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**Postural balance in low back pain patients
assessed by
the one leg stand test
and by
centre of pressure excursions
on a portable force platform**

PhD dissertation

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Preface

This thesis was made between January 2007 and March 2011 as part of my employment with the Department of Occupational Therapy and Physiotherapy and in collaboration with the Department of Rheumatology and the Danish Ramazzini Center, Department of Occupational Medicine; all are part of the Aarhus University Hospital, Denmark.

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Table of content

1.	ENGLISH SUMMARY	1
2.	DANISH SUMMARY	3
3.	INTRODUCTION.....	5
3.1.	POSTURAL BALANCE	6
3.2.	RELIABILITY	8
3.2.1.	<i>Reliability of OLST: Points to be considered.....</i>	<i>9</i>
3.2.2.	<i>Reliability of CoP excursions assessed on a portable force platform: Points to be considered.....</i>	<i>9</i>
3.3.	VALIDITY	10
3.3.1.	<i>Validity of CoP excursions assessed on a portable force platform: Points to be considered.....</i>	<i>11</i>
3.4.	SUMMARY	12
4.	AIM OF THE THESIS.....	13
5.	METHODS	14
5.1.	LITERATURE ON LOW BACK PAIN AND POSTURAL BALANCE	14
5.1.1.	<i>Low back pain and OLST</i>	<i>14</i>
5.1.2.	<i>Low back pain and CoP excursions assessed on a force platform</i>	<i>14</i>
5.2.	SUBJECTS	17
5.3.	CLASSIFICATION	19
5.4.	OUTCOME MEASURES	20
5.4.1.	<i>One Leg Stand Test.....</i>	<i>20</i>
5.4.2.	<i>CoP excursion assessed on a portable force platform.....</i>	<i>21</i>
5.4.3.	<i>Pain.....</i>	<i>22</i>
5.4.4.	<i>Fear of pain</i>	<i>22</i>
5.4.5.	<i>Function.....</i>	<i>23</i>
5.4.6.	<i>Muscular condition.....</i>	<i>23</i>
5.5.	ETHICS	23
5.6.	SUMMARY OF METHODS IN THE STUDIES	23
5.6.1.	<i>Study I.....</i>	<i>23</i>
5.6.2.	<i>Study II.....</i>	<i>24</i>
5.6.3.	<i>Study III</i>	<i>25</i>
6.	RESULTS	26
6.1.	STUDY I.....	28
6.2.	STUDY II	29
6.3.	STUDY III	30
7.	DISCUSSION	32
7.1.	KEY FINDINGS	32
7.2.	CONSIDERATION OF POSSIBLE MECHANISM AND EXPLANATIONS	32
7.3.	COMPARISON WITH RELEVANT FINDINGS FROM OTHER STUDIES	34
7.4.	LIMITATIONS	35
7.5.	GENERALIZABILITY	37
8.	CONCLUSION	38
9.	PERSPECTIVES AND FUTURE RESEARCH	39
10.	REFERENCES.....	40
11.	STATEMENTS	47
12.	APPENDICES	48

Abbreviation list

APmdispl:	Anterior-posterior mean displacement
APmVel:	Anterior-posterior mean velocity
CoM:	Centre of mass
CoP:	Centre of pressure
DOMS:	Delayed onset muscle soreness
EC:	Eyes closed
EO:	Eyes open
FABQ:	Fear Avoidance Beliefs Questionnaire
ICC:	Intra-class correlation coefficient
LBP:	Low back pain
LOA:	Limits of agreement
MLmdispl:	Medial-lateral mean displacement
MLmVel:	Medial-lateral mean velocity
mVel:	Mean velocity
NRS:	Numerical rating scale
OLST:	One Leg Stand Test
RMQ:	Roland Morris Disability Questionnaire
RR:	Romberg Ratio
RRarea:	Romberg Ratio using C90area
RRvel:	Romberg Ratio using mean velocity
SEM:	Standard Error of the Measurement

1. ENGLISH SUMMARY

The present PhD project arose out of discussions concerning the significance of balance to low back pain (LBP) patients, e.g. on the possibilities for objectively measuring balance in everyday clinical practice.

Balance requires a well-functioning interplay between cognitive, motor, and sensory systems. The cognitive systems take care of co-ordination and overall interaction, the motor systems primarily comprise bone and muscle, and the sensory system encompasses the vestibular, somatosensory, and visual senses. The concept of balance is often described in terms of postural control which refers to the act of maintaining, achieving or restoring a state of balance during any posture or activity. Postural control is divided into postural orientation and postural balance, with postural balance designating all “static” positions, standing or sitting. This dissertation addresses postural balance while standing.

Studies have shown impaired postural balance in LBP patients. Such studies have been conducted in laboratory settings, and there is a lack of outcome measures that can objectively measure balance and changes in balance in clinical practice. Before recommendations of outcome measures for evaluating balance can be made, their reliability and validity must be elucidated.

Literature states that the change in postural balance in LBP patients is primarily caused by impact to the somatosensory system. The claim is supported by the fact that the difference between healthy controls and LBP patients is more pronounced when tested with eyes closed (EC) compared to eyes open (EO); under EC conditions balance is maintained on the basis of somatosensory and vestibular information.

The present dissertation encompasses three studies and addresses two different tools used to assess postural balance with EO and EC: The one-leg stand test and centre of pressure (CoP) excursions assessed on a portable force platform. The project also considered the Romberg Ratio, which quantifies the dependency on vision.

The participants of this PhD project comprise two populations:

- 1) LBP patients active on the labour market and who have been recommended an exercise regime upon consultation with a rheumatologist. A total of 124 LBP patients were examined upon inclusion, of which 96 were examined again at a 3-month follow-up session.
- 2) Healthy controls recruited at a shopping mall, including 10 women and 10 men for each decade between the ages of 20 to 59, i.e. a total of 80 controls.

The first study described the reliability of the OLST and CoP excursions and the Romberg Ratio. The OLST was found unsuitable for assessing postural balance as it involved a ceiling effect in EO tests and unacceptable reliability of EC tests. As a result, the OLST was not examined any further. Reliability of the length, velocity, and mean displacement of CoP excursions was acceptable, while the reliability of the Romberg Ratio was close to acceptable. The second study tested the criterion validity of CoP excursions up against pain, fear of pain, function, and muscular conditioning. The study revealed no concurrent validity, neither when comparing balance parameters with other parameters at baseline nor when considering changes over the course of three months. Predictive validity of CoP excursions was tested in relation to changes in pain and function. No correlation was found, i.e. no evidence of

predictive validity. Balance data was used as both non-normalised and normalised data where CoP excursions were adjusted for age, height, weight, and sex. The validity of the Romberg Ratio was also tested, and no relation with other parameters was found.

The third study compared data from 188 LBP patients aged 20-59 with 80 healthy controls to describe “known groups validity”. No difference between the two groups was discovered with non-normalised or normalised data. No difference between the groups could be identified by means of the Romberg Ratio. Furthermore, different CoP parameters were compared. We found high correlations between various velocity parameters; however, no relevant correlation between velocity and displacement was identified.

In conclusion, our studies showed that the test battery employed caused no adverse effects, and a pain relief after testing. We can, therefore, conclude that the test battery is acceptable for LBP patients who have been recommended an exercise regime.

We found a ceiling effect in the EO OLST and poor reliability of the EC OLST. As regards CoP excursions on a portable force platform we found good reliability for trace length, velocity, and displacement. Validity of CoP excursions was correlated with other significant parameters, and no good concurrent validity was found. Predictive validity of CoP excursions was described in relation to pain and function, and no correlation was found. CoP data from LBP patients was compared to data from healthy controls and we found no difference between the groups, meaning that we cannot document “known groups validity”. Validity and reliability of the Romberg Ratio was examined, and no evidence supporting the validity of this parameter was determined. Literature on the subject presents no uniform picture, and most studies are based on small populations. In summary, measuring postural balance cannot be recommended in LBP patients.

Our studies of CoP data show a strong correlation between various velocity parameters. We recommend that future studies employ mean velocity and anterior-posterior displacement.

Future studies should examine methods for assessing postural control in LBP patients.

Another contribution to evidence concerning the significance of balance might involve an intervention study describing the effect of balance training in relation to pain and function in LBP patients. Finally, studies should determine whether the portable force platform is as accurate as the more expensive and more time-consuming laboratory equipment.

2. DANISH SUMMARY

Dette ph.d.-projekt udsprang af diskussioner om balancens betydning for patienter med lænderygbesvær herunder muligheden for objektiv måling af balance i daglig klinisk praksis. Balance forudsætter et velfungerende samspil mellem kognitive, motoriske og sensoriske systemer. De kognitive systemer er ansvarlige for koordination og overordnet samspil, de motoriske systemer består hovedsageligt af knogler og muskler, og de sensoriske systemer består af de vestibulære, de somatosensoriske samt de visuelle sanser. Overordnet balance betegnes ofte postural kontrol, der omfatter evnen til at opnå, bevare eller genoprette en tilstand af balance ved alle stillinger eller aktiviteter. Postural kontrol inddeles i postural orientering og postural balance, hvor postural balance omfatter stillestående (eller siddende) stillinger. Denne afhandling omhandler undersøgelser af postural balance i stående stilling. Undersøgelser har vist nedsat postural balance hos patienter med lænderygbesvær. Disse undersøgelser er udført i bevægelseslaboratorier, og der mangler redskaber, der objektivt kan måle balance og ændringer i balance i daglig klinisk praksis. Før redskaber til vurdering af balance kan anbefales, skal reliabilitet og validitet belyses.

Litteraturen beskriver, at den ændrede posturale balance hos lænderygpatienter primært skyldes påvirkninger i det somatosensoriske system. Dette understøttes af, at forskellen mellem raske kontrolpersoner og lænderygpatienter er mere udtalt, når der testes med lukkede i forhold til åbne øjne, idet balancen derved opretholdes på baggrund af somatosensoriske og vestibulære informationer.

Denne afhandling indeholder tre studier, og omhandler to forskellige redskaber der anvendes til vurdering af postural balance med åbne og lukkede øjne: etbensstand samt centre of pressure (CoP) udsving vurderet på en transportabel balanceplatform. Endvidere undersøgte Romberg Ratio, der belyser den visuelle sans bidrag til postural balance.

Deltagerne i denne ph.d. afhandling består af to populationer:

1) Lænderygpatienter med tilknytning til arbejdsmarkedet, der efter undersøgelse af en reumatologisk speciallæge er anbefalet at træne. I alt 124 lænderygpatienter blev undersøgt ved inklusion, og 96 patienter blev undersøgt igen ved 3-måneders opfølgning.

2) Raske kontrolpersoner rekrutteret i et indkøbscenter med 10 kvinder og 10 mænd i hvert 10-års interval 20-59 år, dvs. i alt 80 kontrolpersoner.

I det første studie belyses reliabiliteten af etbensstand og CoP udsving samt Romberg Ratio. Etbensstand blev vurderet uegnet til vurdering af postural balance, idet der var lofteffekt ved test med åbne øjne, og reliabiliteten var uacceptabel i test med lukkede øjne. Etbensstand blev derfor ikke yderligere undersøgt. Reliabiliteten af længden, hastigheden og den gennemsnitlige forskydning af CoP udsving var acceptabel, reliabiliteten af Romberg Ratio var tæt på acceptabel.

I det andet studie blev criterion validity af CoP udsvingene testet imod smerte, frygt for smerte, funktionsniveau, muskeludholdenhed samt kondition. Undersøgelsen viste ingen concurrent validity, hverken når balanceparametre blev sammenholdt med de øvrige parametre ved baseline, eller ved ændringer i løbet af 3 måneder. Predictive validity af CoP udsvingene blev testet i forhold til ændringer i smerte og funktion. Der blev ikke fundet en sammenhæng, og derfor ingen evidens for predictive validity. Balancedata blev benyttet både

som ikke-normaliserede og som normaliserede data, hvor CoP udsvingene blev justeret for alder, højde, vægt og køn. Validiteten af Romberg Ratio blev også testet, og der blev ikke fundet en sammenhæng med de andre parametre.

I det tredje studie blev data fra 118 lænderygpatienter i aldersgruppen 20-59 år sammenholdt med 80 raske forsøgspersoner for at beskrive 'kendte grupperes validitet'. Der blev ikke fundet forskel mellem de to grupper, hverken med ikke-normaliserede eller normaliserede data. Der kunne ikke påvises forskel mellem grupperne i Romberg Ratio. Endvidere blev forskellige CoP parametre sammenholdt. Vi fandt stor overensstemmelse mellem forskellige hastighedsparametre, hvorimod der ikke kunne påvises en relevant sammenhæng mellem hastighed og forskydning.

Sammenfattende viser vores undersøgelser, at det anvendte testbatteri ikke gav bivirkninger, og at en del patienter angav smertelindring efter test. Det kan derfor konkluderes, at testbatteriet er acceptabelt for lænderygpatienterne, der efter speciallægeundersøgelse blev anbefalet træning.

Vi fandt lofteffekt i etbensstand med åbne øjne og dårlig reliabilitet i etbensstand med lukkede øjne. Med hensyn til CoP udsving på en transportabel balanceplatform fandt vi god reliabilitet af udsvingenes længde, hastigheden og forskydning. Validiteten af CoP udsvingene blev sammenholdt med andre væsentlige parametre, og der blev ikke fundet god concurrent validity. Predictive validity af CoP udsvingene blev belyst i forhold til smerte og funktion, og der var ingen korrelation. CoP data fra lænderygpatienterne blev sammenlignet med data fra raske kontrolpersoner, og vi fandt ingen forskel på grupperne og kan således ikke dokumentere 'kendte grupperes validitet'. Validitet og reliabilitet for Romberg Ratio blev undersøgt og der blev ikke fundet evidens for validiteten af denne parameter. Litteraturen på området er ikke entydig, og de fleste studier er baseret på små populationer. Vi kan konkludere, at måling af postural balance ikke umiddelbart kan anbefales hos lænderygpatienter.

Vores undersøgelser af CoP data viser, at forskellige hastighedsparametre er stærkt korrelerede. Vi kan anbefale, at gennemsnitlig hastighed samt anterior-posterior forskydning anvendes i fremtidige studier.

Fremtidige studier bør undersøge metoder til vurdering af postural kontrol hos lænderygpatienter. Et andet bidrag til evidensen om balancens betydning kunne være et interventionsstudie, der belyser effekten af balancetræning i forhold til smerte og funktion hos lænderygpatienter. Endelig bør det undersøges, om den transportable balanceplatform er lige så nøjagtig som dyrere og mere tidkrævende laboratorieudstyr.

3. INTRODUCTION

The present project arose out of discussions on balance assessment in low back pain (LBP) patients and implementation of outcome measures in daily clinical practice. There was no consensus on clinically applicable tests and their usability for medical doctors and physiotherapists within the field of postural balance and LBP. This study focuses on test characteristics of measures of postural balance.

The concept of balance is often described in terms of postural control which refers to the act of maintaining, achieving or restoring a state of balance during any posture or activity.¹ In order to maintain the wide range of activities that constitute normal daily life, a well-functioning postural control is necessary.¹⁻³ Postural control is often investigated in connection to falls and fall prevention⁴ but maintaining postural control is much more than just the absence of falling.^{3,5,6} Postural control is divided into postural orientation and postural balance, with postural balance designating all “static” positions, standing or sitting.³ The assessment of postural balance is useful for a wide spectrum of diagnoses, e.g. disorders in the lower extremities, neurological diseases, LBP, or risk of falling.^{3,5,7,8} It is proposed that measure of postural balance is an assessment of whole body performance, and thereby important in a wide range of diseases both as diagnostic tool and as an evaluation of outcome.^{9,10}

LBP is a common and costly musculoskeletal complaint; it is one of the most prevalent and costly health problems.¹¹ A precise diagnosis is often impossible with LBP, and about 85% of cases are estimated to be non-specific.¹² LBP is a broad diagnosis and includes heterogeneous groups of low-back disorders with differing etiologies and prognoses.^{13,14} The lack of sufficient knowledge concerning primary causative mechanisms for LBP emphasizes the need for secondary prevention of negative consequences of LBP.^{15,16}

The one year prevalence of LBP in Denmark is estimated to be 35%, and studies show that the reported proportion of patients who still experienced pain 12 months after the initial LBP incident may be as high as 62%.^{13,17} Studies have failed to show an increase in incidence or prevalence over time even though multiple intervention forms have been tested.¹⁸

It is estimated that 35% of the Danish population experience LBP during one year.¹⁸ Of these 37% seek treatment, primarily at general practitioners, chiropractors, and physiotherapists, and 6-10% are referred to the secondary sector.¹⁸ From 2001 to 2005 13,694 patients had contact to Aarhus University Hospital with LBP as their primary diagnosis (2,738 a year).¹⁹ Studies of postural balance in LBP patients indicate poorer postural balance compared to healthy controls,^{2,20} and impaired somatosensory information (i.e. information from proprioceptive, cutaneous, and joint receptors) has been suggested as a possible mechanism causing this decrease.²¹ However, there is limited knowledge on whether poorer postural balance is a consequence or a predictor of LBP, or both, but some evidence suggests that people with poor postural balance have an increased risk of LBP.²²

Valid outcome measures in postural balance could play a role in both diagnosis and prognosis of LBP as it might offer a way of sub-grouping LBP patients in order to tailor treatment better. A small, unsystematic pilot project revealed differences in how clinicians tested balance in LBP patients. In LBP core stability has played a role during the last years; although challenged, the underlying theory of imbalance is still discussed.²³ If imbalance is to be taken

into consideration, one possible way of testing the importance is by assessment of postural balance.

Different ways of testing postural balance were considered. Test during movement is most comparable to daily life, but as the variability seemed too high in daily clinical practice such tests were excluded, meaning that only tests on postural stability were considered.

The One Leg Stand Test (OLST), where the patient is observed and timed, offers an easy, quick and low-cost test for evaluating postural balance.²⁴⁻²⁶ Furthermore, results from the small pilot enquiry aimed at different rheumatologists and physiotherapists found that the OLST was used in daily clinical practice.

Another instrument for evaluating postural balance is the force platform which is among the tools frequently used in clinical research.^{21,27,28} Postural balance on the force platform is measured through centre of pressure (CoP) excursions. CoP excursions is objective and has advantages in terms of minimal variability in test performances and in being sensitive to small changes.⁷ The CoP excursions reflect postural sway and are traditionally used as an indicator of postural control; a larger sway magnitude is related to poorer postural control.³ As portable force platforms are becoming cheaper and time-efficient protocols have been developed, their usage seems relevant in daily practice, but clinical use of these techniques was not thoroughly investigated.

A number of authors have reported that LBP patients are more dependent on vision compared to a healthy population.^{2,9,10,27,29} For both LBP patients and healthy controls, postural balance is poorer in eyes closed (EC) tests compared to eyes open (EO) tests, but in EC tests the difference between LBP patients and healthy controls becomes more distinct.^{29,30} The visual contribution to postural balance is one of the things to be considered.

Hence, the present thesis focuses on assessing postural balance in clinically applicable ways and explores the following three main questions:

- What is the reliability of two clinically applicable tests of postural balance in LBP patients – the OLST and test of CoP excursions as assessed on a portable force platform?

And, if they are reliable:

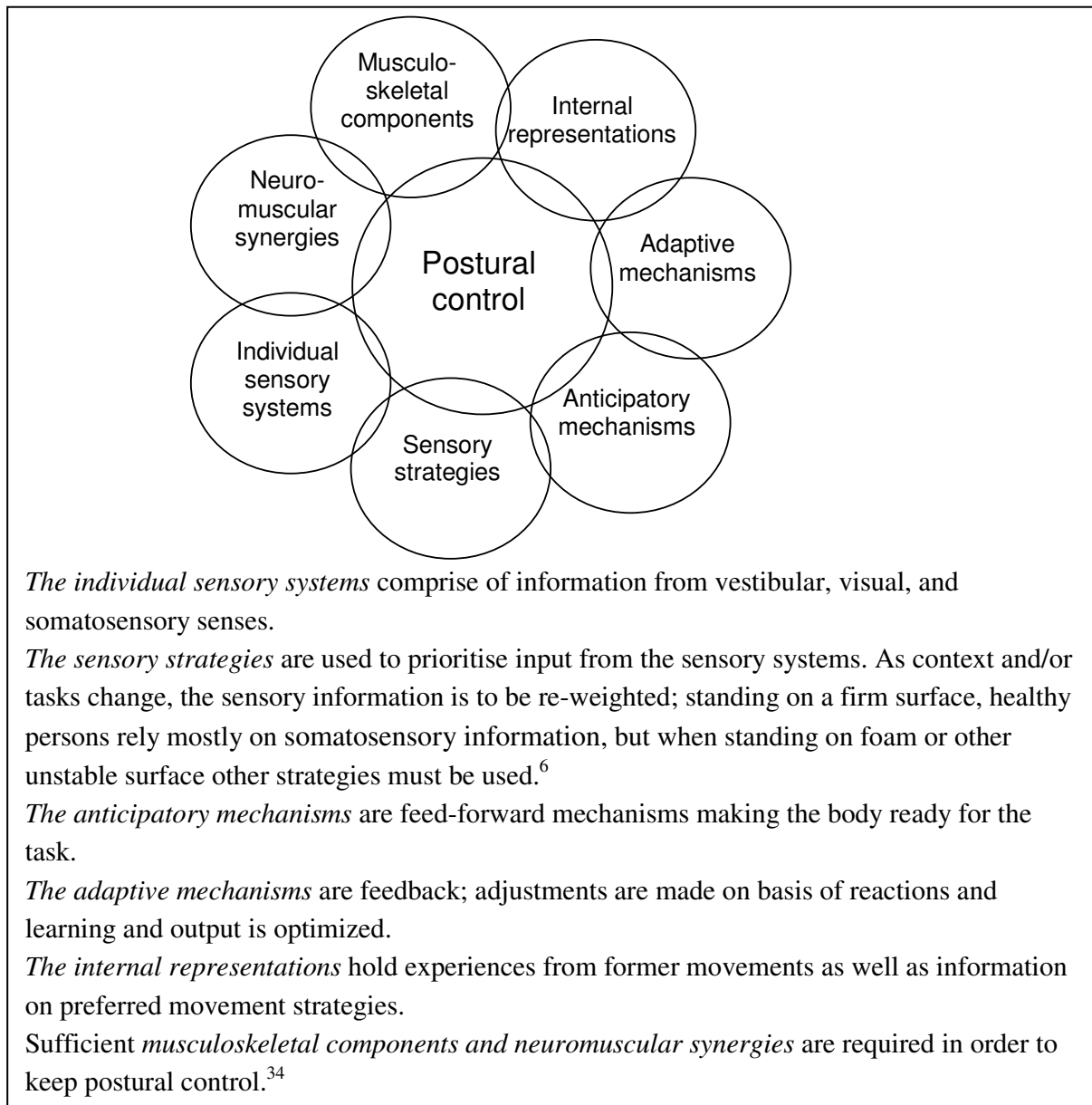
- What is the criterion validity of these tests when correlated to pain, fear of pain, function, and muscular conditioning?
- Is it possible to distinguish between LBP patients and healthy controls sampled from a population comparable to LBP patients using the known groups method?

3.1. Postural balance

Postural control is achieved by a complex of dynamic interactions of vestibular, visual, and somatosensory information analyzed in a complex regulatory feedback system resulting in constantly changing outputs.^{2,10,31} Information from the sensory systems is interpreted in the central nervous system, appropriate responses are formulated, and the motor system is activated to perform movements.⁵ A systems approach is helpful when describing postural control, because it focuses on the interrelations between the different components of the whole system. In the model described by Shumway-Cook and Woollacott, postural control is divided into postural orientation and postural stability (or postural balance).³ Postural orientation is the ability to make effective and efficient movements of the body through space

and of the limbs over a stable body. Postural balance is the ability to control the centre of mass (CoM) in relation to the base of support. All tasks and all movement emerge from interaction between postural orientation and postural balance. The orientation and stability requirements depend on task and context. Shumway-Cook and Woollacott describes afferent and efferent subsystems that, in complex interactions, define postural control; see Figure 1.³ When one or more of these subsystems are impaired, postural control is hampered.³

Figure 1. Subsystems in postural control. From Shumway-Cook and Woollacott (with permission from the authors)³



No single assessment tool can evaluate all aspects of postural control, including all subsystems.⁶ Clinicians must have the subsystem to be tested in mind and give emphasis to that system. It could be argued that both postural orientation and postural balance should be tested. However, although some clinical tests like the Berg Balance Scale and the Tinetti Balance Assessment Tool examine both postural orientation and postural balance, these tests are only relevant for patients with very poor postural control.^{32,33} In patients with impaired

postural control, but no risk of falling, these tests are not sensitive enough to show small deficits. A ceiling effect will appear, i.e. patients score close to maximum and a retest will not be able to display improvement.

If impaired somatosensory information is the leading mechanism behind impaired postural balance in LBP patients as suggested,²¹ the main systems to be tested are individual sensory systems and sensory strategies. Musculoskeletal components and neuromuscular synergies can both be impaired due to LBP³⁴ and must be taken into consideration as well; a decrease in postural balance could be expected if the postural tone is affected due to LBP (i.e. positive neurologic findings).

Postural balance is more pronounced than postural orientation both when standing on one leg and standing on a force platform. The standing position is assumed to be familiar, emphasis in these positions will be on musculoskeletal components, neuromuscular synergies, and individual sensory systems. When testing with EO and EC sensory strategies are to be changed.

3.2. Reliability

In classical theory on test characteristics, reliability rests on the assumption that every test score consists of a true score and an error.³⁵ Hence, reliability refers to reproducibility or repeatability and assesses the error in an outcome measure.³⁶ Reliability is a very important test property and it is a prerequisite for validity; a valid outcome measure needs to be reliable – but a reliable outcome measure is not necessary valid.

The different types of reliability of interest within the field of physical performance outcome measures as stated in figure 2. The issue of reliability in connection with OLST and the force platform is addressed in the following sections 3.2.1 and 3.2.2.

Figure 2. Reliability types relevant to physical performance outcome measures

A clear and precise test protocol help minimise variability in test performances.¹⁴ Vague or indistinct test protocols are a great source of variability in physical performance measures.

Inter- and intra rater reliability are important in tests where the tester plays a role in the assessment.³⁵

Intra-subject variability (i.e. biological variation) should be given attention; things like fatigue, comfort, and comprehension of the task must be taken into consideration.³⁵ Intra- or inter session reliability can vary if the biological variation is large and time between tests are to be contemplated.

Learning effect is to be given consideration if the task is different from activities done in daily life. It may be solved by preliminary trials in order to familiarise patients with the task.³⁵ Attention should be given to the number of preliminary trials and time allowed to familiarise.

Calibration and reproducibility of technical equipment (e.g. watch, force platform) is a precondition for results comparable to others.

3.2.1. Reliability of OLST: Points to be considered

A clear and precise test protocol: A review of the literature revealed no consensus on the test protocol.^{24,37-46} Most studies of the OLST are performed among the elderly. A few studies used qualitative testing,⁴⁷ but only timed tests were included. In the published studies timing varied between 30s^{38,48} 60s^{49,50} and unlimited time.^{42,43,45} Only a few of the studies on OLST are reporting test trials in order to familiarise patients with the test, and the number of test trials vary from one to unlimited.^{37,38,46,49} The OLST is performed with one⁴⁶ to five^{24,50} trials. Some use the mean score^{38,41} while others use the best⁴⁸ of the test trials. There is no consensus on the position of arms^{38,41,42} and of the lifted leg.^{37,41-44} Most of the studies performed OLST without shoes, but one study found no difference in timing whether tests were performed barefoot or with shoes.³⁷ In the literature OLST is mostly done with EO and EC, a few studies recommend fixing the gaze on a particular point when testing with EO. Based on the literature OLST test protocol can vary with at least eight parameters. After several minor pilot tests, a test protocol for the present study was decided upon.²⁵ The procedure is described in the methods section.

Inter- and intra rater reliability: As the physiotherapist starts and stops time and decides whether and when it proves impossible for the patient to maintain the position, variation between testers as well as variation between the same tester is of interest and needs to be assessed.²⁵ Intra rater reliability is usually better than inter rater reliability. If intra rater reliability is unacceptable there is no reason for testing inter rater reliability.

Intra subject variability: Variability in balance between patients has been reported,²² and a decrease in balance parameters after prolonged standing is reported, indicating that fatigue could bias results.⁵¹ It is therefore important that patients have a rest before testing. One of the pilot studies revealed differences between tests performed in a gym with other patients compared to a quiet room, and lower results were seen in the gym. Comfort and comprehension of the task could be important and emphasis was placed on making patients feel at ease.

Learning effect: Although standing on one leg is assumed to be a common task, performance might improve after some test trials. One study find no difference between test trials in the elderly³⁷ but our pilot study presented differences between four tests, especially with EC. It is therefore important with a few test trials.

3.2.2. Reliability of CoP excursions assessed on a portable force platform: Points to be considered

A clear and precise test protocol: CoP excursions is a commonly used method for assessing postural balance^{3,9,10,21,27,31,51-57} but there is no consensus on the test procedure. A review of the literature yielded three studies concerning reliability of CoP measures in LBP patients;^{9,54,58} a subsequent published review found the same studies.²⁸ Sampling duration varied from 10 s⁵⁹ to 120 s⁵⁸ with a recommendation of 60s.⁶⁰ No consensus was found on which sampling and cut-off frequencies to use. After consulting experts, signals were sampled at 200Hz and filtered with a low-pass filter at 7.8Hz cut-off frequency. The foot position was standardised.⁶⁰ Arms hanging down as in most other studies, and patients were barefoot.²⁸ As

it is suggested that the somatosensory system plays a role in the relationship between postural balance and LBP, tests were carried out with EO and EC.

Inter- and intra rater reliability: The force platform is objective,³ and therefore the issue is not considered in the present thesis.

Intra subject variability (i.e. biological variation) is to be given attention; things like fatigue, comfort, and comprehension of the task must be taken into consideration.³⁵ Intra- or inter session reliability can vary if the biological variation is large, and time elapsed between tests should be considered.

Learning effect is to be given consideration if the task is different from activities done in daily life. It may be solved by preliminary trials in order to familiarise patients with the task.³⁵

Attention to the number of preliminary trials and time to familiarise is to be given. As standing can be considered part of daily routine and even standing with EC can be assumed to be a well-known procedure, patients are instructed to stand and had just 5-20s to get accustomed to the position.

Calibration and reproducibility of technical equipment are important to consider. The force platform were calibrated prior to test, and the four channels were checked before every test in order to ensure zero setting.

3.3. Validity

Validity is the extend to which an assessment tool measures what it is intended to measure.³⁵

Validation of an outcome measure is an ongoing process, as an outcome measure never can be said to be completely valid or invalid. It is always a question of to which extent validity is achieved. Different types of validity concepts match physical performance outcome measures such as test of balance. The most relevant concepts are listed in text box 2.^{14,35,61-63} There is a slight variation in the definitions employed by various authors; Finch et al.⁶¹ and Carter et al.³⁵ refer to rehabilitation research. They are used as primary sources. Level of validity is only provided by Terwee et al. and Innes and Straker.^{62,63}

The different types of validity of interest within the field of physical performance outcome measures as stated in figure 3. In section 3.3.1 these different types of validity will be considered in relation to the force platform. Poor reliability of OLST was found in study I and no further study of the validity of OLST was conducted as reliability is a prerequisite for validity.

Figure 3. Validity types relevant to physical performance outcome measures

Face validity concerns whether an assessment tool appears to measure what is intended to be measured.⁶¹ The judgment is made on the “face” of the test, so this can be judged by health professionals and patients alike. Face validity is essential as most physical performance outcome measures rely on tasks conducted by both patient and tester.

Content validity is the degree to which a measure is a complete representation of the area of interest.^{35,61}

Criterion validity is the extent to which a test provides results consistent with other outcome measures. Criterion validity is divided into concurrent and predictive validity.^{63,35} Predictive validity examines the ability to predict a subsequent event, while concurrent validity compares results to other related outcome measures at the same time.

Construct validity is the degree to which test results are consistent with theories on the construct to be tested.^{61,35} Construct validity is the broadest type of validity and there is no single method to determine this type of validity, but rather an accumulation of evidence. A definition of the content of the construct to be tested is a prerequisite for construct validity. Content and criterion-related validity may be used to support construct validity, but the known groups method is also an important factor.

Known Groups Method involves the ability of the test results to discriminate between groups which are known to be different (e.g., patients and healthy controls).^{31,65}

3.3.1. Validity of CoP excursions assessed on a portable force platform: Points to be considered

A review of the literature revealed studies concerning the known groups method, and sparse information on other aspects of validity of CoP excursion in LBP patients.

Face validity: Postural balance in LBP patients is often described via parameters of body sway measured as CoP excursions.^{20,29} Furthermore, the force platform test was explained to doctors and physiotherapist, none of whom questioned whether aspects of postural balance is tested. During the project more than 150 patients were tested and had the procedure explained to them; none of them questioned the purpose of the test. Face validity is considered good among both medical staff and patients.

Content validity: The complete area of interest must be postural control. CoP excursion data examines postural balance while standing still, meaning that it covers only a part of postural control. Whether CoP excursions is representative to postural control in LBP patients is not known, as no relevant studies were found on this issue.

Criterion validity: There is no gold standard in neither postural control³ or LBP.⁶⁴ If postural balance is to be useful as an outcome measure in treatment of LBP, CoP parameters should be compared to pain, fear of pain, and physical function as they are the outcomes of interest in LBP treatment.⁶⁴ Concurrent validity have been studied on two Finnish populations giving inconclusive evidence.^{22,65,66} One study on predictive validity gave revealed no predictive value of the CoP parameters.⁶⁵

Construct validity: As was mentioned above, the construct to be evaluated is postural balance, defined as the ability to control the CoM in relation to the base of support.³ When assessing

CoP, postural balance while standing still is of interest. It is traditionally said that sway magnitude is related to poorer postural balance.³ A study on clinical balance assessment tools states that higher mean velocity (mVel) is associated with multiple conditions with known balance decrease.⁷ Even though studies on CoP excursions in LBP patients have been conducted during the last two decades no clear proof on construct validity was found in the literature. The theoretical influence of LBP on postural balance is complex⁶⁷ and affected by co-existing factors: Pain, fear of pain, positive neurologic findings, adoption of an alternate movement strategy, and low muscular conditioning.^{20,21,29,67,68}

Known Groups Method: Unlike other aspects of validity, the known groups method is treated in a number of studies. A search of literature yielded only one study comparing CoP parameters in LBP patients and healthy controls in which the recommended number of 50 participants in each group was exceeded.^{62,69} Four other studies had more than 20 participants in each group,^{2,21,70,71} and other studies employed fewer than 20 participants.^{10,27,29,51,56,58,72-74} A recently published review confirmed these findings.²⁰ In contrast to the review, we found the evidence inconclusive; especially when taking into consideration sample size and sample population for healthy controls.

3.4. Summary

LBP is one of the most common types of musculoskeletal pain. LBP patients have poorer postural control compared to healthy controls, and assessment and training of postural balance are discussed. Impaired somatosensory information has been suggested as a possible mechanism causing the decrease in postural balance. There is limited knowledge on whether poorer postural balance is a consequence, a predictor, or both in LBP, but some evidence suggests that people with poor postural balance have an increased risk of LBP.

Postural balance is achieved through a complex of dynamic interactions of vestibular, visual, and somatosensory information analyzed in a complex regulatory feedback system resulting in constantly changing outputs. The postural control model with seven subsystems described by Shumway-Cook and Woollacott is used to describe postural balance. In both LBP patients and healthy controls postural balance decreases with EC compared to EO conditions, but some authors find that the difference is more distinct in LBP patients. In LBP patients the impaired postural balance could be caused by influence on the individual sensory systems, the sensory strategies, the musculoskeletal components, and the neuromuscular synergies. Clinically applicable measures of postural balance are relevant, but reliability of OLS and CoP excursions on a portable force platform in a clinical setting has not been demonstrated. If reliable, the validity is of concern as studies on validity of measures of postural balance in LBP patients are few in number.

4. AIM OF THE THESIS

The present thesis consists of three papers. The first paper investigated reliability of the OLST and CoP excursions on the portable force platform. Paper II and III investigated different aspects of validity of CoP excursions on the portable force platform.

The objectives were:

- To determine reliability of clinically applicable measures of postural balance (Paper I)
- To determine criterion validity of clinically applicable measures of postural balance (Paper II)
- To determine the difference in postural balance between LBP patients and healthy controls sampled from a population comparable to LBP patients (Paper III)

5. METHODS

5.1. Literature on low back pain and postural balance

A literature search was conducted in order to find studies on postural balance and LBP.

5.1.1. Low back pain and OLST

A regular search in the "Medline" database using the terms ("*one-leg stance test*" OR "*one-leg standing*" OR "*one-legged standing*" OR "*one-leg stance*" OR "*one-legged stance*" OR "*one-legged balance*" OR "*one-leg balance*" OR "*unipedal stance*" OR "*single limb stance*") AND (*lumbago* OR *lbp* OR "*low back pain*" OR "*Low Back Pain*"[Mesh]) combined with a manual search identified seven studies on the subject published from 2005 to 2011. The inclusion criteria were: Papers in English or Nordic languages that were concerned with postural balance measured as one leg stand of subjects with LBP. Of the seven papers identified, six were excluded for various different reasons, see table 1. This left one study, which is discussed in section 7 of this thesis.

Table 1. OLST studies excluded

Reasons for excluding	Number of studies excluded
Study used CoP data as outcome	4 ⁷⁵⁻⁷⁸
Study used quality of movement as outcome	2 ^{47,79}

5.1.2. Low back pain and CoP excursions assessed on a force platform

A regular search in the "Medline" database using the terms ("force platform" OR "force-platform" OR "forceplate" OR "force plate" OR "balance platform" OR "balance plate" OR "pressure plate") AND ("Postural Balance"[Mesh] OR "centre of pressure" OR "centre of weight" OR "centre of gravity" OR sway OR steadiness OR "postural instability" OR balance OR posture) AND (*lumbago* OR *lbp* OR "*low back pain*" OR "*Low Back Pain*"[Mesh]) combined with a manual search identified 44 studies on the subject published from 1991 to 2011. The inclusion criteria were: Papers in English or Nordic languages that were concerned with COP measures taken on a force platform of subjects with LBP. Studies including less than 20 LBP patients were excluded as they seem too small to offer convincing evidence on this matter.⁶² The search strategy was subsequently applied to different electronic databases: EMBASE, Web of Science, and the Cochrane library without further results. Of the 44 papers identified, 33 were excluded for various reasons, see table 2. This left 11 studies (table 3), which are all discussed in section 7 of this thesis.

Table 2. Force platform studies excluded

Reasons for excluding	Number of studies excluded
Study concerned sitting balance only	5 ⁸⁰⁻⁸⁴
Study was a review of literature	1 ²⁰
Study tested different aids, e.g. braces, or suggested new tests	7 ⁸⁵⁻⁹¹
Study concerned patients with parkinsonism	1 ⁹²
Study concerned LBP patients after disc surgery	1 ³⁰
Study did not have patients stand still on two feet	3 ^{31,75,93}
Study included less than 20 LBP patients	14 ^{10,27,29,51,56,58,73,74,78,94-99}

Table 3. Papers on postural balance in LBP patients using force platform parameters

Author	Year of publication	Sample size (LBP patients)	Gender	Age in years	Purpose of study (relevant for this thesis)
Nies and Sinnot ²	1991	20 LBP patients 25 healthy		20-60	Known groups difference
Luoto ⁶⁹	1996	99 LBP patients 61 healthy	53 female 46 male	20-60	Known groups difference with a 6 months follow-up
Takala et al. ⁶⁶	1997	167 with LBP symptoms 275 non-symptomatic	134 female 298 male	working population	To describe the association between CoP parameters and LBP
Takala ²²	2000	123 with LBP symptoms 307 non-symptomatic	128 female 309 male	working population younger than 54	To determine the predictive value of tests in a working population
Kuukkanen ⁶⁵	2000	90 LBP patients	41 female 49 male	mean age 40	Describe sway in LBP patients and to evaluate associations between sway and pain intensity
Brumagne ⁷²	2004	20 LBP patients 20 healthy	20 young 20 elderly		Describe sway in LBP patients under different situations
Mok ²¹	2004	24 LBP patients 24 healthy		mean age 37	Known groups difference
Brumagne ¹⁰⁰	2008	56 LBP patients 33 healthy		mean age 23	Known groups difference
Brumagne ⁷⁰	2008	21 LBP patients 24 healthy	27 female 18 male	mean age 23	Known groups difference
Salavati et al. ⁷¹	2009	22 LBP patients 22 healthy	18 female 26 male	mean age 26	Known groups difference
Clayes ¹⁰¹	2011	106 with LBP symptoms 50 healthy	114 female 42 male	mean age 19	Known groups difference

5.2. Subjects

The population in the thesis comprised two sub-groups: (1) A cohort of LBP patients referred for expert evaluation to the rheumatologic outpatient clinics at Aarhus University Hospital or Aarhus Rheumatology Clinic ¹⁰² and (2) A group of healthy controls recruited from a shopping mall.

Inclusion criteria for patients were: Persistent LBP, active on the labour market, concerns about ability to maintain current job, willingness to accept a workplace visit, ages 17-63, and Danish-speaking. Exclusion criteria were: Planned low back surgery, pregnancy, and serious other illnesses.

Inclusion criteria for healthy controls were: Ages 20-59. Exclusion criteria were: Acute or persistent LBP, low back surgery, pain of more than 2 on a numerical rating scale (NRS), pregnancy, conditions with known influence on postural balance, e.g. whiplash or vestibular diseases, and serious other illnesses. Healthy controls were consecutively included until 10 men and 10 women within each decade from ages 20-59 had been included.

The number of LBP patients seen in the two outpatient clinics from November 2006 to April 2009 was 1461. Of these 413 met the inclusion criteria (see table 4); 53 patients refused to participate. The 360 remaining patients were randomised into three groups. The randomisation was to different intervention groups. The intervention is not a matter of this thesis as the subject is on measurement properties and not intervention. Thereby all LBP patients from the cohort are potential participants in the three studies.

Table 4. LBP patients not meeting inclusion criteria

Age not between 18-63	178
Disability pension	150
Unemployed	173
Students	77
Not Danish speaking	101
Referred for surgery	280
No workplace barriers and no need of advice on physical activity	61
Other reasons *	28
Total number of patients not meeting inclusion criteria	1048

* Moving to other region/country; other illnesses; pregnancy; do not want to inform employer about health problems; in the process of changing job.

Of the 360 randomised patients 61 did not complete physical tests at baseline. All 299 participating patients were tested using the OLST. The portable force platform was available from June 2008; the 185 patients enrolled from that point onwards and were tested on the force platform. A flowchart addressing these 185 patients is shown in figure 4. There were no statistical difference between the 124 patients completing baseline tests on a portable force platform and the 299 patients enrolled in the study when comparing baseline data (p-value

0.11 to 0.88). Of the 124 patients completing baseline test 96 completed 3 months follow-up. There were no statistical difference between the 124 patients completing baseline tests and the 96 patients completing follow-up (p-value 0.17 to 0.78). Baseline data are presented table 5.

Figure 4. Flowchart of patients tested on force platform.

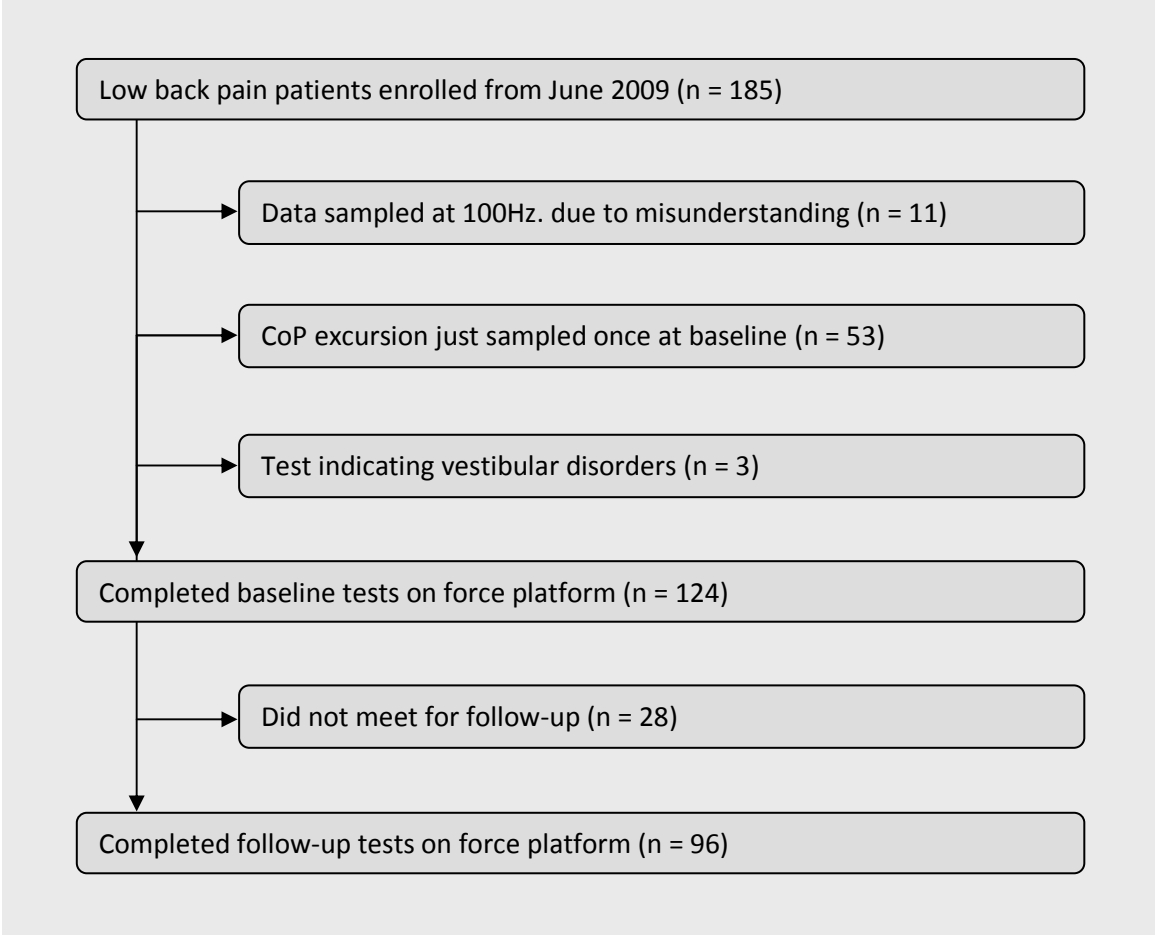


Table 5. Baseline characteristics of patient.

	Completed baseline test OLST (n =299)	Completed baseline on force platform (n = 124)	Completed follow-up on force platform (n = 96)
Age, mean (SD)	44.23 (10.1)	44.07 (10.3)	44.85 (10.0)
Female, n (%)	172 (55.8%)	67 (53.6%)	(53.1%)
Height, mean (SD)	173.6 (9.1)	174.0 (9.3)	173.8 (9.5)
Weight, mean (SD)	79.7 (16.5)	79.0 (15.2)	77.9 (16.0)
Body Mass Index, mean (SD)	26.4 (4.5)	26.0 (4.3)	25.7 (4.7)
Quebec Task Force classification			
1 Without radiating pain, n (%)	78 (25%)	40 (32%)	29 (30%)
2 Radiating pain but not below knee level, n (%)	79 (26%)	22 (18%)	15 (16%)
3 Radiating pain below knee level, n (%)	151 (49%)	62 (50%)	52(54%)
4 Positive neurologic findings†, n (%)	111 (36%)	34 (27%)	30 (31%)
LBP duration in years, median (quartiles)	2.6 (0.7; 10.4)	3.5 (1.1; 11.0)	3.0 (0.8; 10.3)
Pain			
Numerical Rating Scale (0-10), mean (SD)	6.39 (2.55)	5.97 (2.49)	5.93 (2.48)
SF-36 bodily pain (0-100), mean (SD)	43.59 (20.31)	44.13 (18.49)	46.46 (19.15)
Fear of pain			
Fear Avoidance Beliefs Questionnaire- physical activity (0-24), mean (SD)	10.62 (5.43)	10.71 (5.49)	10.92 (5.31)
Function			
Roland Morris Questionnaire (0-23), mean (SD)	11.34 (5.70)	10.76 (5.45)	10.53 (5.34)
SF-36 physical functioning (0-100), mean (SD)	69.06 (20.66)	70.88 (20.45)	72.24 (19.74)
Muscular conditioning			
Maximum oxygen uptake (ml O ₂ /min-1/kg-1), mean (SD)	30.56 (9.42)	31.83 (10.57)	31.26 (10.31)
Trunk muscle endurance extensors, (0-240 sec), median (quartiles)	117 (54; 176)	100 (42; 161)	106 (49; 169)
Trunk muscle endurance flexors, (0-240 sec), median (quartiles)	74 (46; 136)	83 (49; 155)	89 (48; 136)

† At least two abnormal results: Unilateral abnormality in muscle strength, reflex, or sensation

5.3. Classification

Based on medical records from the rheumatologic examination at inclusion, all patients were classified according to the Quebec task force classification.¹⁰³ LBP patients were assigned to one of the following groups: (1) LBP without radiating pain, (2) LBP with radiating pain but

not below knee level, or (3) LBP with radiating pain below knee level. Patients were classified as positive in neurologic findings if at least two abnormal neurologic results were found (unilateral abnormality in muscle strength, reflex, or sensation).

5.4. Outcome measures

All physical tests and measures of postural balance were performed by one of three skilled physiotherapists; the author of the thesis performed 66% of the tests while the two other physiotherapists performed 29% (EI) and 5% (IBS). Test conditions (light, room temperature) were standardised. All tests were performed in the same order for every patient: OLST first, then CoP measurements, and after a 10-minute break retests of the balance performances followed by test of muscle endurance and maximum oxygen uptake. Pain, fear of pain, and function were assessed by questionnaires administered at baseline and after 3 months. In order to reduce the risk of fatigue affecting postural balance, patients had a 15-minute rest prior to testing.

5.4.1. One Leg Stand Test

The test protocol was established after a review of the literature.^{24,37-46,104,105} The OLST was carried out by having barefoot patients fold their arms across their chest, one foot lifted approximately 10cm and placed behind the weight-bearing leg; no contact between the legs was allowed from the knees down (Figure 5).²⁵ The test was carried out with EO, focusing at a point 2m ahead, and with EC. The patients were timed while standing on the left and right leg, respectively. To familiarize patients with the task, a couple of preliminary trials were performed. Timing was stopped after 60s EO or 30s EC, or when the position could no longer be maintained. When using the EO OLST we chose a cut point of 60s, as testing beyond this timeframe might effectively constitute a test of muscle endurance or other parameters not relevant for balance. A pilot study showed that almost no LBP patients could stand on one leg for more than 30s with EC, prompting our choice of cut point. Most patients in the pilot study were able to stand for between 5 and 20s with EC, and this spectrum appears clinically relevant. Patients able to stand for more than 30s with EC were excluded from further studies. Each OLST trial consisted of 8 tests, with the best of two EO results and best of two EC results recorded for each leg. In clinical practice, interventions will be based on patients having poor balance; therefore, results from the leg with the shortest stand time were used for analysis.²⁵

Figure 5. Test position: One Leg Stand Test



5.4.2. CoP excursion assessed on a portable force platform

CoP excursion was tested using a four-channel portable force platform (HurLabs BT4). The platform measures 610x610x60mm and weighs 12kg. The platform was calibrated prior to testing, and the four channels were checked before every test. Patients were instructed to look straight ahead and stand as still as possible in the centre of the platform with arms hanging down. The foot position was standardized: a 2 cm heel-to-heel distance and an angle of 30° between the medial sides of the feet (Morton's foot position) (Figure 6); the position was ensured by means of a wooden template. The test was carried out with EO, focusing at a point 2m ahead, and with EC. The participants stood still for at least 5s (pre-phase) before the measurement. After the pre-phase, CoP was measured during the next 60s; signals were sampled at 200Hz and filtered with a low-pass filter at 7.8Hz cut-off frequency. The following measures were examined: *Trace length*: The trajectory (in mm) of the CoP; *Velocity*: mVel (in mm/s) of the CoP as well as anterior-posterior mean velocity (APmVel) and medial-lateral mean velocity (MLmVel); *mean displacement* from the centre, the anterior-posterior mean displacement (APmdispl) and medial-lateral mean displacement (MLmdispl) (in mm); and *C90 area*: area (in mm^2) of the smallest ellipse containing 90 percent of the CoP points.^{106,107} As velocity and trace length are connected (velocity is trace length/60), it could

be argued that one of these would be enough. In order to compare our results reliability with others, both trace length and velocity are presented in paper I.^{8,9,58}

In order to quantify the visual contribution to posture we calculated the Romberg Ratio (RR) (EC/EO). The RR quantifies the dependency on vision, and an RR of 1.3 indicates that the sway is increased by 30% with EC compared to EO. RR was calculated using velocity (RRvel), and C90area (RRarea) as these CoP parameters are comparable with other test protocols.

Figure 6. Test position: Test on the portable force platform



5.4.3. Pain

An 11-point NRS¹⁰⁸ was used to assess mean pain during the last 7 days. The health-related quality of life questionnaire SF-36 was used to assess bodily pain.¹⁰⁹

5.4.4. Fear of pain

Fear avoidance behaviour was assessed using the Fear Avoidance Beliefs Questionnaire (FABQ).¹¹⁰ The FABQ consists of two parts: FABQ-work (W), and FABQ-physical activity (PA).

5.4.5. Function

Back-specific function was assessed using the Roland Morris Disability Questionnaire (RMQ).^{111,112} Physical function were assessed using the health-related quality of life questionnaire SF-36.¹⁰⁹

5.4.6. Muscular condition

Muscular condition was addressed via trunk muscle endurance, using the modified Sorensen test¹¹³ and the modified Kraus-Weber test,¹¹³ and maximum oxygen uptake (ml O₂/min/kg) estimated by the Aastrand bicycle test.¹¹⁴

5.5. Ethics

The patients in this ph.d. thesis were all enrolled in a study approved by the Danish Data Protection Agency on the 6th of March 2006 (ref: 2006-41-6190) and approved by the Ethics Committee of Medical Research in Central Denmark Region on the 13th of February 2006 (ref: 2006-2.0/8) and notified as Current Controlled Trials ISRCTN13071157. The objectives in the three studies for the thesis were not approved by the Ethics Committee as they are not required to approve validity studies, but the Ethics Committee were informed, and all procedures were in accordance with the Helsinki declaration. Written and informed consent were obtained from both LBP patients and healthy controls before enrolment in the study. The physical tests, especially the muscle endurance tests, could potentially be harmful to LBP patients as we asked patients to maintain a fixed position for as long as possible with a maximum of 240s. Tests for lumbar trunk flexors and extensors are developed for LBP patients and have been tested without reports on adverse events¹¹³ and the test battery were examined in a pilot study which gave no reason for prolonged LBP. The test might induce delayed onset muscle soreness (DOMS) in some patients and patients were informed about this. Telephone numbers to the persons in charge were to find in the written information and patients were able to contact health personal if they experienced adverse effects.

5.6. Summary of methods in the studies

5.6.1. Study I

The objective of study I was to examine the intra-session reliability of CoP parameters on a portable force platform, the RRvel, and the OLST in LBP patients. A second objective was to test the correlation between CoP parameters and OLST in order to reveal whether they measure the same aspect of postural balance (Appendix A).

Participants

The study population was the first 52 LBP patients from the LBP cohort who completed two tests on force platform at baseline.

Sample size

The sample size in reliability studies should exceed 50;³⁶ 52 patients were included.

Design

A cross sectional study with test and retest in the same session.

Statistical analysis

Velocity data were logarithm-transformed to obtain an approximately normal distribution and to avoid heteroscedasticity.¹¹⁵ Paired t-tests were performed to examine differences between tests and the agreement was examined by Bland-Altman plot.^{115,116} Limits of agreement (LOA) represents a measure of random error of individual patients,^{115,116} and the Standard Error of the Measurement (SEM) representing error in a single measurement, was calculated.^{36,117} An error of 6–7% in the SEM is considered to indicate a high reliability, while over 12.5% is considered to indicate poor reliability.¹¹⁸ The intra-class correlation coefficient (ICC) model 2.1, was calculated.¹¹⁶ Correlations were calculated using Spearman's rho.

5.6.2. Study II

The objective of study II was to determine the criterion validity of CoP excursion as a measure of postural balance in patients with LBP assessed on a portable force platform. Concurrent validity was tested to outcome measures recommended in LBP evaluation: Pain, fear of pain, and physical function. Predictive validity was compared to pain and back-specific function (RMQ) (Appendix B).

Participants

The study population was all LBP patients from the cohort who completed tests on force platform at baseline and at follow-up

Sample size

A search of literature gave no good recommendations on sample size in studies of criterion validity. Some studies on test characteristics suggests a sample >50 in validity studies, but not especially for studies on criterion validity.^{36,62} It was possible to include 96 patients from the LBP cohort; this was found to be acceptable.

Design

- 1) A cross sectional design where CoP data were compared to other relevant LBP outcomes measured at the same time.
- 2) A 3 months follow-up design where change in CoP data were compared to change in other relevant LBP outcome measures.

Statistical analysis

Descriptive statistics were used to characterise participants. CoP data were logarithm-transformed to obtain an approximately normal distribution.¹¹⁵ Considering the influence of age and individual characteristics of CoP measures,²⁸ analyses were conducted for both (1) non-normalised CoP measures and (2) CoP measures normalised relative to the subjects' age, and weight.²⁸ Intra-person change were calculated on basis of original data as changes were normally distributed. Concurrent validity was examined by correlating CoP with pain, fear of pain, and physical function measured at the same point of time⁶³ and through the correlation between changes in CoP and changes in pain, fear of pain, and physical function. Spearman's correlation coefficient (r) was used. Criterion validity was evaluated by the criteria described by Innes.⁶³ Predictive validity was tested using postural balance at inclusion and by examining whether measures were different in patients with a clinical relevant improvement

compared to patients with no or negative changes.⁶³ The two most fundamental clinical outcomes (mean pain during the last week and RMQ) were used.¹¹⁹

5.6.3. Study III

The objective of study III was to validate measures of postural balance in LBP patients as assessed on a portable force platform. This was done by the known groups method and testing differences between LBP patients and healthy controls. Another aim was to determine the association between different CoP parameters (Appendix C).

Participants

The study population was LBP patients and healthy controls. All LBP patients from the cohort aged 20-59 were included. Healthy controls were recruited from a shopping mall. The controls were samples at different week days and different time of the day in order to make the sample as representative for customers at the shopping mall as possible. Controls were consecutively included until ten men and ten women within each decade from ages 20-59 had been included.

Sample size

The suggested sample size of studies of known groups validity should exceed 50;⁶² 118 patients and 80 controls were included.

Design

A cross sectional design where CoP data from two groups were compared.

Statistical analysis

Velocity data were logarithm-transformed to obtain an approximately normal distribution. Considering the influence of individual characteristics of CoP measures, analyses were conducted for both normalized and non-normalized CoP data.²⁸ Normalized data were adjusted using linear regression models. Postural balance was normalized according to sex, mean height, weight and age. Known groups validity was evaluated by testing differences in scores between LBP patients and healthy controls. Sub group analysis were done to patients with and without positive neurologic findings¹⁰³ normalized to height and weight. Pair wise spearman's correlation coefficient (r) between different CoP measures was calculated on the original data and the residuals from the linear regression as non-normalized and normalized data respectively. Correlation coefficients $r > 0.70$ were considered good.⁶²

6. RESULTS

A total of 124 LBP patients were enrolled as patient population for the studies comprising the thesis. All patients completed a baseline test battery comprising OLST, COP excursions, trunk muscular endurance, and maximum oxygen uptake. A three-month follow-up were possible in 96 patients.

The main findings from the three studies conducted for this present thesis are listed below. Additional information about the results can be found in appendices A-C.

Characteristics of the 124 patients completing baseline and 96 patients completing tests at follow-up are presented in table 6.

Table 6. Outcome measures at baseline and follow-up in LBP patients

Outcome measure	Baseline	n	Follow-up	n
<i>Pain</i>				
Mean pain during the last week (0-10), mean (SD)	4.92 (2.75)	120	3.46 (2.82)	93
Mean pain during the last 3 months (0-10), mean (SD)	5.98 (2.48)	120	4.10 (2.68)	93
SF-36 bodily pain (0-100), mean (SD)	45.2 (18.8)	123	56.95 (20.17)	95
<i>Fear of pain (Fear Avoidance Beliefs Questionnaire – FABQ)</i>				
FABQ-physical activity (0-24), mean (SD)	10.9 (5.7)	119	10.9 (5.3)	91
<i>Function</i>				
Roland Morris Questionnaire (0-23), mean (SD)	10.6 (5.5)	122	8.3 (5.7)	95
SF-36 physical functioning (0-100), mean (SD)	71.6 (20.6)	124	78.2 (18.8)	93
<i>Muscular conditioning</i>				
Maximum oxygen uptake (ml O ₂ /min/kg), mean (SD)	32.0 (10.7)	119	34.2 (10.5)	85
Trunk muscle endurance flexors, (0-240 sec), median (quartiles)	83 (47; 170)	124	103 (69; 240)	93
Trunk muscle endurance extensors, (0-240 sec), median (quartiles)	109 (47; 170)	124	124 (81; 184)	96
<i>Postural Balance</i>				
One Leg Stand Test EC, sec, geometric mean (CV)	6.95 (66%)	113	8.38 (60%)	76
mVel EC, mm/sec, geometric mean (CV)	15.83 (29%)	118	16.21 (31%)	96
APmdispl EC, mm, mean (SD)	-57.9 (17.0)	118	-58.8 (17.8)	96

EC: Eyes closed; mVel: Mean velocity; APmdispl: Anterior-posterior mean displacement

Before initiating the test battery there was some concern as to whether the one-hour physical test would induce an increase in pain. In order to observe this, actual pain was rated on an 11-point NRS before and five minutes after testing. At baseline prior to the physical test, patients rated pain at 2.54 (SD 1.96) while pain after test came to 1.94 (SD 2.04). A paired t-test showed a significant reduction ($p=0.0001$). At the three-month follow-up the corresponding pain ratings were 2.25 (SD 2.44) before test and 1.79 (SD 2.50) after test. This reduction was significant ($p=0.0002$). Patients were divided into three groups according to their change in pain when post-test ratings were subtracted from pre-test ratings: Deteriorated (change >2), No change (change between 2 and -2), and Improved (Change >-2). In table 7 the changes in present pain are presented. In just 8% of patients, pain deteriorated after the physical test, while the test reduced pain in 25% at baseline. The corresponding figures were 4% and 15% at follow-up. No patients reported adverse events except DOMS, which was reported in four patients (data on DOMS is not systematically reported).

Table 7. Changes in pain ratings. Ratings after test less ratings before physical test

	Baseline test (n=122)	3-month follow-up (n=96)
	n (%)	n (%)
Deteriorated (≥ 2)	10 (8%)	4 (4%)
No change (1 to -1)	81 (66%)	77 (80%)
Improved (Change ≤ -2)	31 (25%)	15 (16%)

6.1. Study I

Maribo T, Stengaard-Pedersen K, Jensen LD, Andersen NT, Schiottz-Christensen B. Postural Balance in Low Back Pain Patients: Intra-session Reliability of Center of Pressure on a Portable Force Platform and of the One Leg Stand Test. Accepted for publication. Gait & Posture. 2011

Results from 49 patients completing OLST and tests of CoP excursions on the portable force platform are presented. There was a clear ceiling effect in the EO OLST as 88% reached the maximum time limit; no further analysis was carried out for the EO OLST. In the EC OLST 6% reached the maximum time limit; these patients were excluded from further analysis. We found a significant difference of 13% ($p=0.03$) between test and retest in the EC OLST; furthermore the SEM was 28.3% (23.5%; 35.8%), with both results showing poor reliability. The correlation between OLST and the CoP parameters was statistical which indicates that they do not represent the same construct.

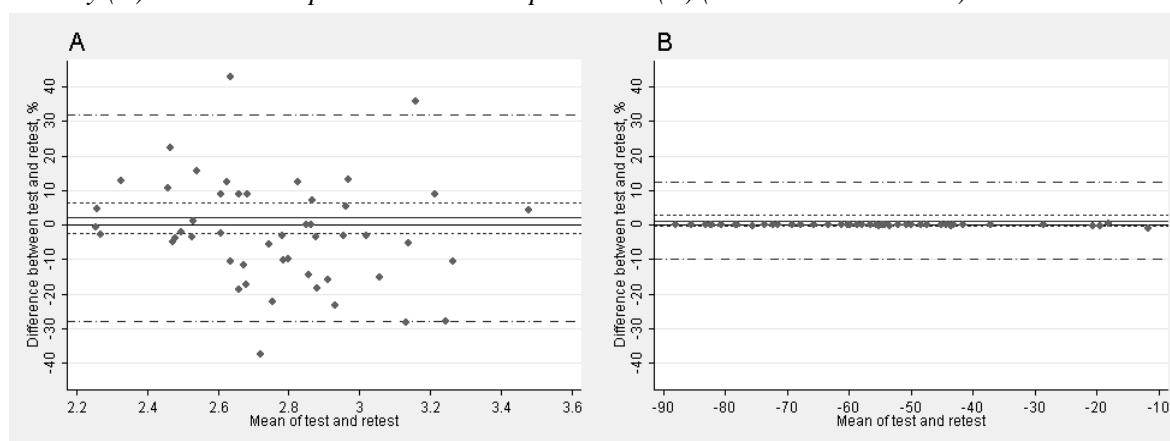
In Study III we recommend the use of mVel and APmdispl. APmdispl is not presented in the paper but additional unpublished data on APmdispl are shown in table 8. Figure 7 presents the Bland Altman plot for the additional statistical analysis.

Table 8. Reliability parameters for mean velocity and anterior-posterior mean displacement with eyes closed (non-normalised data)

	Test		
	Retest	Difference (95% CI)	SEM (95% CI)
mVel, mm/sec, geometric mean (CV)	16 (27.9%) 16 (30.9%)	-2.0% (-6.2%; 2.4%)*	10.9% (9.1%; 13.6%)*
APmdispl, mm, mean (SD)	-56.18 (18.73) -57.43 (17.81)	1.25 (-0.39; 2.88)	4.02 (3.35; 5.02)

SEM: Standard Error of Measurement ; * based on log transformed data.

Figure 7. Differences between test and retest plotted against the mean. The eyes-closed tests for mean velocity (A) and anterior-posterior mean displacement (B) (non-normalised data)



There were no significant differences between test and retest in mVel or APmdispl ($p=0.34$ and 0.14 , respectively), and ICC were considered good (0.85 and 0.95 , respectively). Results from other CoP parameters are shown in Study II.

6.2. Study II

Maribo T, Schiottz-Christensen B, Jensen LD, Andersen NT, Stengaard-Pedersen K. Postural Balance in Low Back Pain Patients: Validity of Centre of Pressure assessed on a portable force platform. Resubmitted with minor changes. Eur.Spine J. 2011

Data from baseline test and a 3-month follow-up of 96 LBP patients was analysed in the study. The mean intra-patient change from baseline to follow-up showed improvements in all outcome measures. Changes in pain, fear of pain, back-specific function and muscular conditioning were statistically significant ($p < 0.05$). Changes in mVel and APmdispl were neither statistically significant in the non-normalised data ($p=0.43$ and $p=0.63$, respectively) nor in the normalised data ($p=0.48$ and $p=0.75$).

When testing concurrent validity the correlation between mVel or APmdispl and pain, fear of pain, function and muscular conditioning were examined; none of the associations showed a validity higher than poor. Using non-normalised data the correlation between mVel and estimated maximum oxygen uptake at inclusion was $r=-0.43$; no other correlations were higher than $r=0.25$. Using normalised data the correlations between mVel and SF-36 bodily pain were $r=-0.30$ and SF-36 physical functioning $r=-0.33$; no other correlations were higher than $r=0.24$.

Predictive validity was tested using change in mean pain during the last week and RMQ and comparing clinical relevant changes. We found no predictive validity in mVel or RRvel as there were no significant differences between the groups ($p>0.05$).

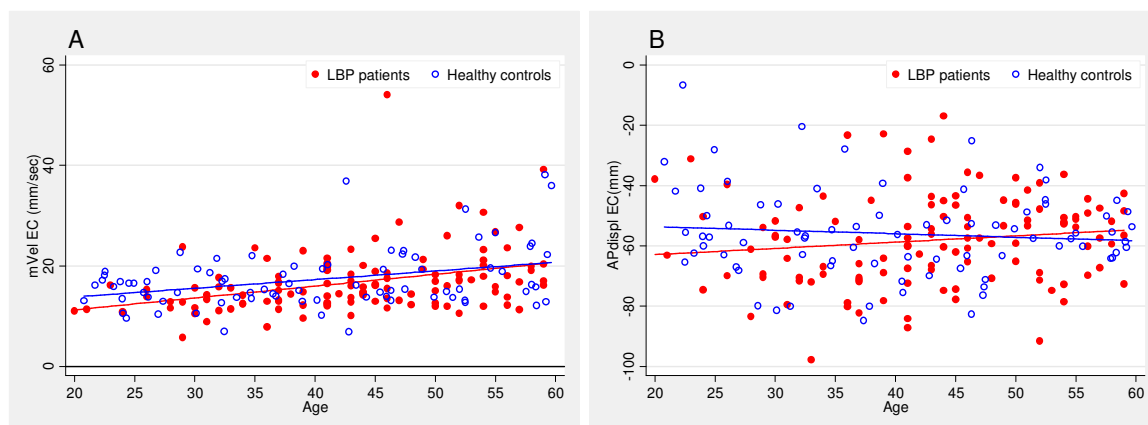
6.3. Study III

Maribo T, Jensen LD, Stengaard-Pedersen K, Andersen NT, Schiottz-Christensen B. Postural Balance in Low Back Pain Patients: Centre of Pressure Excursion in Low Back Pain Patients and healthy controls assessed on a portable force platform. Submitted. Spine (Phila Pa 1976.). 2011

A total of 121 patients from the LBP cohort completed two tests on the force platform at baseline. Three patients were excluded due to vestibular disorders. Eighty healthy controls were recruited from a shopping mall.

Normalized and non-normalized CoP data were analysed. We found no statistically significant differences between LBP patients and healthy controls in data on postural balance. In appendix C we show sex stratified data in the four decades. Figure 8 shows the normalised data from LBP patients and healthy controls for mVel and APmdispl without stratification.

Figure 8. The eyes closed tests for mean velocity (A) and anterior-posterior mean displacement (B) for LBP patients and healthy controls. Normalised data.



We performed a sub-group analyses of patients with and without positive neurologic findings and found no difference between these two groups. After the paper were written another sub-group analyses were performed where patients with radiating pain below knee level ($n=38$) was compared to LBP patients without radiation pain ($n=58$). There were no statistical significant difference between these two group in mVel ($p=0.13$) or APmdispl ($p=0.21$). In appendix C correlations between different CoP data but not MLmVel and MLmdispl are presented. In table 9 we present the correlation between mVel, APmVel, MLmVel, APmdispl, and MLmdispl; all with EC.

Table 9. Correlation (r) between measures of postural balance in low back pain patients (eyes closed data only)

		n=118	mVel	APmVel	MLmVel	APmdispl	MLmdispl
No	rm	mVel	-	0.97	0.87	0.16	0.02

	APmVel	0.97	-	0.73	0.15	0.02
	MLmVel	0.87	0.73	-	0.11	0.04
	APmdispl	0.16	0.15	0.11	-	0.12
	MLmdispl	0.02	0.02	0.04	0.12	-
Non-normalised data	mVel	-	0.98	0.88	0.32	0.07
	APmVel	0.98	-	0.78	0.32	0.07
	MLmVel	0.88	0.78	-	0.26	0.06
	APmdispl	0.32	0.32	0.26	-	0.11
	MLmdispl	0.07	0.07	0.06	0.11	-

mVel: Mean velocity; APmVel: Anterior-posterior velocity; MLmVel: Medial-lateral velocity; APmdispl: Anterior-posterior mean displacement; MLmdispl: Medial-lateral mean displacement. Normalised data are adjusted for age, weight and height. Correlations >0.70 are in bold.

The correlations between the three velocity parameters were good ($r > 0.70$) in both normalized and non-normalized data. The correlations between the two displacement parameters were poor.

7. DISCUSSION

7.1. Key findings

This thesis presents data on physical tests from a cohort of LBP patients,¹⁰² of whom 124 patients completed the test battery, which included tests of OLST and CoP excursions on a portable force platform. Follow-up data from the total test battery was available for 96 patients, making this the largest follow-up study on postural balance in LBP patients yet completed.

Intra-session reliability of measures of postural balance was examined in 49 patients. We found poor reliability for the OLST, and therefore this test of postural balance was excluded from further study. The reliability of mVel and APmdispl was acceptable, whereas reliability of other CoP parameters turned out to be poor.

We found poor concurrent validity of mVel and APmdispl, as well as poor predictive validity when associating mVel and APmdispl with changes in pain and function.

Known groups validity was examined where the 121 LBP patients between the ages 20 and 59 were compared to 80 healthy controls. We found no proof of validity as there was no significant difference between LBP patients and healthy controls in mVel and APmdispl adjusted for age, sex, height and weight.

Furthermore we found no significant differences in postural balance between LBP patients with and without neurologic findings or patients with or without radiating pain below knee level.

After performing the physical test battery patients rated their actual pain significantly lower than prior to testing, and no patients reported adverse results except DOMS, making the test battery safe for LBP patients.

7.2. Consideration of possible mechanism and explanations

The decrease in pain found after physical testing might be explained by the warming-up effect after physical test including the Åstrand bicycle test. Reduced pain is commonly seen after a warm-up period. Another possible mechanism is that fear of pain was relieved after testing as patients were told to do things that might have bothered them before. I quote from a recent study where a patient states: "I said at one point during the test: 'Oh – I feel like lying down and stretching my back, but I daren't'. And the physiotherapist says: 'Go ahead – you won't damage anything'. So I did it and it was heaven, because I felt that I hadn't stretched my back for a long time. Then he laid his hand on my back and it was a blessing".¹²⁰ No matter what caused the reduced pain, the test is safe for LBP patients in this setting as just four patients (1.3%) reported aggravated pain of more than 2 on the NRS at baseline and three patients (1.2%) at follow-up. Data on DOMS was not systematically obtained, but five patients called after testing to report increased pain. The patients were asked if the increased pain was present at rest; as this was not the case the patients were reassured; all had reduced pain when they were called after one week.

In study I we found a clear ceiling effect in the EO OLST with 88% of the LBP patients reaching the maximum time. If we had chosen a different test position, e.g. 90° flexion in hip

and knee on the non-weight-bearing leg, the ceiling effect might have been avoided, but in a pilot study this position increased LBP, prompting patients to stop due to pain. In contrast to an older study on LBP²⁵ we found a significant difference of 1s between test and retest in the EC OLST. This small difference is of no clinical importance, but as the SEM is another proof of poor reliability, the OLST is not recommended for clinical practice.

If this study were to be done again we would have considered carrying out the OLST on the force platform in order to compare the timing with CoP excursions. This would not, however, necessarily have yielded more valuable information as other problems, such as cut point, enter the scene. The geometric mean EC OLST was 7s and 8s, respectively, and only 50% of LBP patients were able to perform EC OLST for more than 7s. When testing CoP excursions, pre-phase was 5s as it is seen that CoP excursions are greater during the first seconds. This would make the EC OLST on the force platform impossible using the test position we have developed. The correlations between OLST and the CoP excursions suggest that the two outcome measures present different aspects of postural balance. This could have been explored further if the EO OLST was done on the force platform.

In study II we found no proof of concurrent validity; this was against our hypothesis of an association between postural balance and relevant LBP outcome measures. This might be due to poor sampling of CoP data. We gave much consideration to the test procedure and pilot-tested different test positions in both standing position and dynamic positions. Testing CoP while standing still is the most commonly used method for investigating postural balance²⁸ and the procedure we used is very close to recommendations published after our study was initiated.²⁸ Those recommendations differ from our test procedure with respect to test trials and sampling duration. If CoP testing is to be used in clinical settings the advantage of using 5 trials and a sampling duration of 90s should be explored, as the evidence behind these recommendations seems weak. Variability may be higher for the portable force platform than for laboratory equipment. If this is the case, the lack of concurrent validity might be due to bias. Study II revealed no evidence for predictive validity. This may have been affected by the timeframe. The follow-up period of 3 months may have been too short to allow changes in balance to manifest themselves.

In study III we tested whether there was a difference between LBP patients and healthy controls, and we found no evidence supporting this hypothesis. The lack of difference in postural balance between the groups, measured by means of CoP excursions while standing still, do not necessarily mean that LBP patients have normal postural control. When the LBP patients were interviewed for the study and asked about their balance, some revealed functional limitations due to balance problems. These were not disabling, but included things like “I’ve changed my habit of walking with the dog – I don’t go in the woods in the afternoons. I need the light to see where I place my feet” or “After my LBP I need support from the wall when I close my eyes when washing my hair”. Measuring CoP excursions while standing still simply does not reflect such limitations.

We and others found a great inter-subject variability in CoP measures,²² making it difficult to determine whether a single CoP result is normal or abnormal. Some even argued that the great variation questions the value of such results in health examinations.²² Impaired somatosensory information has been suggested as a possible mechanism causing the impaired postural balance in LBP patients.^{21,55,95} It is suggested that impaired somatosensory information

manifests itself as greater dependency on vision in LBP patients compared to healthy controls,^{2,9,27,29,100} but no relevant outcome measures are presented to reflect this difference. The intra-subject RR could possibly solve this problem as it reflects the ratio of a given value of EO and EC tests, respectively. The great inter-subject variability could be reduced as this ratio reflects dependency on vision. Our results on RRvel showed results that were only 1% away from acceptable reliability in RRvel using only one test session. To enhance reliability a mean of two tests was used.⁵³ Even so, the validity of the RRvel was poor and other outcome measures reflecting somatosensory information has to be found.

7.3. Comparison with relevant findings from other studies

In keeping with our results, previous studies have shown that the EO OLST is not challenging enough for healthy persons, nor for LBP patients.^{25,26}

In an earlier study we used the OLST for LBP patients.²⁵ If the same statistical procedure is used on the data from the first study²⁵ the SEM of EC OLST is 27.2% (95% CI 22.7%; 33.7%) which is comparable to the results from study I.

When comparing EC OLST with normative data we found significantly poorer performance than others.^{24,26} The difference is most likely due to the fact that our study comprised LBP patients whereas the studies of normative data included healthy persons; furthermore the test positions were different.

Three studies have investigated reliability of CoP measurements in LBP patients; these only present the ICC as a statistical parameter and find values from 0.44 to 0.91.^{8,9,58} Only one of these studies had a population comparable to ours.⁹ Leitner et al. presented an ICC of 0.77 using COP data comparable to us.⁹

As regards concurrent and predictive validity of postural balance in LBP patients, Kuukkanen and Mälkiä tested 82 LBP patients reporting APmVel and MLmVel.⁶⁵ They found no association between CoP parameters and pain or functional capacity, which matches our results on concurrent validity. No predictive value of the CoP parameters were found in their study either.⁶⁵ Takala and Viikari-Juntura found an association between mean displacement and future LBP in their study, but this was only seen in women.²² In another study Takala et al. found only slight associations between LBP and postural balance, but the results from the study are not clear.⁶⁶ A recent review states: “There is insufficient data to suggest a relationship between pain intensity, previous pain duration or the level of perceived disability and the magnitude of COP excursions”.²⁰ This thesis and the study by Kuukkanen and Mälkiä form part of evidence that contradicts such a relationship.

In contrast to other types of validity studies on known groups validity are well represented in literature as we found 22 studies on this topic. When comparing known groups a minimum of 50 participants in each group is recommended⁶² and only two studies exceeds this number.^{100,101} In the following, results from our study are compared to other studies with 20 participants or more. Nies and Sinnott were the first to test LBP patients on a force platform. They used “dispersion factor” as outcome measure, making it incomparable to our results.² Luoto et al. tested 99 LBP patients and 61 controls reporting mVel.⁶⁹ Their results are comparable to our findings except as regards female patients with severe LBP. Mok et al. tested 24 LBP patients and 24 controls, reporting mVel and maximum anterior-posterior

displacement.²¹ Their results for both patients and controls were significantly lower than ours, but they report results from both one-leg and bipedal stances in the same figures. Brumagne et al. tested 21 LBP patients and 24 controls reporting APmdispl.⁷⁰ They found no difference between patients and controls. The difference between patients and controls is almost comparable to the differences we found among females, which is in accord with our results as there were more female than male participants in their study. In another study Brumagne et al tested 56 persons with LBP and 33 controls reporting anterior-posterior displacement.¹⁰⁰ In contrast to our studies they found a difference between patients and controls. Salavati et al. tested 22 LBP patients and 22 controls reporting mVel.⁷¹ The study objective meant that no tests on difference were performed; their results show no difference in EO ($p=0.05$) tests, but a significant difference in EC ($p=0.04$) tests (calculations are carried out by the authors). Their results are comparable to ours except mVel EC, where their results were lower than ours. Clayes et al. tested 106 students with LBP and 50 healthy controls.¹⁰¹ In contrast to our results they report that the healthy students had less APmdispl than LBP patients. In summary these studies are inconclusive as four studies showed a difference and other four studies found no difference. The validity is determined by factors such as sample size, lack of medical examination of some of the persons with LBP and control group sampling. The two studies with sufficient sample size point in different directions regarding known groups difference in postural balance parameters. Ruhe et al. did a review on CoP excursions including studies with fewer than 20 patients and concluded that there is a difference between LBP patients and controls; the difference is more pronounced with EC.²⁰ These results were not reproduced in our large study. In some of the studies patients were medically examined, but other LBP population were students or workers reporting LBP without a firm medical examination making it difficult to compare the LBP groups. As to source population some studies used health professionals or students and some did not even report the source population. Health professionals can be assumed to be more physically active and have better balance than LBP patients.

7.4. Limitations

A main limitation concerns the lack of a criterion validity study comparing the portable force platform and a laboratory force platform. The variability of the portable force platform might be higher than for laboratory equipment. If this is the case, the lack of concurrent validity might be due to bias. We performed a small reliability study where we examined a 50 kg obstacle on the force platform and made test and retest 12 times. Reliability parameters for the additional data for mean velocity and anterior-posterior mean displacement are shown in table 10. Compared to the reliability parameters from the LBP patients (see table 8) the reproducibility of the portable force platform is quite low and acceptable. We conclude, that the variability seen in the CoP parameters are primary due to biological variation.

Table 10. Reliability parameters for mean velocity and anterior-posterior mean displacement for a 50 kg obstacle

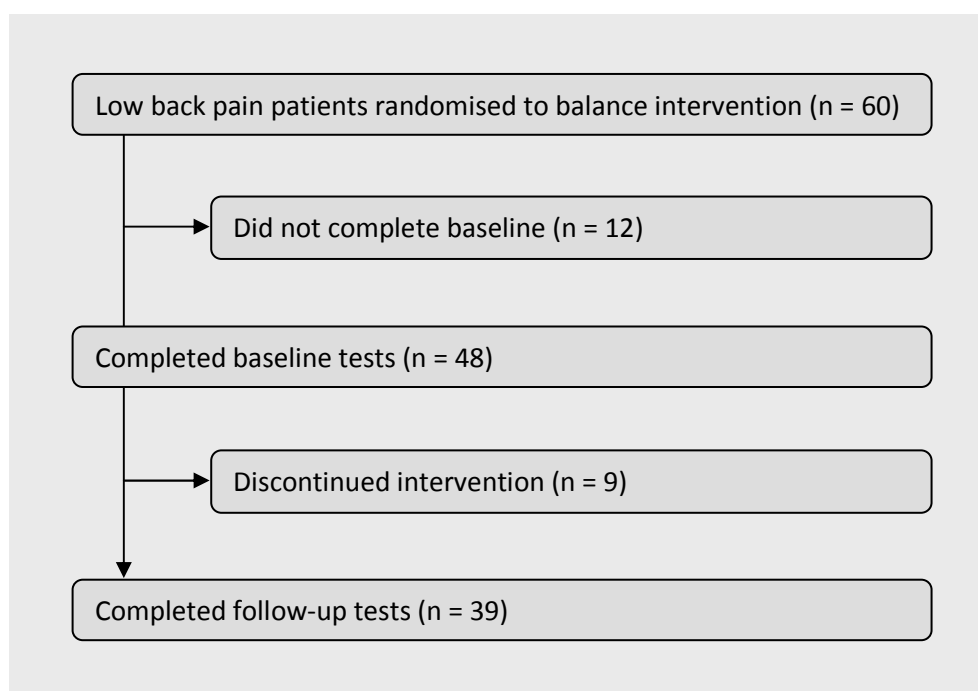
	Test		SEM (95% CI)
	Retest	Difference (95% CI)	
mVel, mm/sec, geometric mean (CV)	2.2 (0.9%)	-0.6% (-2.5%; 1.4%)*	2.1% (1.5%; 3.6%)*
	2.2 (2.1%)		
APmdispl, mm, mean (SD)	13.17 (0.04)	-0.20 (-0.26; 0.14)	0.06 (0.04; 0.10)
	13.38 (0.09)		

SEM: Standard Error of Measurement ; * based on log transformed data.

Study II revealed no evidence for predictive validity. This may have been affected by the timeframe. The follow-up period of 3 months may have been too short to allow changes in balance to manifest themselves.

Another limitation of the thesis is the lack of a study testing the effect of balance training in LBP patients. An appropriate element of validity of postural balance would be an intervention aiming to improve postural balance. We planned an intervention study for this thesis, and 60 patients from the LBP cohort were randomly assigned to balance intervention. This intervention failed due to method-related problems. The intervention was planned, and balance exercises (appendix E) were produced after review of the literature. Only 39 (65%) of the randomised patients showed up for follow-up as shown in figure 9.

Figure 9. Patients randomised to balance intervention



The considerable drop-out would hamper results, but what shattered the intervention was more important – the intervention turned out to be useless in the marked segment. Instruction and a pamphlet was not enough to ensure compliance in LBP patients. The patients in the balance training group stated that the balance training should have been adjusted shortly after baseline as exercises got too easy and boring. Balance exercises for LBP patients are to be

adjusted to be progressively harder within the first week after initiation if compliance and change are to be clinically important. Furthermore, training of postural control should be an integrated part of physical training.

7.5. Generalizability

As regards external validity, our LBP cohort was strictly defined by setting, clinical and demographic characteristics, comprising only LBP patients referred to an outpatient rheumatologic clinic. The two outpatient clinics covered the same mixed urban and suburban geographical area. In Denmark, which has a population of about 6 million people, approximately 670,000 persons come into contact with their general practitioner because of LBP each year. About 5% of these are referred to secondary care at an outpatient clinic.¹⁸ The LBP cohort completing the full test battery includes patients from a variety of social strata, comprising 31% highly educated professionals or managers, 44% public servants such as teachers, office workers and nurses, and 24% blue collar workers comparable to an earlier study in LBP patients.¹²¹ As our source population comprised an unselected population, the findings can be generalised to LBP patients not referred to surgery, having a workplace connection, and sharing the clinical characteristics of the actual study population. The healthy controls were sampled from a shopping mall on different days and different times of day. The inclusion criteria for healthy controls were wide and the findings can be generalised to Danish healthy controls 20-59 years of age from a mixed urban and suburban geographical area.

8. CONCLUSION

In our studies we examined postural balance, pain, fear of pain, function, and muscular condition in a population of LBP patients referred for rheumatologic evaluation. A total of 124 patients were tested at baseline and 96 at a 3-month follow-up session. Postural balance was tested by means of the OLST and CoP excursions on a portable force platform, furthermore RR was calculated.

We found a clear ceiling effect in the EO OLST and poor reliability for the EC OLST. Therefore, the OLST was not examined any further.

We found acceptable reliability for trace length, velocity, and mean displacement when testing CoP parameters. The criterion validity of the CoP parameters was tested against pain, fear of pain, function, and muscular condition, which revealed no proof of concurrent validity. The predictive validity was tested against changes in pain and function, and no positive association was found. The known groups method showed no difference between LBP patients and healthy controls.

The reliability of RR were close to acceptable but as the validity was poor the studies revealed no evidence for this parameter.

The literature on reliability and validity of measures of postural balance in LBP patients is inconclusive and in most studies the sample size is too small.

In conclusion, the data from the present thesis, which has a sufficient sample size, point to not recommending the use of measures of postural balance in LBP patients. The OLST is not feasible due to ceiling effect with EO and poor reliability with EC. Regarding CoP excursions on a portable force platform, the data suggests acceptable reliability for some parameters, but poor validity was found and this method can therefore not be recommended for LBP patients. An examination of the CoP data showed that the different velocity parameters were highly correlated, providing no reason for using parameters other than mean velocity. The correlation between velocity and displacement is low, indicating that they reveal different aspects of postural balance. On the basis on our study, mean velocity (mVel) and the anterior-posterior mean displacement (APmdispl) are to be recommended in future studies of postural balance. The test battery applied for this thesis gave no adverse events, and LBP patients even reported a reduction in present pain after test. Some patients experienced DOMS after testing. The test battery is safe for LBP patients advised to carry out physical training.

9. PERSPECTIVES AND FUTURE RESEARCH

The studies performed in the present thesis can not recommend measures of postural balance in diagnose or evaluation of patients with LBP. Postural balance might not reflect dysfunctions in postural control in LBP patients and studies testing postural control is needed. Laboratory studies could reveal whether LBP patients or subgroups of LBP patients experience poorer postural control compared to healthy persons and which subsystem suffers most. Next step would be studies on clinical applicable outcome measures of postural control in LBP patients. Clinical relevant outcome measures are to be at hand if the question on postural control in LBP patients are to be more than just academic. When the test characteristics are found acceptable an intervention study focusing on the effect of balance training on pain and function in LBP patients are to be planned. Such intervention should be a randomised study with tailored physical training with or without balance exercises. Another question still remains: Whether measurement error is higher using the portable force platform compared to laboratory force platforms secured to the ground. The portable force platform was used to enhance clinical relevance as such platforms can fit into a normal examination room. If CoP measures are to be employed in standard examinations, it would seem necessary for platforms to be portable. We have found no studies comparing different test devices. Such studies seem relevant before putting portable platforms to use in the clinic.

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11. STATEMENTS

Declaration of co-authorships:

Maribo T, Stengaard-Pedersen K, Jensen LD, Andersen NT, Schiottz-Christensen B. Postural Balance in Low Back Pain Patients: Intra-session Reliability of Center of Pressure on a Portable Force Platform and of the One Leg Stand Test. Resubmitted with minor changes. *Gait & Posture*. 2010

Maribo T, Schiottz-Christensen B, Jensen LD, Andersen NT, Stengaard-Pedersen K. Postural Balance in Low Back Pain Patients: Validity of Centre of Pressure assessed on a portable force platform. Submitted. *Eur.Spine J*. 2011

Maribo T, Jensen LD, Stengaard-Pedersen K, Andersen NT, Schiottz-Christensen B. Postural Balance in Low Back Pain Patients: Centre of Pressure Excursion in Low Back Pain Patients and healthy controls assessed on a portable force platform. Submitted. *Spine (Phila Pa 1976.)*. 2011

12. APPENDICES

Appendix A

Maribo T, Stengaard-Pedersen K, Jensen LD, Andersen NT, Schiottz-Christensen B. Postural Balance in Low Back Pain Patients: Intra-session Reliability of Center of Pressure on a Portable Force Platform and of the One Leg Stand Test. Resubmitted with minor changes. *Gait & Posture*. 2010

Appendix B

Maribo T, Schiottz-Christensen B, Jensen LD, Andersen NT, Stengaard-Pedersen K. Postural Balance in Low Back Pain Patients: Validity of Centre of Pressure assessed on a portable force platform. Submitted. *Eur.Spine J*. 2011

Appendix C

Maribo T, Jensen LD, Stengaard-Pedersen K, Andersen NT, Schiottz-Christensen B. Postural Balance in Low Back Pain Patients: Centre of Pressure Excursion in Low Back Pain Patients and healthy controls assessed on a portable force platform. Submitted. *Spine (Phila Pa 1976.)*. 2011

Appendix D

Balance exercises