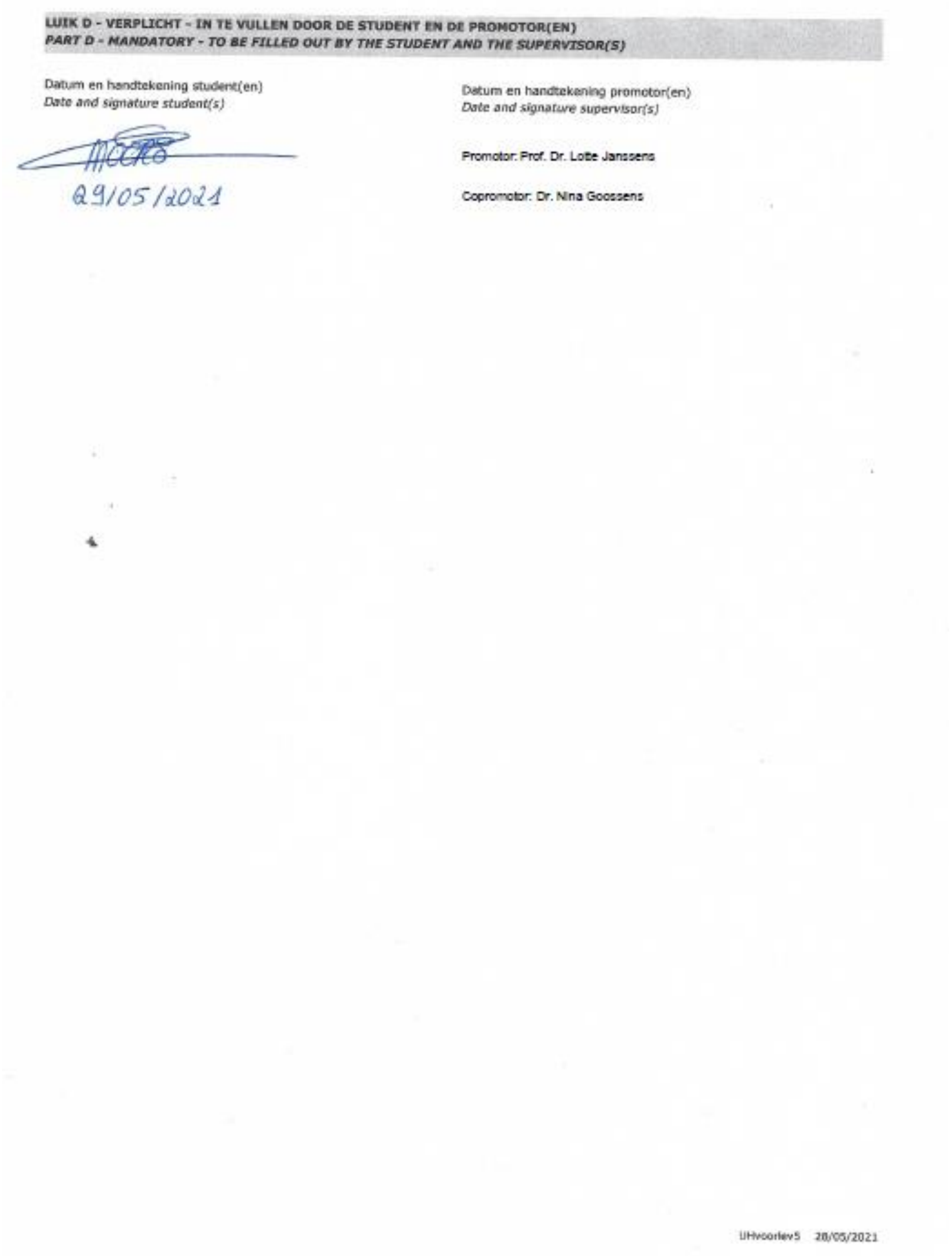

LUIK D - VERPLICHT - IN TE VULLEN DOOR DE STUDENT EN DE PROMOTOR(EN)
PART D - MANDATORY - TO BE FILLED OUT BY THE STUDENT AND THE SUPERVISOR(S)

Datum en handtekening student(en)
Date and signature student(s)

29/05/2021

Datum en handtekening promotor(en)
Date and signature supervisor(s)

Promotor: Prof. Dr. Lotte Janssens

Copromotor: Dr. Nina Goossens

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