Exploring the measurement properties and effectiveness of a postural monitor and feedback device

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Abstract

Frequent or sustained bending postures are considered to play a role on the development or maintenance of non-specific low back pain (NSLBP). The provision of postural feedback could help workers or patients with NSLBP to improve postural awareness and, consequently, to avoid hazardous or pain-provoking postures. The Spineangel® is an accelerometer and was developed to monitor posture and to provide an audio-feedback according to a pre-set postural threshold. The aims of this study were to: explore the measurement properties of the Spineangel®; and to assess the feasibility of a trial to investigate the effectiveness of the Spineangel®. One laboratory-based cross-sectional study was carried out to assess the within-task, within-session, and between-day reliability as well as the concurrent validity of the Spineangel® as a lumbo-pelvic posture monitoring device when clipped on the belt or waistband during a wide range of occupational activities. Another cross-sectional field study was carried-out to assess the within-day reliability of the Spineangel® as a postural monitoring device and to measure the cumulative lumbo-pelvic postural exposure in a group of health care workers. Findings from these studies results from these two cross-sectional studies suggest the Spineangel® is a reliable and valid device for monitoring gross lumbo-pelvic posture. The feasibility randomized controlled trial aimed to assess the feasibility of a trial to investigate the effectiveness of the Spineangel® as an EF device for modifying daily activity postures. A group of 62 workers from a health care institution were randomly allocated into one of the three groups: placebo group (CG), intermittent feedback group (IFG) and constant feedback group (CFG). Based on follow-up and adherence rates, findings from the feasibility randomized controlled trial suggest conducting a RCT with a similar method to the present study is not feasible, unless additional strategies to minimize the non-adherence to wear the Spineangel® at work are adopted. The provision of constant postural feedback seems promising for promoting changes in postural behaviour and future studies with an adequate sample size should be capable of identifying whether there are differences between constant EF and placebo.
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Preface

“Research is what I'm doing when I don't know what I'm doing.”

Wernher von Braun

This thesis is a report of what I have learned while doing this research on the use of a postural monitor and feedback device to change postural behaviour. Certainly, there is much to be explored on this topic.
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List of abbreviations

AM: angular measurements
AM1: angular measurement 1 (without the Spineangel®)
AM2: angular measurement 2 (without the Spineangel®)
AM3: angular measurement 3 (without the Spineangel®)
ANCOVA: analysis of covariance
ANOVA: analysis of variance
CC: case-control
CFG: constant feedback group
CG: control group
CI: confidence interval
COPSOQ II: second short version of the Copenhagen Psychosocial Questionnaire
CV_me: Coefficient of Variation of Method Error
d: effect size, t-test
DA: Daniela Aldabe
DCR: Daniel Cury Ribeiro
Df: degree of freedom
EF: extrinsic feedback
EMG: electromyography
f: effect size, ANOVA
FG: feedback group
GCS: global coordinate system
GS: Gisela Sole
Hz: hertz
ICC: intraclass correlation coefficient
IFG: intermittent feedback group
JCS: joint coordinate system
JHA: J. Haxby Abbott
JOSPT: Journal of Orthopaedic and Sports Physical Therapy
KP: knowledge of performance
KR: knowledge of results
L3: third lumbar vertebrae
LBP: low back pain
LCS: local coordinate system
LL: lower lumbar
LM: linear measurements
LM1: linear measurement 1 (without the Spineangel®)
LM2: linear measurement 2 (without the Spineangel®)
LM3: linear measurement 3 (with the Spineangel®)
LMM: lumbar monitor motion
m: metre
ME: method error
Min: minutes
MRC: Medical Research Council
NOS: Newcastle-Ottawa Scale
NSLBP: non-specific low back pain
ODI: Oswestry disability index
OMERACT: Outcome Measures in Rheumatology
OR: odds ratio
PBU: pressure biofeedback unit
PC: prospective cohort
RCT: randomized controlled trial
ROM: range of motion
RR: relative risk
r_s: pearson correlation coefficient
S1: first sacral
S1: sensor 1
S2: sensor 2
S3: sensor 3
SAFE: SpineAngel® Feedback Experiment

SD: standard deviation

s: seconds

SEM: standard error of measurement

SF-36: short form 36 questionnaire

T12: twelfth thoracic vertebrae

TL: Total lumbar

UK: United Kingdom

USI: ultrasound imaging

VAS: visual analogue scale
**Conflict of interest**

I hereby declare that I have no actual or potential conflicts of interest.
Outputs from work conducted during the thesis

Publications


Manuscript to be submitted:

Conference presentations


1 Introduction

This thesis explores the measurement properties and effectiveness of a lumbo-pelvic postural monitor and feedback device, the Spineangel®. The research was developed over a 3 year period and was based on collaboration between the Centre for Physiotherapy Research, University of Otago, and Movement Metrics®, the company that developed the Spineangel®. Movement Metrics® had an interest in having the reliability, validity and effectiveness of the Spineangel® assessed. The company’s need informed the research direction for this PhD. This device was designed to monitor lumbo-pelvic movements and to provide audio-feedback whenever a postural threshold was exceeded. It was developed to be used as a rehabilitation tool for the management of low back pain (LBP), in particular for helping patients to change postural behaviour, or to be used as a prevention tool to help workers to avoid potentially hazardous posture. It is similar in size to an electronic pager and, according to the manufacturer; the device was designed to be worn on the usual dress belt or clothing waistband (Figure 1-1).

The Spineangel® consists of an integrated circuit accelerometer recording postural movements in the sagittal and coronal planes. The device can be used in two different forms: either as continuous recording or in an intermittent mode. The continuous recording mode allows the register of posture in sagittal and coronal planes with frequency sampling at 10 Hz and can record for up to 512 MB (approximately 7 hours). According to the manufacturer, every 100ms each axis is read 4 times and averaged (using simple block average). These samples are further averaged by another block average of the 4 most recent samples, i.e. spanning a 300 ms period. Next, the data is processed and converted into angle (using a sin(x) function for angle approximation). The intermittent mode records the number of times a pre-set postural threshold is exceeded and can record for up to approximately 10 days. Both modes (continuous and intermittent) can be used with the audio-feedback mode activated. Under these conditions, the audio-feedback is triggered if the pre-set postural threshold is exceeded.
Figure 1.1. The Spineangel® device.

Monitor and feedback devices are used as part of prevention or management of musculoskeletal disorders (Vedsted et al., 2011, Herbert et al., 2008, Ferreira et al., 2007). Common risk factors for work-related musculoskeletal disorders include mechanical factors (e.g. repetitiveness or duration of a sustained posture, physical loading at work, insufficient rest) (Bakker et al., 2009, Miranda et al., 2008) and psychosocial factors (e.g. mental stress, time pressure, peer-support at work, job satisfaction) (Vandergrift et al., 2012, Harcombe et al., 2009, McGill et al., 2003). Feedback devices have been used for minimizing mechanical risk factors (Vedsted et al., 2011). For example, electromyography (EMG) -based feedback has been shown to help workers reduce trapezius muscle contraction during computer work (Madeleine et al., 2006). In a clinical setting, the inclusion of postural feedback as part of a rehabilitation programme has led to improved clinical outcomes, when compared to physiotherapy alone (Magnusson et al., 2008).

Despite the amount of research on LBP, it continues to be a burden at individual and societal level (Dagenais et al., 2008). It is generally accepted that LBP is a multifactorial disorder and best practice recommends patients should be classified into three different groups: serious spinal pathology (representing 1-2%), nerve root problems (approximately 5%) and non-specific low back pain (NSLBP, the majority of the patients). Patients presenting with NSLBP have no clear diagnosis (Savigny et al., 2009) and randomized controlled trials (RCT) have shown no differences in outcomes when comparing different treatment approaches (Little et al., 2008, Team, 2004). Some researchers propose patients...
presenting with NSLBP should be sub-grouped in order to improve clinical outcomes (Foster et al., 2011, O'Sullivan, 2005, McCarthy and Cairns, 2005, Childs et al., 2004).

The role of posture as a risk factor for NSLBP has also been debated. A recent systematic review has found conflicting evidence for bending posture as a risk factor for LBP (Wai et al., 2010). On the other hand, the methods used to monitor posture in epidemiological studies have been critiqued (Teschke et al., 2009). It has been suggested that qualitative postural assessments (e.g. observation, self-administered questionnaires) may not provide sufficient information for assessing the association between posture and LBP as they were found to be inaccurate (Van Eerd et al., 2009, Teschke et al., 2009). Rather, a combination of qualitative and quantitative postural assessments seem to provide better risk estimates for posture as a risk factor for LBP (Teschke et al., 2009).

From a clinical perspective, physiotherapists consider posture to play an important role in the onset or maintenance of LBP (Dankaerts et al., 2006, Van Dillen et al., 2009). Several studies have reported the presence of altered spinal posture in patients with NSLBP and have identified that targeting posture during the rehabilitation programme was associated with clinical improvements (Van Dillen et al., 2005, Dankaerts et al., 2007).

1.1 Repetitive or sustained trunk flexion and the risk of low back pain

Laboratory studies have shown sustained or repetitive trunk flexion to be associated with deleterious effects on spinal neuromuscular functioning (Claude et al., 2003, Parkinson et al., 2004). Studies using feline models suggest that regardless of load magnitude, the acute effect of sustained or repetitive trunk flexion is to increase laxity of spinal passive tissues and decrease reflexive spinal muscle activity, exposing the spine to increased instability (Ben-Masaud et al., 2009, Youssef et al., 2008, Hoops et al., 2007). High load magnitude associated with repetitive or sustained trunk flexion was reported to lead to the same deleterious acute effects but also to lead to inflammatory response in lumbar ligaments and a neuromuscular compensation by increasing spinal muscle activation (Ben-Masaud et al., 2009). Such compensation aims to increase spinal stability but it also increases intervertebral compression forces (Ben-Masaud et al., 2009, King et al.,
Therefore, exposure to repetitive lifting tasks with high load magnitude is considered to be a risk factor for LBP.

Exposure to sustained or repetitive trunk flexion associated with low load magnitude was found to lead to similar deleterious mechanical effect, but to a different neuromuscular effect. While it is associated with increased laxity of spinal ligaments, it leads to deficient muscle activity that can last for hours without the presence of a late neuromuscular compensation (Ben-Masaud et al., 2009).

Studies in humans found similar results (Shin and Mirka, 2007, Olson et al., Parkinson et al., 2004, Olson et al., 2004). Frequent or sustained trunk flexion has been shown to cause creep of passive spinal tissues, leading to decreased spinal stiffness (Parkinson et al., 2004), acute increased activity of spinal extensor muscles (Shin and Mirka, 2007) followed by reduced spinal muscular activity and, later, by spasms of spinal muscles (Olson et al., 2009, Solomonow et al., 2008, Solomonow et al., 2003a). Additionally, while performing active and cyclic trunk flexion, ligament-muscular reflexes become hyperactive (Olson et al., 2009), providing extra spinal stability to compensate for the reduced contribution from spinal passive tissues. Ligament micro-injury and those changes in spinal mechanical and neuromuscular functioning are considered to be the underlying mechanisms for increased risk of LBP (Olson et al., 2009, Solomonow et al., 2008, Panjabi, 2006) (Figure 1-2).

Field studies have also reported increased risk of LBP due to postural factors (Punnett et al., 1991, Harkness et al., 2003, Punnett and Wegman, 2004). Punnett et al. (1991) found low back disorders were associated with mild trunk flexion in a group of automobile workers. Likewise, Vandergrift et al. (2012) reported the adoption of awkward postures predicted incident of LBP in a similar group of workers. Health care workers are also exposed to increased risk of developing LBP due to, among other factors, postural loading (Harcombe et al., 2009, Videman et al., 2005). Combined, findings from laboratory and epidemiologic studies provide strong evidence that exposure to non-neutral (i.e. trunk flexion greater than 20°) trunk posture is associated with increased risk of LBP (Punnett and Wegman, 2004).
When exposed to repetitive or sustained trunk flexion, healthy subjects can also present with reduced lumbar position sense (Dolan and Green, 2006, Wilson and Granata, 2003). Similarly, patients presenting with NSLBP can present with altered postural awareness and reduced lumbar position sense (Newcomer et al., 2000). Impairment of lumbo-pelvic proprioception may have a negative effect on lumbar neuromuscular function, thereby potentially increasing the risk of low back injuries (Dolan and Green, 2006, O'Sullivan et al., 2003). Therefore, prevention programmes for NSLBP should include minimizing the exposure to repetitive or sustained trunk flexion at work (Freitag et al., 2012, Mathiassen and Paquet, 2010), and the management of patients with NSLBP should often include postural re-education as part of the rehabilitation protocol (Van Dillen et al., 2009).

Figure 1-2. Mechanical and neuromuscular effects for exposure to sustained or repetitive trunk flexion.

1.2 Postural monitor and feedback devices in ergonomics and rehabilitation

Portable and user-friendly postural monitor and feedback devices have the potential to change postural behaviour during daily-life activities (Dean and Dean, 2006, Donatell et al., 2005). The ideal instrument should be capable of reliably monitoring posture (Boocock et al., 1994), while also providing postural feedback for the user (Dean and Dean, 2006). From a clinical perspective, the provision of
real-time feedback during daily activities could help patients with NSLBP avoid pain-provoking postures and help workers change postural behaviour, reducing the exposure to hazardous posture at work.

1.2.1 The use of postural monitor devices

Posture is considered by clinicians, researchers and ergonomists to be one of the numerous risk factors related to the development and maintenance of occupational LBP (Ferguson et al., 2012, Vandergrift et al., 2012, Gallagher et al., 2005). The conflicting findings from epidemiological and laboratory-based studies suggest better methods of quantifying posture at the workplace (Teschke et al., 2009, Punnett et al., 1991, Wai et al., 2010). Previous studies have used a variety of monitor devices for postural monitoring (Boocock et al., 1994, Ferguson et al., 2004a, Hodder et al., 2010, Wong and Wong, 2008, Seidel et al., 2011) and the use of those instruments in prospective cohort studies may improve postural risk estimates for LBP.

A common problem for postural monitor devices is the trade-off between portability and accuracy of measurements. The Moment Exposure Tracking System™ is an example of a more complex instrument capable of estimating dynamic load moment exposure and recording spinal posture at the workplace (Marras et al., 2010). The advantage of this instrument is its ability to measure dynamic hand forces in different directions (i.e. lifting-lowering and pushing-pulling) improving the ability for estimating accurate spinal loads (Marras et al., 2010). The device consists of a rigid backpack frame; therefore, its portability is reduced. The Lumbar monitor motion (LMM™) is an accurate device for spinal postural recording (Marras et al., 1992) and has been used for assessing spinal load during different tasks (Marras et al., 2009, Marras et al., 2006). The CUELA measurement system is another example of a more accurate instrument for monitoring spinal movement (Freitag et al., 2007). Similar to the Moment Exposure Tracking System and the LMM™ instrument, increased accuracy is followed by reduced portability and simplicity. In contrast, the Spineangel® is portable, reliable and user-friendly.
1.3 **A framework for the development and evaluation of complex intervention studies**

This thesis explores the use of a postural monitor and feedback device to reduce the exposure to flexed posture at work in a group of workers at a health care institution. An audit of recent injuries found lumbar spine to be the most frequent site of injury reported by this group of workers (Appendix A). This research was planned and executed according to the “Developing and evaluating complex interventions: new guidance” guidelines published by the Medical Research Council (MRC) in the United Kingdom (UK). This guideline presents a framework for researchers assessing complex interventions (MRC, 2008). Complex interventions are defined as those having numerous potential confounding factors. Such factors can interfere with the research outcomes individually or by interacting with other factors (MRC, 2008). This makes it difficult to identify the active elements of a complex intervention study. As a result, the design and delivery of the intervention and analysis of the data from complex intervention research is very challenging. Examples for dimensions of complexity include: the number of and the potential interaction between factors within intervention and control groups, the number of groups and different organizational levels targeted by the intervention, and the number and variability of outcome measures. Although there is no clear boundary for categorizing simple and complex interventions, it is reasonable to classify any pragmatic study as a complex intervention study (MRC, 2008).

According to the MRC guidelines, trials for complex interventions can be classified into different stages with each stage focusing on a different research question (MRC, 2008). The development stage is responsible for the development of theories and the identification of components of interventions and their respective underlying mechanisms. The feasibility stage focuses on the testing of a feasibility protocol, identifying recruitment and retention rates and informing sample size for future studies. At the evaluation phase, randomized controlled trials are conducted to assess the effectiveness and cost-effectiveness of an intervention and to improve understanding of the effect of the intervention. Finally, at the implementation phase, the focus is on disseminating an intervention, assessing the long term follow-up, and monitoring the implementation of the
intervention. There is interplay between the stages, in which knowledge obtained at one phase helps to inform research conducted at the next stage. The research reported in this thesis can be classified as being at the Development and Feasibility stages (Figure 1-3).

Figure 1-3. Research development and evaluation for complex interventions (adapted from MRC guidelines (2008)).

### 1.4 The relevance of pilot and feasibility studies

The MRC guidelines for the development and evaluation of complex intervention studies highlight the importance for piloting a protocol prior to embarking on a large trial (MRC, 2008). In a time of economic austerity, piloting studies become even more relevant as these can save time, effort and financial resources (Thabane et al., 2010). The rationale for conducting a pilot or feasibility study is to define factors related to (1) processes, (2) resources, (3) management and (4) scientific issues (Thabane et al., 2010). The first focuses on determining the feasibility of each phase required at the main study (e.g. recruitment rates, retention rates). Resources factors refer to the assessment of time and financial issues for collecting data (e.g. time to fill out survey forms, costs). Management factors target optimizing potential human or data problems such as data management issues at participating centres, and problems with instruments used
to collect data. Finally, scientific aspects refer to assessing treatment safety, dose-response levels, treatment effects estimation and its variance (Thabane et al., 2010).

Despite its relevance, the development of feasibility or pilot studies for complex intervention studies had received little attention from the scientific community (Thabane et al., 2010) and, if published, the quality of reporting is usually poor (Arain et al., 2010). This is evidenced by the lack of guidelines for reporting this type of study (such as CONSORT for reporting RCT) as well as by the use of terms such as ‘pilot’ and ‘feasibility’ for referring to any study that is conducted prior to a large RCT (Thabane et al., 2010, Arain et al., 2010, Shanyinde et al., 2011, Moher et al., 2010). In an attempt to address these gaps, the differences between feasibility and pilot, the reasons for conducting one or the other type of study and how these should be reported have been recently discussed in the literature (Thabane et al., 2010, Arain et al., 2010, Shanyinde et al., 2011).

At the moment, there is no clear agreement for defining pilot and feasibility studies (Thabane et al., 2010, Arain et al., 2010, Shanyinde et al., 2011). While some authors suggest these are similar terms (Thabane et al., 2010), others propose they target different questions (Arain et al., 2010, Shanyinde et al., 2011). According to one definition, a pilot study can be considered as a miniature of the main study and it focuses on assessing whether the components of the research protocol work together; whereas a feasibility study can be defined as one that is conducted to estimate parameters that are required to better design the main study and it tends to be more flexible than a pilot study (Arain et al., 2010). Examples of such parameters include: willingness of participants to be randomized and clinicians/centres to recruit participants; characteristics of the proposed outcome measure and its standard deviation; follow-up and adherence rates; and response rates to questionnaires (Arain et al., 2010). Neither pilot or feasibility studies should focus on the effectiveness of an intervention as the primary aim (Thabane et al., 2010, Arain et al., 2010, Shanyinde et al., 2011). These studies should still be published, despite the likelihood of not having ‘significant’ findings (Arain et al., 2010). Some researchers have suggested guidelines in an attempt to improve the reporting of pilot and feasibility studies (Thabane et al., 2010).
1.5 The research problem

The Spineangel® is a relatively new device and only two studies have thus far been conducted with this device. The first was a case report (Horton and Abbott, 2008) and the second a cross-sectional laboratory-based study (Intolo et al., 2010). Numerous questions remain unanswered with regards to this instrument:

- Is the Spineangel® a reliable or valid postural monitoring tool when used clipped to belt or waistband?

- What is its measurement error when used to monitor posture in (a) a laboratory- and (b) a field-based setting?

- Would subjects use this device as a feedback tool for a prolonged period of time, such as one month? If so, what would the adherence rates be?

- Can it help to induce changes in postural behaviour? If so, what is the variability of postural behaviour change?

- What is the best form of providing postural feedback with the Spineangel®?

- Will people perceive the Spineangel® as a helpful tool to avoid potentially hazardous posture?

In order to find answers for these questions, a sequence of stepwise studies were conducted with the outcomes of each study used to inform the next one. Firstly, the reliability and validity of the Spineangel® needed to be defined. A study in a very controlled setting, with the Spineangel® attached to the skin at the iliac crest, had previously shown the device to provide reliable and valid pelvic measurements when forward bending with hands reaching the knee (Intolo et al., 2010). However, the reliability and validity of the Spineangel® when attached to the belt or waistband (as recommended by manufacturer) was unknown. Secondly, it was necessary to explore different forms of postural feedback delivery when using the Spineangel®. Therefore, a feasibility RCT was conducted to test a protocol for assessing the effectiveness of postural feedback for modifying work-related posture. The research field related to postural monitoring and feedback as...
rehabilitation or a prevention tool is still in its infancy and greater understanding of the role of these devices in the management or prevention of NSLBP is needed.

1.6 Aims of the Thesis

The overall aims of this thesis were to explore the measurement properties and the feasibility of utilizing the Spineangel® as a postural monitor and feedback device when fixed to the belt or waistband. The three specific aims were to:

1. Assess the within-task, within-day, and between-day reliability of the Spineangel® postural measurements;

2. Assess the validity of the Spineangel® as a postural monitor device;

3. Conduct a feasibility randomized controlled trial on the effectiveness of the Spineangel® as a postural monitor and feedback device to change postural behaviour.

1.7 Thesis structure

This thesis is a report of each stage of the research progress and is structured in 8 chapters. Chapter 2 is a systematic review with an aim of identifying the level of evidence for three cumulative postural domains: range of motion (ROM), duration, and frequency of trunk flexion as risk factors for LBP (Burdorf and van der Beek, 1999). Chapter 3 reviews the literature on the use of feedback and management of LBP and identifies different forms of feedback provision, discussing how it should ideally be provided to the user. Since a recent study critically reviewed the available technology on monitor and postural feedback devices (O'Sullivan et al., 2010b), it was deemed more appropriate to review the literature on the ideal forms of feedback provision. Chapter 4 is a cross-sectional study and describes the reliability and accuracy of the Polhemus Fastrak™ when used conjointly with the Spineangel® device. As the former was used as the gold standard for measuring lumbo-pelvic movement in Chapter 5, it was first necessary to assess its accuracy when the Spineangel® was placed close to the Fastrak™ sensors as metal within the sensor field has been shown to potentially distort Fastrak™ measurements (McGill et al., 1997). Chapter 5 is a cross-sectional study and presents the validity and reliability findings for measurements obtained by the Spineangel® as a lumbo-pelvic monitor. Chapter 6
is a cross-sectional field study and presents the within-day reliability of the Spineangel® as a lumbo-pelvic monitor during part of a work shift. The final study for this thesis was a feasibility study on the use of the Spineangel® as an intervention tool for changing postural behaviour. Testing it with a group of health care workers known to be at risk of occupational LBP was considered to be an appropriate and strategic option. This group of workers is considered to be exposed to hazardous posture (Kromark et al., 2009, Harcombe et al., 2009) and the recruitment of participants would be facilitated by establishing a partnership with a health care organization. Therefore, Chapter 7 reports a feasibility RCT on the effectiveness of the Spineangel® as an feedback device for modifying posture during work-related activities. Chapter 8 brings together a general discussion of all findings and presents future research directions for the Spineangel® as an ergonomic or rehabilitation tool. A rationale for the use of feedback devices as rehabilitation tools and a brief trial protocol for testing the effectiveness of the Spineangel® for ergonomics intervention are presented. The links between each chapter are illustrated in Figure 1-4.
Chapter 2  
Dose-response relationship between work-related cumulative postural exposure and LBP: a systematic review

Chapter 3  
Extrinsic feedback and the management of LBP: a critical review of the literature.

Chapter 4  
The reliability and accuracy of Fastrak™ when used conjointly with the Spineangel®.

Chapter 5  
The concurrent validity and reliability of the Spineangel® as a lumbopelvic monitor device.

Chapter 6  
Cumulative postural exposure measured by the Spineangel®: a cross-sectional field study.

Chapter 7  
The Spineangel® as a postural feedback device to change postural behaviour: a feasibility RCT.

Chapter 8  
General discussion and future research directions.

Figure 1-4. Flowchart thesis. LBP = low back pain; RCT = randomized controlled trial.
2 Dose-response relationship between work-related cumulative postural exposure and low back pain: A systematic review

2.1 Overview

The Spineangel® postural feedback threshold is dependent on three different cumulative postural domains: range of motion (ROM), duration and frequency with which trunk forward bending is performed. In order to define the postural threshold to be used for the field study (described in Chapter 7), a systematic review was conducted to assess the level of evidence for these three postural domains as risk factors for LBP (Burdorf and van der Beek, 1999).

2.1.1 Background

Mechanical and non-mechanical factors can be associated with development of LBP (Marras, 2008, Vandergrift et al., 2012, Marras et al., 2000, Marras, 2005). Non-mechanical factors can be both personal (e.g. age, gender, body mass index, back muscle strength and resistance, spinal mobility) and psychosocial (Vandergrift et al., 2012, da Costa and Vieira, 2010). While personal factors can explain up to 12% of first LBP occurrence (Adams et al., 1999), psychosocial factors seem to be more closely associated with the maintenance of the chronic stages of NSLBP (Ehrlich, 2003, Koes et al., 2006).

From a physical perspective the association between cumulative trauma and LBP is thought to be linked to repetitive spinal loading (Ben-Masaud et al., 2009, McGill, 2007). Mechanical factors, such as high physical demand, lifting tasks, and adoption of awkward postures (da Costa and Vieira, 2010) are important biomechanical variables for estimating risk during task assessment (Kumar, 1990, Norman et al., 1998, Waters et al., 2006). A wide range of mechanical risk factors for LBP have been reported in the literature, including peak lumbar shear force (Kerr et al., 2001), frequency of repetitive loading (Le et al., 2007), cumulative lumbar compression (Kerr et al., 2001, Kumar, 1990), cumulative spinal loads (Norman et al., 1998), cumulative lumbar extensor moments (Norman et al., 1998), external forces applied to the hand (Norman et al., 1998), peak spinal flexion
velocity (Norman et al., 1998), trunk lateral and twisting velocity (Marras et al., 1995), and the amount of trunk flexion (e.g. greater than 20°) (Punnett et al., 1991, Marras et al., 1995).

Subjects with LBP can also have increased co-contraction of spinal muscles, which has been linked to an increased risk of spinal tissue injury (Ferguson et al., 2004b). While laboratory studies have clearly shown that repetition, sustained load, and/or flexed posture can induce spinal neuromuscular disorders (Ben-Masaud et al., 2009, Parkinson et al., 2004), field studies have reported conflicting results (Bakker et al., 2009). The role of work posture as a risk factor for LBP is controversial and, while some studies report increased risk for workers exposed to flexed posture at work, current guidelines for LBP prevention suggest that there is limited evidence for posture as a risk factor for LBP (Burton et al., 2006). Due to the likely cumulative effect, duration (Parkinson et al., 2004, Milosavljevic et al., 2007), trunk ROM (Hoogendoorn et al., 2000a), and frequency of trunk flexion (Solomonow et al., 1999) are considered to be the three main domains that influence cumulative postural exposure (Burdorf and van der Beek, 1999). The interaction between these postural factors is complex and can lead to a non-linear reduction of tissue load-tolerance over time (Waters et al., 2006), contributing towards micro-rupture of lumbar soft-tissues (Solomonow et al., 2003a).

As indicated above, personal and psychosocial (non-mechanical) factors also contribute towards LBP (Vandergrift et al., 2012, da Costa and Vieira, 2010, Krause et al., 1998, Hoogendoorn et al., 2000b), while personal factors can explain up to 12% of first LBP occurrence (Adams et al., 1999). Psychosocial risk factors reported in the literature include stress, anxiety, negative emotions, and depression (Nicholas et al., 2011). It has also been suggested that work-related psychosocial factors such as high work demands, poor peer support at work, and low job control may increase the risk of LBP (Kerr et al., 2001). A recent study reported that these work-related psychosocial factors (high work demand and low job control) are associated with a new episode of LBP, but only if workers were exposed to high physical demands at work (Vandergrift et al., 2012). In addition, mental processing, work pace and a psychosocial stressful environment were reported to increase spinal loading, by increasing muscle co-contraction (Davis et al, 2002, Marras et al., 2000). The effect of psychosocial stress on spinal loading
may explain how psychosocial factors increase the risk of LBP. It is also accepted that a previous history of LBP is the most powerful predictor for a new episode of LBP (Burton et al., 2006).

In order to develop better injury prevention programmes, it is important to establish and understand the dose-response relationship between the effects of cumulative flexed posture and the development of LBP (Jansen et al., 2004, Vieira and Kumar, 2006). A recent systematic review focusing on awkward posture as a risk factor for LBP (Wai et al., 2010) included both quantitative and qualitative postural outcome measures. Although qualitative postural measures are commonly used, objective postural measurements are likely to provide more accurate information regarding work-related posture (Spielholz et al., 2001). In order to evaluate the role of cumulative posture exposure as a risk factor for LBP, a systematic review was conducted to assess the level of evidence for range of motion, duration and frequency of trunk flexion as risk factors for LBP by including only studies that adopted quantitative outcome measures.

### 2.2 Methods

#### 2.2.1 Eligibility criteria

To be eligible for inclusion, studies were required to be a prospective cohort or case-control design; focus on LBP (defined as discomfort and pain, with or without leg pain, above inferior gluteal folds and below the costal margin) (Waddell, 2004); be available in full report in a peer reviewed journal; study a working age population (18 to 67 years); describe job activity; describe occupational exposure related to posture; focus on postural exposure; and consider range of motion, duration or frequency of trunk flexion as independent variables. The following studies were excluded: of cross-sectional, quasi-experimental, RCT, thesis dissertations or literature review design; unrelated to occupational posture; focused on sitting posture; inclusion of patients with LBP during pregnancy or related to “red flag” conditions (such as osteoporosis and rheumatoid arthritis) (Bakker et al., 2009). No language restriction was imposed.
2.2.2 Literature search

The guidelines from the Cochrane Back Review Group (Furlan et al., 2009) were followed for the development of the search strategy (Table 2-1). The key terms included in the electronic searches of Medline (1966 to August 2011), Cumulative Index to Nursing and Allied Health Literature (CINAHL) (1982 to August 2011), EMBASE (1988 to August 2011), and Scopus (August, 2011) are listed in Table 2-1. Furthermore, reference lists of all retrieved articles were hand searched for additional potentially eligible studies.

Table 2-1. Search strategy and key terms used.

<table>
<thead>
<tr>
<th>Database</th>
<th>Keywords</th>
<th>Number of studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cinahl</td>
<td>(1) Case-Control Studies; (2) Prospective Studies; (3) Longitudinal Studies; (4) Cohort Studies; (5) Retrospective Studies; (6) 1 or 2 or 3 or 4 or 5; (7) causality; (8) etiology; (9) aetiology; (10) precipitating factors; (11) odds ratio; (12) risk; (13) risk factors; (14) 7 or 8 or 9 or 10 or 11 or 12 or 13; (15) back pain; (16) low back pain; (17) back injuries; (18) spinal injuries; (19) cumulative trauma disorder; (20) 15 or 16 or 17 or 18 or 19; (21) posture; (22) movement; (23) sustained posture; (24) lifting; (25) mechanical stress; (26) stooped; (27) trunk flexion; (28) 21 or 22 or 23 or 24 or 25 or 26 or 27; (29) 6 and 14 and 20 and 28;</td>
<td>13</td>
</tr>
<tr>
<td>Embase</td>
<td>(1) body posture; (2) &quot;movement (physiology)&quot;; (3) lifting or biomechanics; (4) mechanical stress; (5) stooped; (6) lifting effort; (7) trunk flexion or kinematics; (8) 1 or 2 or 3 or 4 or 5 or 6 or 7; (9) backache; (10) low back pain; (11) repetitive strain injury or cumulative trauma disorder or occupational disease; (12) 9 or 10 or 11; (13) epidemiology; (14) etiology; (15) risk; (16) risk factor; (17) 13 or 14 or 15 or 16; (18) case control study; (19) prospective study; (20) longitudinal study; (21) cohort analysis; (22) retrospective study; (23) 18 or 19 or 20 or 21 or 22; (24) 8 and 12 and 17 and 23;</td>
<td>47</td>
</tr>
<tr>
<td>Medline</td>
<td>(1) Posture; (2) movement; (3) sustained posture; (4) &quot;Moving and Lifting Patients&quot;/ or Lifting/ or Weight Lifting; (5) Mechanical stress; (6) stooped; (7) trunk flexion; (8) 1 or 2 or 3 or 4 or 5 or 6 or 7; (9) back pain; (10) low back pain; (11) back injuries; (12) spinal injuries; (13) cumulative trauma disorders; (14) 9 or 10 or 11 or 12 or 13; (15) Causality; (16) etiology; (17) aetiology; (18) precipitating factors; (19) odds ratio; (20) risk or risk factors; (21) 15 or 16 or 17 or 18 or 19 or 20; (22) Case-Control Studies; (23) Prospective Studies; (24) Longitudinal Studies; (25) Cohort Studies; (26) Retrospective Studies; (27) 22 or 23 or 24 or 25 or 26; (28) 8 and 14 and 21 and 27 and 29; (30) Osteoarthritis/ or Osteoarthritis, Spine; (31) Arthritis; (31) Pregnancy; (32) Thoracic Vertebrae/ or Thoracic Injuries; (33) Cervical Vertebrae; (34) 29 or 30 or 31 or 32 or 33; (35) 28 not 34;</td>
<td>66</td>
</tr>
<tr>
<td>Scopus</td>
<td>(1) posture; (2) movement; (3) sustained posture; (4) lifting; (5) mechanical stress; (6) stooped; (7) trunk flexion; (8) 1 or 2 or 3 or 4 or 5 or 6 or 7; (9) back pain; (10) low back pain; (11) back injuries; (12) spinal injuries; (13) cumulative trauma disorder; (14) 9 or 10 or 11 or 12 or 13; (15) causality; (16) etiology; (17) aetiology; (18) precipitating factors; (19) odds ratio; (20) risk; (21) risk factor; (22) 15 or 16 or 17 or 18 or 19 or 20 or 21; (23) case control study; (24) prospective study; (25) longitudinal study; (26) cohort study; (27) retrospective study; (28) 23 or 24 or 25 or 26 or 27; (29) osteoarthritis; (30) spine osteoarthritis;</td>
<td>168</td>
</tr>
</tbody>
</table>
2.2.3 Study selection

Endnote software (v.12) was used for electronic storage of all identified studies. Following exclusion of duplicates, the principal investigator (DCR) screened all identified titles and article types for relevance. At this stage, only unrelated publications such as thesis dissertations and review articles were excluded. Two reviewers (DCR and DA) then screened all search results for potentially relevant titles and abstracts. Potentially eligible articles were then accessed in full text format and fully screened by DCR and DA against the inclusion and exclusion criteria. Disagreement between reviewers was either resolved by discussion and arrival at a consensus. Where consensus could not be achieved, a third reviewer (GS) resolved the disagreement by forming a majority opinion. The reviewers were not blinded to journal titles, authors and institutions, as blinding has been shown not to affect study selection and data extraction (Berlin, 1997).

2.2.4 Data collection

The methods used for data collection and analysis followed recommendations published by the Cochrane Back Review Group (Furlan et al., 2009), as well as the Cochrane Handbook for Systematic Reviews for Interventions (Higgins and Green, 2009). Data were extracted from all included studies by one reviewer (DCR), and subsequently confirmed by a second reviewer (DA). These data included the following: study design; study population; setting (occupation); job characteristics; response rates; type of LBP outcome (acute, chronic, or recurrent); measurement and control of LBP confounders (physical and psychosocial factors); association measurement for risk (relative risk or odds ratio, and the confidence interval values) between posture (range of motion, duration of sustained posture or frequency of bending) and LBP; statistical information (statistical methods, significance values, adjustment for confounders). Disagreement between reviewers was either resolved by discussion and agreement, or resolved by consultation with a third review author (GS) if required.
2.2.5 Summary measures

The extracted summary measures refer to risk estimate (e.g. odds ratio, relative risk) for three domains of flexed trunk posture: trunk range of motion; duration of sustained posture; and frequency in which the flexed posture was adopted. Odds ratio is a relative measure of risk, while relative risk is the probability that a subject in an exposed group will develop a disorder (e.g. LBP) relative to the probability that a subject in an unexposed group will develop the same disorder. Both measures do not imply causation.

2.2.6 Assessment for risk of bias in included studies

Risk of bias in the included studies was assessed by DCR and DA, independently, using the Newcastle-Ottawa Scale (NOS) for observational studies (Wells et al., 2010). The criteria adopted for each item are described in Table 2-4 and Table 2-5. Disagreement between reviewers was either resolved by discussion or by use of the third reviewer as previously described. For the purpose of this study, high-quality studies were considered as those with a summative quality score of at least 5, and where appropriate statistical analysis was used (e.g. risk adjustment) (Wai et al., 2010).

2.2.7 Statistical analysis

Heterogeneity of outcome measures meant data were considered too disparate for further subgroup analysis between postural variables (trunk range of motion, duration of sustained posture, and frequency in which the flexed posture was adopted) and LBP variables (acute, chronic, and recurrent LBP). SPSS version 16 (SPSS Inc. Illinois, USA) software was used for statistical analysis. Inter-rater reliability for assessment of risk of bias agreement between reviewers was measured by use of the Kappa statistic. Qualitative syntheses and analyses of data were primarily based on The Guidelines for Systematic Reviews in the Cochrane Back Review Group (Furlan et al., 2009). As the Cochrane Back Review Group recommends the use of five levels of evidence the following descriptors were adopted: strong, moderate, limited, unclear and no evidence (Table 2-2) (Furlan et al., 2009).
Table 2-2. Level of evidence for assessing posture as a risk factor for low back pain.

<table>
<thead>
<tr>
<th>Level of Evidence</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strong evidence</strong></td>
<td>Consistent findings reported in at least 75% high quality studies (NOS rating ≥5), no limitation on study design, direct and precise data and no known or suspected publication biases.</td>
</tr>
<tr>
<td><strong>Moderate evidence</strong></td>
<td>One of the listed domains (i.e. study design, direct and precise data, publication bias) were not met.</td>
</tr>
<tr>
<td><strong>Limited evidence</strong></td>
<td>Two of the domains (i.e. study design, direct and precise data, publication bias) were not met.</td>
</tr>
<tr>
<td><strong>Unclear evidence</strong></td>
<td>Three of the domains (i.e. study design, direct and precise data, publication bias) were not met.</td>
</tr>
<tr>
<td><strong>No evidence</strong></td>
<td>No studies found.</td>
</tr>
</tbody>
</table>

2.3 Results

2.3.1 Study Selection

The search strategy resulted in 294 studies, of which 42 were included for full assessment. Thirty-four studies did not meet final selection criteria leaving 8 studies for full review (Hoogendoorn et al., 2000a, Harkness et al., 2003, Jansen et al., 2004, Van Nieuwenhuyse et al., 2006, Yip, 2004, Punnett et al., 1991, Josephson and Vingård, 1998, Miranda et al., 2002). Of these, 6 were prospective cohort studies (Hoogendoorn et al., 2000a, Harkness et al., 2003, Jansen et al., 2004, Van Nieuwenhuyse et al., 2006, Yip, 2004, Miranda et al., 2002) and 2 were case-control studies (Punnett et al., 1991, Josephson and Vingård, 1998). As three studies (Hoogendoorn et al., 2000a, van den Heuvel et al., 2004, Hamberg-van Reenen et al., 2006) analysed the same sample, only the 2000 article by Hoogendoorn et al. (2000a) was reviewed. The included studies yielded a total of 7,023 subjects who completed follow-up and were considered for risk analysis. The detailed stages through studies selection and reason for exclusion are described in Figure 2-1.
2.3.2 Study characteristics

Study characteristics are presented in Table 2-3.
<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>Participants</th>
<th>Type of LBP/LBP definition</th>
<th>Follow-up</th>
<th>Methods of investigation</th>
<th>Independent variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harkness et al. (2003)</td>
<td>PC</td>
<td>788 workers from 12 diverse occupational groups. All participants were asymptomatic</td>
<td>New-onset LBP/Pain localized between the 12th rib and gluteal folds lasting for more than 24 h in the last month</td>
<td>1 year: 625 (79%); 2 years: 430 (86%)</td>
<td>LBP: Self-report; Physical Exposure:</td>
<td></td>
</tr>
<tr>
<td>Hoogendoorn et al. (2000a)</td>
<td>PC</td>
<td>861 blue or white-collar jobs from 34 companies</td>
<td>LBP/Regular or prolonged symptoms in the last 12 months</td>
<td>3 years</td>
<td>1) Questionnaire; 2) Physical Examination; 3) Workplace physical load assessment</td>
<td>Trunk flexion ≥ 30°, 5-10% worktime; Trunk flexion ≥ 30°, &gt; 10% worktime; Trunk flexion ≥ 30°, &gt; 10% worktime or Trunk flexion ≥ 60°, ≤ 5% worktime; Trunk flexion ≥ 60°, &gt; 5% worktime;</td>
</tr>
<tr>
<td>Jansen et al. (2004)</td>
<td>PC</td>
<td>769 workers from 7 nursing homes</td>
<td>LBP and LBP with Disability. LBP: any episode of pain lasting for at least a few hours in the last 12 months. LBP with disability: LBP with a disability score &gt; 50.</td>
<td>12 months Drop-out: 32%</td>
<td>1) Questionnaire, 2) Observational multimoment method</td>
<td>Trunk flexion between 20 – 45°; Trunk flexion &gt; 45°;</td>
</tr>
<tr>
<td>Josephson et al. (1998)</td>
<td>CC</td>
<td>694 cases; 1423 controls, population based</td>
<td>LBP/ Definition unclear</td>
<td>36 months</td>
<td>Interview</td>
<td>Working in forward bending position for (duration): &lt; 60 min/day; &gt; 60 minutes/day.</td>
</tr>
<tr>
<td>Miranda et al. (2002)</td>
<td>PC</td>
<td>327 cases; 2077 controls from a forest industry company.</td>
<td>Sciatic pain/ Low back pain with radiating below the knee for &gt; 7 days in the last 12 months</td>
<td>36 months</td>
<td>Questionnaire</td>
<td>Working in forward flexed trunk: &lt; 1/2 hour/day; 1/2 to 1 hour/day; 1-2 hour/day &gt; 2 hour/day</td>
</tr>
<tr>
<td>Study</td>
<td>Design</td>
<td>Participants</td>
<td>Type of LBP/ LBP definition</td>
<td>Follow-up</td>
<td>Methods of investigation</td>
<td>Independent variable</td>
</tr>
<tr>
<td>-----------------------</td>
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<td>--------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------</td>
<td>-----------</td>
<td>--------------------------</td>
<td>--------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Punnett et al. (1991)</td>
<td>CC</td>
<td>95 cases; 135 controls from an automobile assembly</td>
<td>LBP/ At least 3 different episodes or one episode lasting for at least one week, in the last 12 months</td>
<td>10 months</td>
<td>Videotape</td>
<td>ROM Mild forward flexion (21 – 45° of trunk flexion) 0 – 10% of cycle time; Mild forward flexion (21 – 45° of trunk flexion) ≥ 10% of cycle time; Severe forward flexion (&gt; 45° of trunk flexion) 0 – 10% of cycle time; Severe forward flexion (&gt; 45° of trunk flexion) ≥ 10% of cycle time;</td>
</tr>
<tr>
<td>Van Nieuwenhuyse et al. (2006)</td>
<td>PC</td>
<td>716 health care or distribution workers</td>
<td>LBP/ Low back pain with radiating below the knee for ≥ 7 days in the last 12 months</td>
<td>12 months: Drop-out: 16%</td>
<td>1) Questionnaire</td>
<td>≤ 2 hours spent in bending and twisted posture; &gt; 2 hours spent in bending and twisted posture;</td>
</tr>
<tr>
<td>Yip (2004)</td>
<td>PC</td>
<td>144 nurses</td>
<td>LBP/ Discomfort between lower costal margins and gluteal folds, with or without radiation below the knee for at least one day in the last 12 months</td>
<td>12 months. Drop-out: 35.7%</td>
<td>Self-report</td>
<td>Bending to lift an item from the floor level (tertiles)</td>
</tr>
</tbody>
</table>

PC = prospective cohort study; CC = case-control; LBP = low back pain; ROM = range of motion.
2.3.3 Risk of bias within studies

All included studies were rated as high quality with the scores presented in Table 2-4 and Table 2-5 for cohort and case-control studies, respectively. Interrater reliability for assessment of risk of bias agreement between reviewers, measured by means of Kappa analysis, was found to be moderate (Cohen’s kappa: 0.60). Extracted data regarding changes in risk of LBP associated with posture exposure is presented in Table 2-6. The findings are presented in three categories of cumulative postural exposure: ROM, frequency and duration of trunk flexion.
Table 2-4. Risk of bias for cohort studies based on Newcastle-Ottawa Quality assessment scale.

<table>
<thead>
<tr>
<th>Study</th>
<th>Selection</th>
<th>Comparability</th>
<th>Outcome</th>
<th>Total Score*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3 4 5</td>
<td>6 7 8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(including Hamberg-van Reenen et al. (2006), and van den Heuvel (2004))</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total Score* = calculated by the sum of stars (*)

**Selection**

1) Representativeness of the exposed cohort
   A) truly representative of the average in the community (≥75%)*
   B) somewhat representative of the average in the community (>50% or <75%)*
   C) selected group of users e.g. nurses, volunteers
   D) no description of the derivation of the cohort

2) Selection of the non-exposed cohort
   A) drawn from the same community as the exposed cohort *
   B) drawn from a different source
   C) no description of the derivation of the non-exposed cohort

3) Ascertainment of exposure
   A) secure record (e.g. surgical records) *
   B) structured interview *
   C) written self-report
   D) no description

4) Demonstration that outcome of interest was not present at start of study
   A) yes *
   B) no

**Comparability**

5) Comparability of cohorts on the basis of the design or analysis
   A) study controls for personal factors *
   B) study controls for any additional factor (psychosocial factors) *

**Outcome**

6) Assessment of outcome
   A) independent blind assessment *
   B) record linkage (validated questionnaire, e.g. Nordic questionnaire) *
   C) self-report
   D) no description

7) Was follow-up long enough for outcomes to occur
   A) yes (at least one year) *
   B) no

8) Adequacy of follow up of cohorts
   A) complete follow up - all subjects accounted for *
   B) subjects lost to follow up unlikely to introduce bias - small number lost - > 80% *
   C) follow up rate < 75% (select an adequate %) and no description of those lost
   D) no statement
Table 2.5. Risk of bias for case-control studies based on Newcastle-Ottawa Quality assessment scale.

<table>
<thead>
<tr>
<th>Study</th>
<th>Selection</th>
<th>Comparability</th>
<th>Exposure</th>
<th>Total Score*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1  2  3  4</td>
<td>5</td>
<td>6  7  8</td>
<td></td>
</tr>
</tbody>
</table>

Total Score* = calculated by the sum of stars (*)

**Selection**

1) Is the case definition adequate?
   - A) yes, with independent validation *
   - B) yes, e.g. record linkage or based on self-reports
   - C) no description

2) Representativeness of the cases
   - A) consecutive or obviously representative series of cases *
   - B) potential for selection biases or not stated

3) Selection of Controls
   - A) community controls *
   - B) hospital controls
   - C) no description

4) Definition of Controls
   - A) no history of disease (endpoint) *
   - B) no description of source

**Comparability**

5) Comparability of cases and controls on the basis of the design or analysis
   - A) study controls for personal factors *
   - B) study controls for any additional factor psychosocial factors *

**Exposure**

6) Ascertainment of exposure
   - A) secure record (e.g. surgical records) *
   - B) structured interview where blind to case/control status *
   - C) interview not blinded to case/control status
   - D) written self-report or medical record only
   - E) no description

7) Same method of ascertainment for cases and controls
   - A) yes *
   - B) no

8) Non-Response rate
   - A) same rate for both groups *
   - B) non respondents described
   - C) rate different and no designation
2.3.4 Results of individual studies

The risk of LBP associated with cumulative flexed posture categories (ROM and duration) for each study is described in Table 2-6. All studies, with the exception of Harkness et al. (2003), identified increased risk for LBP when both duration and ROM increased (Table 2-6); however, confidence intervals for estimates of risk were wide. No studies investigating frequency of trunk flexion as a risk factor for LBP were identified.
Table 2-6. Causation effect for posture exposure and LBP.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Crude Association (95% CI)</th>
<th>Adjusted Association (95% CI)</th>
<th>Adjusted for</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harkness et al (2003)</td>
<td>OR bending &lt; 15 min: 1.6 (1.1 to 2.3); OR bending ≥ 15 min: 1.3 (0.8 to 1.9)</td>
<td>OR bending &lt; 15 min: 1.3 (0.9 to 2.0); # OR bending ≥ 15 min: 1.0 (0.6 to 1.5) §</td>
<td># Adjusted for gender, age group and occupation; § adjusted for gender, age group, occupation and all other postures</td>
</tr>
<tr>
<td>Hoogendoorn et al (2000a)</td>
<td>Trunk flexion ≥ 30°, 5-10% worktime: RR = 0.98 (0.68 to 1.41); Trunk flexion ≥ 30°, &gt; 10% worktime: RR = 1.17 (0.86 to 1.59); Trunk flexion ≥ 30°, &gt; 10% worktime or Trunk flexion ≥ 60°, ≤ 5% worktime: RR = 1.08 (0.77 to 1.53); Trunk flexion ≥ 60°, &gt; 5% worktime: RR = 1.42 (0.88 to 2.30)</td>
<td>Trunk flexion ≥ 30°, 5-10% worktime: RR = 1.04 (0.70 to 1.54); Trunk flexion ≥ 30°, &gt; 10% worktime: RR = 1.19 (0.86 to 1.65); Trunk flexion ≥ 30°, &gt; 10% worktime or Trunk flexion ≥ 60°, ≤ 5% worktime: RR = 1.09 (0.76 to 1.58); Trunk flexion ≥ 60°, &gt; 5% worktime: RR = 1.48 (0.90 to 2.42)</td>
<td>Gender, age, exercise behaviour during leisure time, quantitative job, demands, decision authority, skill discretion, supervisor support, co-worker support, moving of heavy loads during leisure time, flexion and/or rotation of the upper part of the body during leisure time, driving a vehicle during leisure time, and driving a vehicle at work.</td>
</tr>
<tr>
<td>Jansen et al. (2004)</td>
<td>LBP Trunk flexion between 20 – 45°: 2 h/week (reference) 3 h/week: RR = 1.25 (0.66 to 2.37); 4 h/week: RR = 1.55 (0.44 to 5.37); 5 h/week: RR = 1.55 (0.42 to 5.66); 6 h/week: RR = 1.13 (0.30 to 4.22)</td>
<td>LBP Trunk flexion between 20 – 45°: 2 h/week (reference) 3 h/week: RR = 1.12 (0.71 to 1.77); 4 h/week: RR = 1.25 (0.51 to 3.07); 5 h/week: RR = 1.21 (0.44 to 3.30); 6 h/week: RR = 0.91 (0.34 to 2.47)</td>
<td>Lifting and carrying loads over 10 kg, decision authority, skill discretion, psychosocial demands, year of employment in the facility and age at baseline.</td>
</tr>
<tr>
<td></td>
<td>Trunk flexion &gt; 45°: 30 min/week (reference) 45 min/week: RR = 0.99 (0.66 to 1.49); 1 h/week: RR = 0.98 (0.43 to 2.23); 1 h 30 min/week: RR = 1.31 (0.42 to 4.11); 1 h 45 min/week: RR = 2.02 (0.60 to 6.83)</td>
<td>Trunk flexion &gt; 45°: 30 min/week (reference) 45 min/week: RR = 1.08 (0.90 to 1.30); 1 h/week: RR = 1.16 (0.80 to 1.68); 1 h 30 min/week: RR = 1.34 (0.66 to 2.74); 1 h 45 min/week: RR = 1.40 (0.61 to 3.22)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LBP with disability Trunk flexion between 20 – 45°: 2 h/week (reference) 3 h/week: RR = 0.83 (0.33 to 2.09)</td>
<td>LBP with disability Trunk flexion between 20 – 45°: 2 h/week (reference) 3 h/week: RR = 0.95 (0.53 to 1.72)</td>
<td></td>
</tr>
<tr>
<td>Authors</td>
<td>Crude Association (95% CI)</td>
<td>Adjusted Association (95% CI)</td>
<td>Adjusted for</td>
</tr>
<tr>
<td>-------------------</td>
<td>--------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>4 h/week: RR = 0.70 (0.12 to 4.20)</td>
<td>4 h/week: RR = 0.90 (0.28 to 2.87)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5 h/week: RR = 0.60 (0.08 to 4.57)</td>
<td>5 h/week: RR = 0.83 (0.22 to 3.18)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 h/week: RR = 0.50 (0.07 to 3.72)</td>
<td>6 h/week: RR = 0.80 (0.19 to 3.32)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trunk flexion &gt; 45°: 30 min/week (reference)</td>
<td>Trunk flexion &gt; 45°: 30 min/week (reference)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>45 min/week: RR = 1.56 (0.91 to 2.68)</td>
<td>45 min/week: RR = 1.31 (1.03 to 1.65)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 h/week: RR = 2.44 (0.83 to 7.16)</td>
<td>1 h/week: RR = 1.71 (1.08 to 2.72)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 h 30 min/week: RR = 6.49 (1.28 to 32.98)</td>
<td>1 h 30 min/week: RR = 2.82 (1.16 to 6.86)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 h 45 min/week: RR = 9.82 (2.05 to 47.10)</td>
<td>1 h 45 min/week: RR = 3.18 (1.13 to 9.00)</td>
<td></td>
</tr>
<tr>
<td>Josephson et al (1998)</td>
<td>Working in forward bending position for: OR = 4.3 (1.6 to 12)</td>
<td>Working in forward bending position for: OR = 4.3 (1.6 to 12)</td>
<td>Age, smoking, high energetic workload, high perceived physical exertion, low intellectual discretion, Insufficient social support, Temporary employment, part-time work, night shifts.</td>
</tr>
<tr>
<td></td>
<td>Trunk flexion &gt; 45°: 30 min/week (reference)</td>
<td>Trunk flexion &gt; 45°: 30 min/week (reference)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>45 min/week: RR = 1.56 (0.91 to 2.68)</td>
<td>45 min/week: RR = 1.31 (1.03 to 1.65)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 h/week: RR = 2.44 (0.83 to 7.16)</td>
<td>1 h/week: RR = 1.71 (1.08 to 2.72)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 h 30 min/week: RR = 6.49 (1.28 to 32.98)</td>
<td>1 h 30 min/week: RR = 2.82 (1.16 to 6.86)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 h 45 min/week: RR = 9.82 (2.05 to 47.10)</td>
<td>1 h 45 min/week: RR = 3.18 (1.13 to 9.00)</td>
<td></td>
</tr>
<tr>
<td>Miranda et al. (2002)</td>
<td>Working in forward flexed trunk €: - ≤ 30 min/day: OR = 1.0</td>
<td>Working in forward bending position for: OR = 2.2 (0.7 to 10)</td>
<td>Sex, age, smoking, mental stress, walking, twisting movements of the trunk, working in kneeling or squatting position, and working with the hand above shoulder level.</td>
</tr>
<tr>
<td></td>
<td>- 30-60 min/day: OR = 1.2 (0.8 to 1.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- 1-2 hours/day: OR = 1.3 (0.8 to 2.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- ≥ 2 hours/day: OR = 2.1 (1.4 to 3.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>€ = values adjusted for age and sex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Punnett et al. (1991)</td>
<td>Forward flexion between 21 – 45°: OR = 4.2 (p = 0.014)</td>
<td>Time nonneutral posture (sum of durations of mild, severe and twisting): OR = 8.09 (1.5 to 44.0)</td>
<td>Gender, age, years of employment, years and the plant, history of back injuries, ruptured spinal disc, history of systemic disease, recreational activity, sport at leisure time, lifting tasks, estimated peak compressive force at lumbar spine, twist and lateral bending.</td>
</tr>
<tr>
<td></td>
<td>- ≥10% of cycle time: OR = 6.1 (p = 0.014)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Forward flexion &gt; 45° of trunk flexion: - 0-10% of cycle time: OR = 4.2 (p = 0.014)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Authors</td>
<td>Crude Association (95% CI)</td>
<td>Adjusted Association (95% CI)</td>
<td>Adjusted for</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>--------------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Van Nieuwenhuyse et al. (2006)</td>
<td>- ≤ 2 hours spent in bent and twisted posture: RR = 1.44 (0.86 to 2.42); &gt; 2 hours spent in bent and twisted posture: RR = 2.35 (1.28 to 4.31);</td>
<td>≤ 2 hours spent in bent and twisted posture: RR = 1.30 (0.77 to 2.20); &gt; 2 hours spent in bent and twisted posture: RR = 2.21 (1.20 to 4.07);</td>
<td>Age, sex, inability to change posture regularly, regular recreational sport, pushing or pulling heavy loads, standing for long periods, possibilities to develop skills, job satisfaction, psychological job demands, previous LBP, perceived general health, previous upper limb pain, pain related fear, family situation, language, BMI, pain catastrophizing, previous lower limb pain.</td>
</tr>
<tr>
<td>Yip et al. (2004)</td>
<td>Bending to lift an item from the floor level: Middle tertile p ≤ 0.01</td>
<td>Bending to lift an item from the floor level:</td>
<td>Age</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Middle tertile: RR = 0.66 (0.25 to 1.75)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Highest tertile: RR = 2.76 (1.06 to 7.22)</td>
<td></td>
</tr>
</tbody>
</table>

CI = confidence interval; OR = odds ratio; RR = relative risk; BMI = body mass index; LBP = low back pain.
2.3.5 Synthesis of results

2.3.5.1 Range of motion

Three studies reported different levels of exposure with respect to duration at differing ranges of trunk flexion motion as a risk factor for LBP (Hoogendoorn et al., 2000a, Jansen et al., 2004, Punnett et al., 1991). Hoogendoorn et al. (2000a) reported moderately increased risk for LBP for workers who sustained a work posture either: a) at a minimum of 30° of trunk flexion for more than 10% of work time or; b) at a minimum of 60° for more than 5% of work time. Punnet et al. (1991) found increased risk for LBP when workers are exposed to either 20 to 45°, or more than 45° of trunk flexion, despite duration of exposure (less or more than 10% of work time). Punnet et al. (1991) present an adjusted association for a combined postural variable (time in non-neutral) which reflects the sum of durations of mild and severe flexion and twisting (Table 2-6). Jansen et al. (2004) used the same cut-off ROM values and found trunk flexion between 20 to 45° and more than 45° were weak risk factors (RR values ranging from 1.08 to 1.4) for LBP incident, regardless of the time spent in such postures (Table 2-6). However, these authors found increasing strengths of association with LBP (with disability) when trunk flexion was held above 45° for longer than 45 minutes, with the strongest RR (3.18) demonstrated at 1.50 hour/week (Jansen et al., 2004). This result is significant and the 95% confidence interval ranged from 1.13 to 9.00. There is a lack of similarity for ROM risk estimates between studies and divergent LBP definitions were adopted by all of these studies. As a result, it is concluded that there is only limited evidence for ROM as a risk factor for LBP.

2.3.5.2 Duration

Six articles reported different categories for quantifying the duration of trunk flexion (Table 2-6) (Harkness et al., 2003, Van Nieuwenhuyse et al., 2006, Yip, 2004, Josephson and Vingård, 1998, Miranda et al., 2002, Punnett et al., 1991). Harkness et al. (2003) found a weak association between trunk flexion sustained for more than 15 min and new-onset LBP. Josephson et al. (1998) found increased risk for LBP when a flexed posture was adopted for longer than 60 min/working day. Miranda et al. (2002) found the risk (OR = 2.1) for sciatic pain was significant when the time spent in a flexed posture was greater than 2 hours (Miranda et al., 2002). The odds ratio for this model was adjusted for sex and age (Table 2-6). Van
Nieuwenhuyse et al. (2006) identified increased relative risk for LBP (RR = 2.21) when more than 2 hours/day was spent in bent and twisted postures. These authors have not attempted to independently analyse the flexed and twisted components of this posture. The results from Yip (2004) also suggest an increased risk for LBP when bending to lift an item from the floor during a work shift. This study does not present relative risk estimates but describes the association, measured by the chi-square test, between posture and new LBP symptoms (Yip, 2004). Punnet et al. (1991) reported an increased risk for LBP for workers who adopted nonneutral posture (OR = 8.09). As presented in Table 2-6, confidence interval values are wide for all duration risk estimates. Furthermore, there is a lack of similarity for duration risk estimates between studies as well as for LBP definition. As a result, it is concluded that there is only limited evidence for duration as a risk factor for LBP.

2.3.6 Frequency

No studies reporting quantitative frequency of trunk flexion were identified.

2.4 Discussion

2.4.1 Summary of evidence

This study has explored the dose-response relationships between work-related posture and LBP. Limited evidence has been found for relationships between work-related ROM, duration of postures and risk of LBP. Due to considerable heterogeneity in categories for ROM and duration of exposure, LBP definition and adjustment for risk estimates, meta-analysis was precluded and a qualitative synthesis was alternatively described. Despite this heterogeneity the use of the NOS quality assessment tool rated the 8 included studies as high quality.

The literature describes three cumulative domains associated with working in a flexed posture (ROM, duration and frequency) (Parkinson and Callaghan, 2009, Milosavljevic et al., 2007, Burdorff and van der Beek, 1999). These can interact and lead to non-linear reduction of tissue load-tolerance with time (Waters et al., 2006). The interplay between cumulative postural exposure and cumulative load exposure can lead to different types of structural injury (Parkinson and Callaghan, 2009). Repetitive trunk flexion associated with high
load magnitude can lead to vertebral end plate fracture, while repetitive trunk flexion with low load magnitude can also cause intervertebral disc injury (Parkinson and Callaghan, 2009). While end-plate fractures have been shown to occur with high spinal compression, the load required for mechanical failure decreases as spinal flexion increases (Gunning et al., 2001). During work-related tasks, workers are likely to adopt hazardous postures while handling external loads, and are likely to expose spinal tissues to creep deformation and stress-relaxation (Parkinson et al., 2004). The main challenge seems to precisely quantify such load and postural exposures during observational studies (Vieira and Kumar, 2004). This review focused on postural exposure and identified a number of different and divergent measures of postural exposure.

These divergent postural measures ruled out the use of meta-analysis, thus the results and arguments are presented by descriptive comparison. Consensus on postural measurement is therefore needed for comparative assessment of work-related posture in observational studies. These uncertain relationships suggest that the three domains (ROM, duration of sustained posture, frequency of trunk flexion in a work day) are under-estimated as mechanical risk factors for LBP. Different definitions for LBP were also used by the various authors. For example, Hoogendoorn et al. (2000a) examined regular or prolonged LBP in the last 12 months while Miranda et al. (2002) examined sciatic pain for at least 7 days in the past 12 months (Table 2-3). Additionally, estimates of risk were adjusted for different variables (Table 2-6). As an example, Yip (2004) adjusted estimates of risk for age, while, Hoogendoorn et al. (2000a) adjusted for numerous variables including the following: gender, age, exercise behaviour during leisure time, quantitative job demands, decision authority, and skill discretion. It is suggested that an initiative such as the Outcome Measures in Rheumatology (OMERACT) (Tugwell et al., 2007), introduced by a group of rheumatology researchers to improve outcome measurements related to their field, should be developed for this field of research. Ideally, consensus for outcome measures for ROM, duration and frequency of trunk flexion should be established. These guidelines could also be expanded for trunk rotation and lateral bending. It is likely that, after establishing such guidelines, future research will help to improve current knowledge regarding posture as a risk factor for LBP. Researchers, ergonomists, and health professionals should work together towards the development of consensus for
measures of postural exposure and LBP definition for future studies assessing posture as a risk factor for LBP.

Although this review has not shown strong relationships between posture and LBP the comparative methodological limitations of the included studies preclude an interpretation of no relationship between these variables. Repetitive or sustained trunk flexion has been found to reduce tension in lumbar spine viscoelastic tissues and increase spinal muscle activity (Olson et al., 2009, Solomonow et al., 2003a), and to induce ligament injury and muscle spasm (Solomonow et al., 2003b) as well as changes in spinal ligament-muscle reflex thresholds (Olson et al., 2009). Such ligament and neuromuscular changes are considered to be related to LBP (Panjabi, 2006). Posture is also closely related to spinal tissue loads that occur dependent on how workers perform a task (McGill et al., 2003). The relationship between spinal tissue load and spinal injury is considered to be “U” shaped where very low or very high spinal tissue loads are likely to lead to spinal tissue injury (McGill, 2009). Low spinal tissue loads do not stimulate healthy tissue adaptation, while high spinal tissue load may lead to tissue disruption (McGill, 2009). A similar relationship has been reported for physical activity levels and LBP (Heneweer et al., 2009). The challenge is to identify the ideal amount of spinal tissue load relative to the many postures undertaken in daily living activities and workplace demands. When attempting to minimise for low back injury, not only external load magnitude but also posture, neuromuscular patterns, and spinal kinematics can modulate how spinal tissues will adapt or fail (McGill, 2009, McGill et al., 2003, Gunning et al., 2001, Callaghan and McGill, 2001). A further challenge for reducing risk of low back injury is that the ideal spinal tissue load is likely to vary amongst individuals. Some workers may thus tolerate certain levels of postural exposure while others may develop LBP at similar levels, particularly when compounded by psychosocial factors (Vandergrift et al., 2012). Further research is necessary to identify postural ranges that consistently lead to increased risk for developing LBP. The use of portable and reliable postural monitor devices, such as inclinometers, may provide objective and valuable information regarding this topic (Trask et al., 2007, Teschke et al., 2009). Consensus on postural outcome measures will enhance future epidemiological investigations regarding the role of posture as a risk factor for occupational LBP.
2.4.2 Strengths and Limitations

This review focused only on studies reporting quantitative outcome measures. Studies that reported qualitative exposure for trunk posture (e.g. Likert scales such as not often, often, and very often, etc.) were excluded. No evidence relating to frequency of trunk flexion as a risk factor for LBP was found. However, studies that have qualitatively assessed frequency of trunk flexion (Plouvier et al., 2008, Gheldof et al., 2007) were identified. When attempting to establish a dose-response relationship between cumulative trunk flexion exposure and LBP, qualitative categories of exposure might not provide sufficient information.

The quantification of exposure in the included studies was done by means of different techniques (e.g. interview, self-report, validated questionnaire, videotape), that are likely to have varying degrees of validity. Considering these findings: there is a need to improve quantitative measurements for postural exposure at the workplace (Vieira and Kumar, 2004). Currently, it seems that the risk of cumulative postural exposure has been underestimated due to poor kinematic measurement (Straker et al., 2010).

2.4.3 Previous systematic review

One published systematic review related to trunk flexion as a risk factor for occupational LBP (Wai et al., 2010) was identified. That review included studies where no clear or quantitative definitions were described for “awkward” posture. In contrast, the present review has included only studies with quantitative outcomes for posture as a risk factor for LBP. A further difference was the methods used to grade the quality of evidence. While the present review has adopted the suggested criteria by the Cochrane Back Review Group, Wai et al. (2010) have adopted combined results from the Agency for Health Care Policy and Research and Oxford Centre for Evidence-Based Medicine. Those authors found conflicting evidence for trunk flexion and twisting as risk factors for LBP (Wai et al., 2010) and limited evidence for range of motion, duration and frequency of trunk flexion as risk factors for LBP. These methodological differences are probably the reason for the disparity in the comparative summary of evidence findings between the current investigation and that of Wai et al. (2010).
2.4.4 Implications for the feasibility RCT (Chapter 7)

This review was carried-out to identify postural threshold values for ROM, duration and frequency of trunk flexion to be used in the field study (Chapter 7). However, due to the lack of consensus on postural outcome measures for ROM, duration and frequency, it was not possible to define postural threshold values. Therefore, a cross-sectional study, described in Chapter 6, was carried-out to measure the cumulative postural exposure of a group of care workers. Findings from this systematic review and from the study described in Chapter 6 were combined to provide relevant information for defining the postural threshold values for ROM, duration and frequency of trunk flexion to be used in the feasibility RCT (Chapter 7).

2.5 Final considerations

This study found limited evidence for any association between magnitude (ROM) or duration of trunk flexion and occupational LBP. Further, no evidence was found quantifying frequency of trunk flexion as a risk factor for LBP. It is suggested that a consensus for measures of postural exposure is needed to clarify its role as a risk factor for LBP.
3 Extrinsic feedback and management of low back pain: a critical review of the literature

3.1 Overview

The Spineangel® is a monitor and postural feedback device developed for use as a rehabilitation tool for the management of NSLBP, putatively helping patients change postural behaviour and avoid pain-provocative postures. This chapter critically reviews the literature on the provision of extrinsic feedback (EF) as part of the rehabilitation program for patients with NSLBP. Findings from this review will provide recommendations for future research exploring the application of EF as a rehabilitation tool.

3.1.1 Background

Motor control feedback can be defined as information provided by different sensory receptors as a consequence of a movement (Shumway-Cook and Woollacott, 2007). Such feedback informs about the effect of actions, and is designed to help improve the quality of adaptive responses (Schmidt and Wrisberg, 2008). Information provided by the sensory system is called intrinsic feedback, while the information provided via an external source (another person or instrument) can be described as EF (or, augmented feedback) (Schmidt and Wrisberg, 2008). Depending on the type of task, intrinsic feedback provides sufficient information to help execute or improve task performance. Nonetheless, there can be situations where motor improvements are very difficult to achieve without the support of EF (Guadagnoli et al., 1996), such as in individuals whose intrinsic feedback is impaired, in which case (re)learning of a task can be complex (Herbert et al., 2008).

EF has been used by physiotherapists in the management of patients with specific neuro-musculoskeletal conditions (Dozza et al., 2005, Durham et al., 2009, Magnusson et al., 2008), such as NSLBP, Parkinson disease. Different EF devices include verbal feedback (Durham et al., 2009), visual feedback for postural control and weight bearing symmetry (Hlavackova et al., 2009, Brumagne et al., 2008a), audio-feedback (Wong and Wong, 2008, Dozza et al., 2005), and rehabilitative ultrasound imaging feedback (Teyhen et al., 2005). EF is argued to enhance: a)
central nervous system facilitation of optimal sensory-motor loops; b) patient awareness, confidence and volitional control over specific physiological processes; c) motivation; and d) reinforcement for repetition of successful actions (Huang et al., 2006, Schmidt and Wrisberg, 2008).

Patients with NSLBP are thought to have impaired intrinsic feedback system (Panjabi, 2006, Brumagne et al., 2008a, Descarreaux et al., 2005, Brumagne et al., 2008b) with an alteration in muscular response (Sterling et al., 2001, Jacobs et al., 2009). The adverse alteration of proprioception is thought to play an important role in the maintenance of symptoms and motor impairments (O’Sullivan et al., 2003, Panjabi, 2006, Dolan and Green, 2006). The intrinsic feedback system can be altered due to disrupted paraspinal muscle spindle input, as well as, imprecise central processing, causing lumbar position sense deficits (Brumagne et al., 2000). In addition, partial ruptures of spinal ligaments leads to imprecise feedback input to the central neural system, causing reduced postural awareness and altered motor recruitment patterns (Panjabi, 2006). Examples reported in the literature are the delayed contraction of transversus abdominis muscle in subjects with NSLBP (Hodges, 1999), the localized atrophy and reduced capacity of actively recruit the lumbar multifidus muscle (Wallwork et al., 2009), as well as, increased spinal co-contraction (Marras et al., 2000, Newton-John et al., 1995) which increases spinal load (Marras et al., 2000). It is considered that EF is a useful procedure that facilitates or augments the information provided by the somato-sensory system (Henry and Teyhen, 2007).

Pain also interferes with motor response (Lund et al., 1991). New theories suggest that in response to pain, variable motor responses may take place to protect the injured tissue or remove threat (Hodges, 2011). It has been reported that pain leads to changes in multiple levels of the nervous system. For example, studies have reported changes in muscle spindle sensitivity due to pain (Hodges and Moseley, 2003) and changes in motor cortex area, resulting in altered motor recruitment patterns (Hodges and Tucker, 2011). Due to changes in different levels of the nervous system, different spinal muscle recruitment may take place within and between muscles (Hodges, 2011), leading to altered mechanical behaviour of the spine. The literature suggests that rather than a predictable motor response to pain, different motor strategies are adopted by different patients (Hodges, 2011,
Sahrmann, 2002). Such motor recruitment changes may be beneficial in the short-
term, but detrimental in the long-term (Hodges, 2011). As part of the rehabilitation
programme, clinical interventions focus on retraining of movement performance.

The successful provision of EF depends on the selection of different features
(van Vliet and Wulf, 2006, Park et al., 2000). Characteristics of feedback (e.g. when
to provide EF, what type of information to be delivered) during motor learning
have been discussed in depth (Hebert and Landin, 1994, Newell, 1976, McNevin et
implications for rehabilitation have been presented (McNevin et al., 2000,
Winstein, 1991, Winstein and Knecht, 1990). These characteristics have been
recently investigated during rehabilitation procedures for specific neuromuscular
dysfunctions such as stroke (van Vliet and Wulf, 2006) and NSLBP (Herbert et al.,
2008). However, the studies investigating the use of feedback towards
managements of NSLBP are still limited (Henry and Teyhen, 2007). The aim of this
narrative review was to describe the forms of feedback provision in the literature
regarding management of NSLBP, and to discuss these in light of previously
recommended principles for the use of EF.

3.2 Methods

The electronic search identified studies that have included the use of EF on
the management of NSLBP. The following databases were used: Medline (1950 to
July 2012), CINAHL (1982 to July 2012), PsycINFO (1967 to July 2012), Embase
(1947 July 2012). Additional searches used the PEDro database, as well as searches
of rehabilitation journals including: Manual Therapy, Physiotherapy, Physical
Therapy, Archives of Physical Medicine and Rehabilitation, Journal of Orthopaedic
and Sports Physical Therapy (JOSPT). The search strategy was developed in
consultation with a faculty librarian. The key words and the combination used for
each database are described in Table 3-1. In addition, reference lists of retrieved
articles were scanned for appropriate studies. Language restriction was not
imposed.
Table 3-1. Results for electronic databases searches.

<table>
<thead>
<tr>
<th>Database</th>
<th>Keywords</th>
<th>Number of studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cinahl</td>
<td>(1) Low back pain; (2) Feedback; (3) Biofeedback; (4) Extrinsic Feedback; (5) 2 or 3 or 4; (6) 1 and 5.</td>
<td>54</td>
</tr>
<tr>
<td>Embase</td>
<td>(1) Feedback system; (2) Low back pain; (3) Backache; (4) 2 or 3; (5) 1 and 4.</td>
<td>182</td>
</tr>
<tr>
<td>Medline</td>
<td>(1) Low back pain; (2) Feedback; (3) Feedback, Sensory; (4) Biofeedback, Psychology; (5) 2 or 3 or 4; (6) 1 and 5.</td>
<td>34</td>
</tr>
<tr>
<td>PsycInfo</td>
<td>(1) Back pain; (2) Biofeedback Training; (3) Biofeedback; (4) Feedback; (5) 2 or 3 or 4; (6) 1 and 5.</td>
<td>39</td>
</tr>
</tbody>
</table>

It is common for research conducted at the Development stage to test new exercise approaches in healthy participants, prior to adopt the same intervention in patients (MRC, 2008). With this in mind, in order to gain a comprehensive perspective on how EF has been used by clinical researchers, studies assessing the effect of different exercise programmes on motor control in healthy participants were also considered in this review.

Studies were included if they involved a RCT of subjects with or without NSLBP, exposed to a period of training or treatment using feedback instruments (with or without the addition of verbal or tactile feedback) that focused on motor learning. Studies were excluded if they had any other study design, were narrative or systematic reviews, if the focus of the study was on behavioural therapy or ergonomic training (e.g. the use of feedback to change posture), or if it was not related to motor training.

The quality scores for those studies were assessed by the PEDro database (www.pedro.org.au). For studies not assessed by the PEDro database, the quality assessment findings are reported using the PEDro instrument (CEBP, 2012). Two reviewers (DCR, JHA) independently assessed each study. Differences were resolved by consensus. A third reviewer (GS) was available to adjudicate unresolved differences.

In order to establish the recommended principles for the use of EF, the following textbooks were reviewed (Schmidt and Wrisberg, 2008, Shumway-Cook and Woollacott, 2007, Magill, 2003), as were published articles related to motor learning and control. To identify these studies, an electronic search with the same databases previously described, was conducted and the following key words used
were: motor learning, motor control, feedback, EF, knowledge of results, and knowledge of performance.

3.3 Results

A total of 311 articles were found and 17 studies met the inclusion criteria. The identification, screening, eligibility and inclusion processes are described in Figure 3-1. Main term definitions for content and timing characteristics of feedback provision are described in Table 3-2.

Figure 3-1. Selection process.
Table 3-2. Main term definitions for content and timing characteristics.

<table>
<thead>
<tr>
<th>Content characteristics</th>
<th>Feedback related to the general pattern of movement.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Program feedback</strong></td>
<td>Feedback related to a specific component (part) of the whole movement pattern.</td>
</tr>
<tr>
<td><strong>Parameter feedback</strong></td>
<td>Feedback is pooled and provided after a specific number of trials.</td>
</tr>
<tr>
<td><strong>Summary feedback</strong></td>
<td>Feedback provided refers to mean values (mean error or performance score) of a group of trials.</td>
</tr>
<tr>
<td><strong>Average feedback</strong></td>
<td>The amount of error that is considered to distinguish between successful and unsuccessful trials.</td>
</tr>
<tr>
<td><strong>Bandwidth (error magnitude)</strong></td>
<td>Feedback drives learner's attention to body movement characteristics.</td>
</tr>
<tr>
<td><strong>Internal focus of attention</strong></td>
<td>Feedback drives learner's attention to the effect of the movement.</td>
</tr>
<tr>
<td><strong>External focus of attention</strong></td>
<td>Feedback is provided simultaneously to task execution.</td>
</tr>
<tr>
<td><strong>Concurrent feedback</strong></td>
<td>Feedback is provided after task execution.</td>
</tr>
<tr>
<td><strong>Terminal feedback</strong></td>
<td>Feedback is provided immediately after task execution;</td>
</tr>
<tr>
<td><strong>Immediate</strong></td>
<td>Feedback provision is delayed after the end of the task execution.</td>
</tr>
<tr>
<td><strong>Delayed</strong></td>
<td>Feedback is provided for a fraction of trials (e.g. 30%).</td>
</tr>
<tr>
<td><strong>Self-controlled</strong></td>
<td>Feedback provision depends on learner's decision.</td>
</tr>
</tbody>
</table>

Study design description is presented at Table 3-3. The content and timing characteristics found in the studies identified through the electronic search are outlined at Table 3-4 and Table 3-5, respectively. From the 17 included studies, 6 studies (Herbert et al., 2008, Magnusson et al., 2008, Worth et al., 2007, Van et al., 2006, Teyhen et al., 2005, Henry and Westervelt, 2005) have compared use of EF with no use of EF in the intervention regime (Table 3-3); their main findings are presented in Table 3-6. The other 11 studies have used EF as part of treatment/motor training management; however have not conducted a comparative effectiveness study of EF. As a consequence, all comments regarding the effectiveness of EF provision will be based on the former 6 studies. The latter 11 studies are presented and the way EF was provided is narratively described and compared to the recommendation summary for EF provision. The PEDro quality assessment results are reported in Table 3-3.
### Table 3-3. Study description.

<table>
<thead>
<tr>
<th>Author (Year)</th>
<th>Population</th>
<th>Intervention</th>
<th>Direct comparison between the use or not of EF</th>
<th>Nature of EF (KP or KR)</th>
<th>Type of EF</th>
<th>Instrument / Principle</th>
<th>PEDro Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bush et al. (1985)</td>
<td>72 chronic LBP</td>
<td>8 sessions (period of intervention unclear) G1: Paraspinal EMG feedback; G2: Placebo; G3: No intervention</td>
<td>No</td>
<td>KP</td>
<td>Auditory</td>
<td>EMG</td>
<td>4/10 #</td>
</tr>
<tr>
<td>Donaldson et al. (1994)</td>
<td>36 chronic LBP</td>
<td>G1: EMG Biofeedback, G2: Relaxation; G3: Education</td>
<td>No</td>
<td>Not addressed</td>
<td>Not addressed</td>
<td>EMG</td>
<td>5/10 #</td>
</tr>
<tr>
<td>Ferreira et al. (2007)</td>
<td>240 chronic LBP patients</td>
<td>8-week intervention (12 sessions) G1: General exercise; G2: Motor control exercise + USI; G3: Manipulative therapy</td>
<td>No</td>
<td>KP</td>
<td>Visual</td>
<td>USI</td>
<td>8/10 #</td>
</tr>
<tr>
<td>Flor et al. (1983)</td>
<td>24 chronic LBP</td>
<td>G1: EMG feedback; G2: Pseudo therapy; G3: Conventional medical treatment</td>
<td>No</td>
<td>KP</td>
<td>Auditory</td>
<td>EMG</td>
<td>4/10 #</td>
</tr>
<tr>
<td>Henry et Westervelt (2005) *</td>
<td>48 healthy participants</td>
<td>Teaching abdominal hollowing exercise and retention test after 4 days. G1: minimal verbal feedback; G2: verbal and palpatory feedback; G3: verbal, palpatory and USI</td>
<td>Yes</td>
<td>KP</td>
<td>Verbal, tactile and visual</td>
<td>USI</td>
<td>6/10 ¥</td>
</tr>
<tr>
<td>Herbert et al. (2008) *</td>
<td>30 healthy participants</td>
<td>4-week intervention (8 sessions): multifidus muscle exercise G1: constant USI; G2: variable USI</td>
<td>Yes</td>
<td>KR (verbal) KP (visual)</td>
<td>Visual</td>
<td>Verbal</td>
<td>5/10 ¥</td>
</tr>
<tr>
<td>Hides et al. (1996)</td>
<td>39 LBP patients</td>
<td>4-week intervention G1: Medical management; G2: Medical management and stabilization exercises</td>
<td>No</td>
<td>KP</td>
<td>Visual</td>
<td>USI</td>
<td>7/10 #</td>
</tr>
<tr>
<td>Magnusson et al.</td>
<td>26 LBP patients</td>
<td>5-week intervention (10 sessions) G1: Conventional physiotherapy;</td>
<td>Yes</td>
<td>KP</td>
<td>Visual, auditory,</td>
<td>Postural</td>
<td>3/10 #</td>
</tr>
<tr>
<td>Author (Year)</td>
<td>Population</td>
<td>Intervention</td>
<td>Direct comparison between the use or not of EF</td>
<td>Nature of EF (KP or KR)</td>
<td>Type of EF</td>
<td>Instrument / Principle</td>
<td>PEDro Score</td>
</tr>
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<td>-----------------------------------------------</td>
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</tr>
<tr>
<td>Niemisto et al. (2003)</td>
<td>240 LBP patients</td>
<td>4-week intervention (one session/week). G1: Manipulation and stabilizing exercise (abdominal drawing-in maneuver); G2: Physician consultation</td>
<td>No</td>
<td>KP and KR</td>
<td>Pressure, visual and tactile</td>
<td>PBU</td>
<td>8/10 #</td>
</tr>
<tr>
<td>Rasmussen-Barr et al. (2003)</td>
<td>47 LBP patients</td>
<td>6-week treatment (one session/week). G1: Stabilizing group (PBU); G2: Manual treatment group</td>
<td>No</td>
<td>KP</td>
<td>Pressure</td>
<td>PBU</td>
<td>5/10 #</td>
</tr>
<tr>
<td>Stuckey et al. (1986)</td>
<td>24 chronic LBP</td>
<td>8 sessions (45 min each) G1: EMG feedback; G2: Relaxation training; G3: Placebo condition</td>
<td>No</td>
<td>KP</td>
<td>Visual and auditory</td>
<td>EMG</td>
<td>4/10 #</td>
</tr>
<tr>
<td>Teyhen et al. (2005) *</td>
<td>30 LBP patients</td>
<td>G1: lumbar stabilization exercise; G2: lumbar stabilization exercise + USI; Both groups received 1 session followed short-term re-assessment (3 min after session). Retention test was carried out after 4 days (all patients received home exercises).</td>
<td>Yes</td>
<td>KP</td>
<td>Visual</td>
<td>USI</td>
<td>7/10 #</td>
</tr>
<tr>
<td>Author (Year)</td>
<td>Population</td>
<td>Intervention</td>
<td>Direct comparison between the use or not of EF</td>
<td>Nature of EF (KP or KR)</td>
<td>Type of EF</td>
<td>Instrument / Principle</td>
<td>PEDro Score</td>
</tr>
<tr>
<td>--------------</td>
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<td>-----------------------------------------------</td>
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<td>------------</td>
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</tr>
<tr>
<td>Vasseljen et Fladmark (2010)</td>
<td>109 chronic LBP patients</td>
<td>8-week intervention (8 sessions) G1: Low load exercise (stabilization focused on transverses abdominis) with USI; G2: High load exercise; G3: General exercise.</td>
<td>No</td>
<td>KP (visual observation of muscle contraction)</td>
<td>KP</td>
<td>Visual</td>
<td>USI</td>
</tr>
<tr>
<td>Worth et al. (2007) *</td>
<td>19 LBP patients</td>
<td>Teaching abdominal hollowing exercise and retention test after 4 days. G1: verbal and palpatory feedback; G2: USI</td>
<td>Yes</td>
<td>KP</td>
<td>Visual</td>
<td>USI</td>
<td>5/10 #</td>
</tr>
</tbody>
</table>

G1 = group 1; G2 = group 2; EF = extrinsic feedback; KP = knowledge of performance; KR = knowledge of results; PBU = pressure biofeedback unit; USI = ultrasound imaging; EMG = electromyography. ¥ = PEDro score assessed by the authors; # = PEDro score reported from www.pedro.org.au (CEBP, 2012). * = compared the use or not of extrinsic feedback on training or rehabilitation management.
<table>
<thead>
<tr>
<th>Author (Year)</th>
<th>Program</th>
<th>Parameter</th>
<th>Summary</th>
<th>Average</th>
<th>Bandwidth</th>
<th>Focus of attention (Internal or External)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bush et al. (1985)</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Not addressed</td>
</tr>
<tr>
<td>Donaldson et al. (1994)</td>
<td>No</td>
<td>Yes</td>
<td>Not addressed</td>
<td>No</td>
<td>No</td>
<td>Not addressed</td>
</tr>
<tr>
<td>Ferreira et al. (2007)</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Not addressed</td>
</tr>
<tr>
<td>Flor et al. (1983)</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Not addressed</td>
</tr>
<tr>
<td>Henry et Westervelt (2005) *</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes (Control)</td>
<td>Not addressed</td>
</tr>
<tr>
<td>Herbert et al. (2008) *</td>
<td>No</td>
<td>Yes</td>
<td>Yes (VAR group)</td>
<td>No</td>
<td>No</td>
<td>Not addressed</td>
</tr>
<tr>
<td>Hides et al. (1996)</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Not addressed</td>
</tr>
<tr>
<td>Magnusson et al. (2008) *</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>External</td>
</tr>
<tr>
<td>Newton-John et al. (1995)</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Not addressed</td>
</tr>
<tr>
<td>Niemisto et al. (2003)</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Not addressed</td>
</tr>
<tr>
<td>Nouwen (1983)</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Not addressed</td>
</tr>
<tr>
<td>Author (Year)</td>
<td>Program</td>
<td>Parameter</td>
<td>Summary</td>
<td>Average</td>
<td>Bandwidth</td>
<td>Focus of attention (Internal or External)</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>---------</td>
<td>-----------</td>
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<td>---------</td>
<td>-----------</td>
<td>------------------------------------------</td>
</tr>
<tr>
<td>Rasmussen-Barr et al. (2003)</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Not addressed</td>
</tr>
<tr>
<td>Stuckey et al. (1986)</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>External</td>
</tr>
<tr>
<td>Teyhen et al. (2005) *</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Not addressed</td>
</tr>
<tr>
<td>Van et al. (2006) *</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Not clear (G1); External (for G2)</td>
</tr>
<tr>
<td>Vasseljen et Fladmark (2010)</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Not addressed</td>
</tr>
<tr>
<td>Worth et al. (2007) *</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Not addressed</td>
</tr>
</tbody>
</table>

VAR = variable extrinsic feedback provision group; G1 = group 1; G2 = group 2. * = compared the use or not of extrinsic feedback on training or rehabilitation management.
Table 3-5. Timing characteristics.

<table>
<thead>
<tr>
<th>Author (Year)</th>
<th>Timing Characteristics</th>
<th>Terminal Frequency</th>
<th>Frequency</th>
<th>Reduced frequency</th>
<th>Self-controlled</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Concurrent</td>
<td>Immediate</td>
<td></td>
<td>Constant</td>
<td></td>
</tr>
<tr>
<td>Bush et al. (1985)</td>
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<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Donaldson et al. (1994)</td>
<td>Yes</td>
<td>Not addressed</td>
<td>Not addressed</td>
<td>Not addressed</td>
<td>Not addressed</td>
</tr>
<tr>
<td>Ferreira et al. (2007)</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Flor et al. (1983)</td>
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<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Henry et Westervelt (2005)</td>
<td>Yes</td>
<td>(verbal &amp; visual)</td>
<td>Not clear</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Herbert et al. (2008)</td>
<td>Yes (CON group)</td>
<td>Yes (CON group)</td>
<td>Yes</td>
<td>Yes (VAR group)</td>
<td>No</td>
</tr>
<tr>
<td>Hides et al. (1996)</td>
<td>Yes</td>
<td>Not clear</td>
<td>Not clear</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Magnusson et al. (2008)</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
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<td>No</td>
</tr>
<tr>
<td>Newton-John et al. (1995)</td>
<td>Not addressed</td>
<td>No</td>
<td>No</td>
<td>Not addressed</td>
<td>Not addressed</td>
</tr>
<tr>
<td>Niemisto et al. (2003)</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Nouwen (1983)</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Rasmussen-Barr et al. (2003)</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Stuckey et al. (1986)</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Teyhen et al. (2005)</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Van et al. (2006)</td>
<td>Yes (G2)</td>
<td>Yes (G1)</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Vasseljen et Fladmark (2010)</td>
<td>Yes</td>
<td>Not clear</td>
<td>Not clear</td>
<td>Not clear</td>
<td>No</td>
</tr>
<tr>
<td>Worth et al. (2007)</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

VAR = variable extrinsic feedback provision group; CON = constant extrinsic feedback provision; G1 = group 1; G2 = group 2. * = compared the use or not of extrinsic feedback on training or rehabilitation management.
Before specifically describing the extracted data related to the use of EF in the management of NSLBP, a summary of existing recommendations related to EF in motor learning is presented in two domains: content feedback and timing feedback. NSLBP feedback characteristics are then reviewed and compared with this summary of existing recommendations.

Table 3-6. Main findings for studies that compared the use or not of extrinsic feedback on training or rehabilitation management.

<table>
<thead>
<tr>
<th>Author (year)</th>
<th>Main findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Henry et Westervelt (2005)</td>
<td>The use of ultrasound imaging improved short-term performance for lumbar stabilization exercise (specific contraction for transversus abdominis). However, retention test results demonstrated no differences between the three feedback groups.</td>
</tr>
<tr>
<td>Herbert et al. (2008)</td>
<td>Variable feedback provision resulted in better multifidus muscle recruitment, when compared to constant feedback provision. During the retention test, the variable feedback group also performed better.</td>
</tr>
<tr>
<td>Magnusson et al. (2008)</td>
<td>Patients allocated in the feedback group presented enhanced scores for VAS, SF-36 and kinematic measures.</td>
</tr>
<tr>
<td>Teyhen et al. (2005)</td>
<td>Adding feedback did not improve contraction of transversus abdominis muscle. One possible reason could be insufficient training period.</td>
</tr>
<tr>
<td>Van et al. (2006)</td>
<td>Participants that received ultrasound imaging feedback improved motor recruitment for multifidus muscle and, also, performed better during retention test.</td>
</tr>
<tr>
<td>Worth et al. (2007)</td>
<td>The provision of ultrasound imaging improved short-term performance for abdominal hollowing exercise, nonetheless, retention test results demonstrated no differences between the two groups.</td>
</tr>
</tbody>
</table>

VAS = visual analogue scale; SF36 = short form (SF) – 36 questionnaire.

3.4 Discussion

3.4.1 Recommendations for the use of extrinsic feedback

EF can be provided in two forms: knowledge of results and knowledge of performance (Schmidt and Wrisberg, 2008). Knowledge of results informs about the outcome or achieving the goal/target of a determined task, whereas, knowledge of performance feedback informs about the characteristics of a performed movement or task (Magill, 2000). The characteristics of such EF can have positive, detrimental or null influence on the motor learning outcomes (Wulf et al., 1994). For this reason, before providing EF, content and timing
characteristics should be carefully selected (Butki and Hoffman, 2003, Guadagnoli and Kohl, 2001, Ishikura, 2005).

3.4.1.1 Content characteristics

In the present review, content characteristics are considered as features related to the focus of intervention of the EF (program or parameter), the way EF results are provided (summarized, averaged, or error magnitude – e.g. accepting some minor faults as a successful try), and the type of focus of attention associated with the feedback (Table 3-2). Skill complexity, feedback redundancy and subject experience have an important effect on learning outcomes from EF (Guadagnoli and Lee, 2004, Janelle et al., 1997, Park et al., 2000). When learning a new but easy task, EF does not necessarily result in enhancement of learning. While learning a complex task, provision of EF seems to enhance motor performance (Fredenburg et al., 2001). When there is sufficient intrinsic information, EF provision will not necessarily induce better learning outcomes (Guadagnoli et al., 1996). In this case, it is generally accepted that the therapist should direct and assist the subject to correctly identify and use the available intrinsic feedback information during task execution (Schmidt and Wrisberg, 2008). The more novel the task and less experienced the participant, the more useful EF is likely to be (Guadagnoli et al., 1996, Guadagnoli and Lee, 2004).

3.4.1.1.1 Program and parameter feedback

Learning a new task involves the acquisition of a generalized motor pattern followed by the refinement of specific execution parameters (Schmidt and Wrisberg, 2008). Different types of instruction feedback can be used to improve motor learning during these two phases. Program feedback provides information regarding the general movement pattern, while parameter feedback provides information of a specific component of the entire movement pattern (Schmidt and Wrisberg, 2008). Both forms of feedback can be provided prescriptively or descriptively. The former describes errors and suggests how to correct them while the latter only describes the errors (Schmidt and Wrisberg, 2008). Better results are often obtained when prescriptive feedback is provided.
3.4.1.1.2 Amount of information during feedback provision

The quantity and precision of EF can interfere in the learning process (Guadagnoli et al., 1996, Ishikura, 2005). Summary feedback, which provides information after a specific number of trials, has shown to be superior, when compared to EF provided after every trial (Gable et al., 1991). Average feedback provides mean values (mean error or performance score) of a group of trials (Wulf and Schmidt, 1996), it is considered to deteriorate movement parameter learning (Wulf and Schmidt, 1996), but to be superior to every trial EF. During every-trial feedback, subjects ignore intrinsic feedback information and become excessively dependent on EF (Ranganathan and Newell, 2009, Salmoni et al., 1984).

3.4.1.1.3 Performance bandwidth (error magnitude)

Another important issue is to determine the error magnitude (performance bandwidth) that should be followed by feedback (Smith et al., 1997, Butler et al., 1996, Lai and Shea, 1999). For example, isolated contraction for lumbar multifidus can be considered as successful when no pelvic tilt is performed concomitantly, and multifidus muscle thickening can be visualized on the rehabilitative ultrasound imaging screen (Herbert et al., 2008). In this example, the physiotherapist might consider a performance as successful even when a small amount of pelvic tilt movement occurs simultaneously to multifidus muscle contraction. Some studies support the idea that changing the bandwidth size during motor task trials does not alter motor outcomes (Goodwin and Meeuwsen, 1995, Lai and Shea, 1999). Conversely, Smith et al. (1997) found that a larger bandwidth (10%, when compared to 0 and 5%) has been associated with better retention outcomes. The use of bandwidth for EF provision enhances motor learning if a qualitative knowledge of results feedback is provided when motor outcome is included within the bandwidth (Butler et al., 1996). Apparently, the success of bandwidth is dependent on its association with an instructional feedback (Butler et al., 1996).

3.4.1.1.4 Focus of attention

EF can be applied in a form that drives learner’s attention to body movement characteristics (internal focus of attention) or to the effect of the movement (external focus of attention) (Wulf et al., 2002). Better motor learning outcomes are related to the use of external focus of attention (Wulf et al., 2009,
McNevin et al., 2000, Shea and Wulf, 1999). The reasons for this are unclear, however, it seems that attempts to control the movement itself would interfere in automatic motor control processes and, consequently, lead to deteriorated outcomes (McNevin et al., 2000). The use of an external focus of attention likely facilitates or sustains automatic pathways of motor control and improves motor performance (Wulf et al., 2009).

### 3.4.1.2 Timing characteristics

The excessive use of EF can lead to dependency and, consequently, promote detrimental or null effects on learning process (Butki and Hoffman, 2003, Park et al., 2000, Weinstein and Schmidt, 1990). Concurrent or terminal (immediate or delayed) EF, as well as, the frequency of EF are critical features of application during motor learning (Magill, 2003, Schmidt and Wrisberg, 2008). EF can be provided during every trial (constant), concurrent to the task execution, immediately after task execution or, after a period of time following the end of the task (delayed).

#### 3.4.1.2.1 Concurrent and terminal feedback provision

Whether to provide EF concurrent to or after task execution is a decision to be made by the physiotherapist. Published literature does not support the use of concurrent EF, unless there is impaired intrinsic feedback or insufficient information intrinsic to the task (Magill, 2003, Park et al., 2000, Ranganathan and Newell, 2009). This might be the case for NSLBP patients, who were shown to have impaired intrinsic feedback (Newcomer et al., 2000). Otherwise, concurrent EF has a strong negative guidance effect (Schmidt and Wulf, 1997, Winstein et al., 1996). One possible reason might be related to EF obliterating the use of intrinsic feedback. Learners become dependent on EF during the acquisition phase and, consequently, when EF is removed, subjects are not able to perform the task correctly (Anderson et al., 2005). Even though concurrent visual feedback has been shown to be detrimental (Wulf G and RA., 1997), the provision of concurrent audio feedback is beneficial for motor learning (Konttinen et al., 2004). Concurrent visual feedback appears to induce a different neural pathway when compared to the execution of a task without visual EF. However, the reasons for the better retention results from learning with audio feedback are unclear.
Delayed EF improves motor learning outcomes (Anderson et al., 2005, Magill, 2003). It is possible that, by delaying the feedback provision for a few seconds or minutes after movement execution, subjects have time to better explore their intrinsic feedback and relate it to the motor outcome. When EF is provided, they can then compare the intrinsic feedback information to that provided by the EF (Anderson et al., 2005). However, the optimal delay interval for providing EF has yet to be determined (Magill, 2003).

3.4.1.2.2 Frequency of feedback provision

Additionally, providing EF after every trial (100% EF) appears to deteriorate motor learning, when compared to intermittent EF (e.g. 50%, 20% or 10% EF) (Winstein and Knecht, 1990, Park et al., 2000, Salmoni et al., 1984, Weeks and Kordus, 1998). Weeks et al. (1998) found that uninjured learners, who received 33% relative frequency of knowledge of performance feedback, performed better when compared to 100% relative EF during a soccer throw-in task. The authors suggested that reduced frequency eliminates learner’s dependence on the provision of EF (Weeks and Kordus, 1998). A possible explanation for reduced retention with 100% EF is that EF is a guide for motor execution and learners cannot guide themselves appropriately by task-intrinsic feedback when it is removed (Winstein et al., 1994, Ranganathan and Newell, 2009, Anderson et al., 2005, Salmoni et al., 1984).

Better outcomes were found if the decision for receiving feedback was controlled by the learner (Chiviacowsky and Wulf, 2005, Chiviacowsky and Wulf, 2002). Self-controlled feedback tends to be requested after performances learners believed to be successful (Chiviacowsky and Wulf, 2002, Chiviacowsky and Wulf, 2005, Chiviacowsky and Wulf, 2007). The reason why learners ask for EF after good trials and why it is more effective than a rigid schedule of feedback is unclear (Chiviacowsky and Wulf, 2002). However, recent results point to motivation, where knowledge about successful trials induces learners to reproduce the successful motor pattern (Chiviacowsky and Wulf, 2002, Chiviacowsky and Wulf, 2007). These findings indicate that providing feedback after good trials is superior than after incorrect trials, nonetheless, it is uncertain whether it can be applied to different motor tasks (Chiviacowsky and Wulf, 2007).
3.4.2 **Feedback provision for the management of low back pain**

Different types of EF have been used during management of NSLBP using various conceptual frameworks (Table 3-3). Positive results from these studies are likely related to sensori-motor adaptation occurring independently of type of EF. Sarlegna et al. (2007), tested how adaptive control of reaching movements was affected by different sensory channels (visual, kinesthetic, and verbal knowledge of results) and found there were no differences in motor adaptation between the different feedback groups. This study supports the concept that sensori-motor adaptation is a multi-sensorial flexible process and its efficiency seems to be independent of a specific sensory channel (e.g. vision, audition, or kinaesthesia) (Sarlegna et al., 2007). However, the selection of optimal content and timing characteristics might influence motor adaptation. The provision of EF in the management of NSLBP is discussed in light of previously described principles for the use of EF.

3.4.2.1 **Content characteristics**

3.4.2.1.1 **Program and parameter feedback**

One study (Magnusson et al., 2008) provided program feedback (focusing on the gross movement pattern), while all other studies focused on parameter feedback (Table 3-4). The reason may be that therapists believe that NSLBP patients need to improve specific features of movement patterns in order to enhance the quality of such performed movements. Examples reported in the literature, where parameter feedback was used, include delayed contraction of transversus abdominis muscle (Hodges, 1999), localized atrophy and reduced capacity to actively recruit the lumbar multifidus muscle (Wallwork et al., 2009), as well as, increased amount of spinal co-contraction (Marras et al., 2000, Newton-John et al., 1995, Flor and Birbaumer, 1993) increasing spinal loads (Marras et al., 2000). Nonetheless, it is considered that motor program training and, consequently, program feedback can enhance neural reorganization and motor control (van Vliet and Heneghan, 2006, Shepherd, 2001). Since motor control acquisition is task-specific, the isolated training of a component of the movement might not be as useful as the training of the functional task itself (Shepherd, 2001, Shumway-Cook and Woollacott, 2007, van Vliet and Heneghan, 2006).
3.4.2.1.2 Amount of information during feedback provision

Two studies have provided summary EF (Herbert et al., 2008, Magnusson et al., 2008). In addition, Herbert et al. (2008) results support the provision of variable feedback schedule for improvement of multifidus muscle recruitment. The literature supports the provision of summary EF for motor learning, indicating that it has a better influence on acquisition of a motor skill compared to EF provided at the end of every trial (Guadagnoli et al., 1996, Schmidt et al., 1990). However, other research suggests that there is an optimal number of performance attempts prior to provision of summary feedback (Schmidt et al., 1990). Theoretically, as the complexity of the task is increased, the number of trials to be included in the summary feedback is reduced (and consequently, the frequency of feedback is increased) (Guadagnoli and Lee, 2004, Schmidt and Wrisberg, 2008). Task difficulty will be related to personal previous motor experience and the task itself (Guadagnoli and Lee, 2004). However, for subjects with NSLBP, it is important to consider the disruption magnitude of the intrinsic feedback system (O’Sullivan et al., 2003, Brumagne et al., 2008b), since subjects with increased proprioceptive disruption might benefit from more frequent EF. Nonetheless, this has not been investigated in the NSLBP population.

3.4.2.1.3 Performance bandwidth (error magnitude)

Two studies (Magnusson et al., 2008, Henry and Westervelt, 2005) have used performance bandwidth during training of abdominal hollowing maneuvers in healthy subjects (Henry and Westervelt, 2005) and during rehabilitation program for chronic NSLBP (Magnusson et al., 2008). The former has used it for the control group and the latter used it as a form of progression for rehabilitation spinal exercises. None of these studies have assessed the effect of different bandwidth magnitudes on clinical outcomes.

3.4.2.1.4 Focus of attention

The use of external focus of attention on motor learning in patients with NSLBP has not been compared to internal focus of attention. Literature from the motor learning field suggests that EF should be provided with an external focus of attention (Shea and Wulf, 1999, Wulf et al., 2009). Similar results were found for subjects with Parkinson disease (Wulf et al., 2009), who presented a reduction on
postural instability when instructed to perform a task with an external focus of attention.

Magnusson et al. (2008) used an external focus of attention in their trial of NSLBP treatment while Van et al. (2006) used external focus of attention in healthy subjects during isometric contraction of multifidus muscle. Their findings support the use of EF as an additional tool for rehabilitation of NSLBP and training of multifidus muscle contraction. However, other studies do not support better learning or clinical outcomes from using EF (Teyhen et al., 2005, Henry and Westervelt, 2005, Worth et al., 2007, Herbert et al., 2008). These four studies (Teyhen et al., 2005, Henry and Westervelt, 2005, Worth et al., 2007, Herbert et al., 2008) provided visual feedback to subjects and it is not clear what type of focus of attention was provided. The different findings between those of Van et al. (2006) and Worth et al. (2007) might be related, at least partially, to the type of focus of attention used. While results by Van et al. (2006) support the provision of EF (even during the retention test, the EF group performed better), Worth et al. (2007) found the feedback group performed better only during immediate assessment. At the retention test, no difference was found between groups (Table 3-6).

3.4.2.2 Timing characteristics

3.4.2.2.1 Concurrent and terminal Feedback provision

Rehabilitative ultrasound imaging (visual EF) has been used to enhance contraction of transversus abdominis (Worth et al., 2007). However, Henry and Westervelt (2005) and Teyhen et al. (2005) found provision of rehabilitative ultrasound imaging (visual EF) did not enhance the ability to perform the abdominal drawing-in manoeuvre (Table 3-6). Although different explanations are presented by the authors (Henry and Westervelt, 2005, Teyhen et al., 2005), it is possible that the use of concurrent visual feedback influenced the results. On the other hand, the findings from Van et al. (2006) support the provision of concurrent feedback (Table 3-6). Due to the conflicting evidence, it is clear more research is needed to clarify this topic.

3.4.2.2.2 Frequency of feedback provision

Only one study tested how frequency of EF affected motor learning (Herbert et al., 2008) and found reduced EF frequency was better for motor learning
purposes (Table 3-6). In the present review, rehabilitative ultrasound imaging feedback was considered as a form of parameter feedback (Table 3-2), aiming to improve the control over specific muscles (generally multifidus or transversus abdominis), instead of providing information about the general movement pattern. Interestingly, the findings from Herbert et al. (2008) are in contrast with other authors (Winstein and Knecht, 1990, Park et al., 2000, Salmoni et al., 1984, Weeks and Kordus, 1998). Herbert et al. (2008) found reduction of EF frequency to be useful for acquisition of parameters of fundamental pattern of movement. Nonetheless, reduced frequency of EF appeared to have only a small influence on the parameters of the fundamental pattern of movement (e.g. movement time, amplitude, speed), when motor learning related to manual tasks, such as striking keys in a board, was analyzed (Lai and Shea, 1999, Lai and Shea, 1998, Schmidt, 2003). Although this consideration is only based on the results of one study related to healthy participants (Herbert et al., 2008), further questions include: how does pain experience, in subjects with NSLBP, influence motivations and patterns of neural processing, when compared to healthy participants, when (re)learning a task?; and how does adaptive reorganization of motor cortex (Tsao et al., 2008), considered to be present in NSLBP subjects, influence motor learning?

Magnusson et al. (2008) provided constant EF during the intervention period. Although that is argued to have a detrimental effect on motor learning (Lai and Shea, 1999), their results were favourable for the use of EF. It is important to highlight that the authors provided EF with the following recommended characteristics: program and parameter feedback, an external focus of attention, and summary feedback. It is possible that these characteristics have prevailed over the negative effect of providing constant EF. Moreover, the authors have used three different types of EF: visual, auditory and success rates reports, as well as, variable bandwidth (with increase in bandwidth precision as treatment progressed). Thus the use of bandwidth seems to be useful when followed by some form of instructional feedback (Butler et al., 1996).

Six studies (Newton-John et al., 1995, Nouwen, 1983, Donaldson et al., 1994, Bush et al., 1985, Flor et al., 1983, Stuckey et al., 1986) have used the pain-tension-pain cycle as the theoretical framework to support the use of electromyographic feedback for NSLBP (Table 3-3). Nonetheless, other recent conceptual pain models
have been proposed and, it is clear that pain experience has a more complex interaction with motor control response (Hodges and Moseley, 2003, Moseley, 2003, Arendt-Nielsen and Graven-Nielsen, 2008). No studies were found that investigated the use of electromyographic feedback to improve specific muscle recruitment for individuals with NSLBP.

While other types of feedback are also used by manual therapists, they were not addressed by the studies included in the present review. One example is the use of adhesive medical tape (Greig et al., 2008, Selkowitz et al., 2007), that can be used to provide mechanical support to joint structures and/or to provide proprioceptive feedback to help patients sustain body segment alignment (Jaraczewska and Long, 2006, Greig et al., 2008). If tape is used with the aim of augmenting the intrinsic feedback, then, the same principles described above could be considered.

3.4.3 Future research directions

No evidence was found for a number of areas related to NSLBP and EF (i.e. the effect of different timing and content characteristics in NSLBP outcomes). Future research could explore whether there are differences between knowledge of performance or knowledge of results for EF on NSLBP outcomes. Currently, it is unknown how parameter or program EF influence clinical outcomes in patients presenting with NSLBP. The use of different focus of attention should also be explored, as it may have an important impact in clinical outcomes. Finally, whether immediate or delayed terminal feedback and self-controlled EF can influence NSLBP outcomes still need to be clarified.

When considering the significant and clinically relevant outcomes presented by Magnusson et al. (2008), the use of postural feedback requires further exploration. The way in which postural feedback influences motor control in subjects with NSLBP needs to be identified. Finally, it is possible that different NSLBP clinical presentations will respond in different ways to the provision of EF in its various forms. This is an area that has considerable scope for research where clarification of optimal responses has important clinical promise.
3.5 Implications for the feasibility RCT (Chapter 7)

This review has helped to identify the best forms of EF provision, and informed the design of the feasibility RCT (Chapter 7). Since the literature related to NSLBP and EF still needs to explore a number aspects related to optimal EF delivery, recommendations are based on the available literature primarily related to the motor learning field, which has focused mainly on healthy subjects. In summary, the current literature suggests that EF should be provided with the following content characteristics: program feedback, summary results feedback, and external focus of attention. With regards to timing characteristics, concurrent and constant feedback should be avoided, while reduced frequency or self-selected feedback is recommended by the literature.
4 The reliability and accuracy of Fastrak™ when used conjointly with the Spineangel® device: a preliminary study

4.1 Overview

Previous chapters have reviewed and discussed the literature related to the dose-response relationship between work-related cumulative postural exposure and NSLBP (Chapter 2) and to the use of extrinsic feedback as a rehabilitation tool for the management of NSLBP (Chapter 3). In order to influence postural exposure at the individual level through the provision of postural EF, a lumbo-pelvic postural monitor device is necessary. The assessment of validity of the Spineangel® as a lumbo-pelvic monitor device is described in Chapter 5. Prior to conducting this concurrent validity study against a reference standard (i.e. Fastrak™ measurements), it was necessary to ascertain whether the Spineangel® would interfere with Fastrak™ measurements. In this Chapter, the reliability and accuracy of Fastrak™ linear and angular measurements (LM and AM, respectively) are assessed when the Spineangel® is placed within the detection boundaries of the Fastrak™ sensors and transmitter.

4.1.1 Background

The Spineangel® was developed to be attached to the belt or waistband while the user performs daily activities; however, its validity for assessing lumbo-pelvic movements when used in such a way is unknown. A previous study assessed the validity of the Spineangel® fixed to the skin of the participants and used the real-time motion-capture system as the gold standard device (Intolo et al., 2010). Theoretically, the real-time motion-capture system could be used for assessment of validity and reliability of the Spineangel® device. However, both belt and waistband block the placement of retro-reflective pelvic markers placed over the posterior superior and anterior superior iliac spines. As a result, in order to validate the use of Spineangel® while attached to the waistband or belt, it was deemed more appropriate to use the Fastrak™ as the gold standard comparative measurement of lumbar and pelvic kinematics.
The Fastrak™ root mean square error for rotational measurements was reported to be less than 0.2° (Pearcy and Hindle, 1989). Although magnetic tracking devices such as the Fastrak™ can provide accurate measurements (An et al., 1988) the influence of the accelerometer driven Spineangel® postural measurement device in the electromagnetic field used during Fastrak™ measurements is not known. Metal and electronic equipment can interfere with measurement accuracy of electromagnetic devices such as the Fastrak™ (McGill et al., 1997). The aim of this study was to assess the reliability and accuracy of Fastrak™ position and orientation measurements, when the Spineangel® was placed close to the Fastrak™ sensor(s) and transmitter, under static conditions. This was an essential step before conducting the study that would assess the validity of Spineangel® as a lumbo-pelvic monitor device.

### 4.2 Methods

This is a cross-sectional repeated measure study.

#### 4.2.1 Equipment

Three Fastrak™ sensors, one Spineangel® (Movement Metrics, Hamilton, New Zealand), a personal computer, and an electronic digital calliper (resolution: 0.01 mm) were used. Position and orientation data were obtained using 3-Space Fastrak™ (Polhemus, Colchester, VT, USA) and its frequency sample was set for 10 Hz. Kinematic data were analyzed using a customized program written in Scilab 5 (Scilab Enterprises, 2012).

#### 4.2.2 Procedures

A one metre length of paper was used to guide sensor placement. Two parallel lines (Line 1 and Line 2) 20 cm apart, over a length of 85 cm, were drawn on this paper and additional lines perpendicular to these established intervals of 5 cm (from 0 to 85) along the two parallel lines. Each distance was measured with the calliper (Figure 4-1). This range was chosen as it was likely that such range would cover the distance between sensors and the transmitter during the validity study.
4.2.2.1 Linear measurements

For linear measurement (LM), one sensor was placed 5 cm from the transmitter and then moved sequentially along the remaining 15 positions marked in Line 1. This allowed the recording of 16 static measurements with an interval distance of 5 cm (from 5 cm to 85 cm) (Figure 4-2).

4.2.2.2 Angular measurements

For angular measurements (AM) three sensors were fixed, using double-sided adhesive tape, in a plastic triangular form (Figure 4-3). The length of each side of the triangle was measured with the calliper and the internal angles were calculated by trigonometry. The internal angle between sensors 1 and 2, and sensors 1 and 3 was 65.3° and between sensors 3 and 2 was 49.3°. The plastic triangle was placed in 15 different positions, along Line 1, with respect to the
transmitter. Due to the size of the plastic triangle, when placing it at 75 cm, one of the sensors (S1) was more than 85 cm from the transmitter. Similarly, sensors attached to the borders of the triangle, meant one of the sensors (S3) was located less than 5 cm from the transmitter. For the validity study, it was expected the distance between sensors and the transmitter would range from 5 cm to 85 cm. In this way, angular trials were performed and analysed for distances from 10 to 75 cm.

![Illustration of testing set up for angular measurements with Spineangel®.](image)

**4.2.2.3 Data collection**

Linear and angular measurements were made on two different days both with and without the use of the Spineangel® (M3). The first two LM tests (LM1 and LM2) and the first two AM tests (AM1 and AM2) were conducted without the inclusion of the Spineangel®. The third LM and AM tests (LM3 and AM3, respectively) were conducted with the inclusion of the Spineangel®, which was placed over Line 2, which was drawn in the one-metre paper as previously described.

All measurements were performed on a wooden table and care was taken that no metal materials were located within a distance of 4 metres from the device. When measurements were computed with Spineangel®, this device was placed at Line 2, 20 cm distant from Line 1. This distance was chosen since it is approximately the distance between the lumbar spine (where Fastrak™ sensor could be placed in a human study) and the lateral edge of the pelvic girdle (where it is recommended the Spineangel® be attached to a waist belt).
4.2.3 Data processing and analysis

Statistical analyses were conducted using the Statistical Package for the Social Science (V.16, SPSS Inc., Illinois USA).

4.2.3.1 Reliability of measurements

The reliability of measurements was assessed by means of the Intraclass Correlation Coefficient two way random effects model, consistency definition (ICC (2,1)). The Method Error (ME) was calculated to assess the absolute difference between the two sets of repeated measures. The Coefficient of Variation Method Error (CV_{ME}) was calculated to express such difference relative to the size of mean difference and is expressed as a percentage of the mean difference (Portney and Watkins, 2009). The agreement between measurements was assessed by a Bland and Altman plots of differences versus the mean (Bland and Altman, 1999).

4.2.3.1.1 Consistency of measurements without the Spineangel®

To assess the consistency of measurements without the Spineangel® (reproducibility of the protocol), the ICC (2,1) was calculated for LM and AM without the Spineangel® device. The LM reliability was calculated using LM1 and LM2 as input data, while AM reliability was calculated using AM1 and AM2 as input data.

4.2.3.1.2 Consistency of measurements with the Spineangel®

To assess the consistency of measurements when adding the Spineangel® to the data collection environment, the ICC (2,1) was calculated for LM using LM1 and LM3 measurements, and was calculated for AM using AM1 and AM3 measurements.

4.2.3.2 Accuracy of measurements

Accuracy was calculated for LM and AM. The linear and angular accuracy of the Fastrak™ device was calculated as (Sarro et al., 2009):

\[ a^2 = b^2 + p^2 \]  \hspace{1cm} \text{Equation 4-1}

Where:

\[ a = \text{accuracy}; \]
b = measurement bias. Expressed by the difference between the experimental measurement mean value and the expected value;

p = measurement precision. It refers to the dispersion of experimental measurements with regards to its mean value, expressed by the standard deviation of experimental measurements.

4.2.3.2.1 Accuracy of LM

As it was not possible to measure the exact distance between the sensor and the origin of the coordinate system at the transmitter for LM, the scalar distance between two subsequent sensor positions was calculated as expressed in Equation 4 - 2. This value was considered as the experimental linear measurement.

\[
\text{Experimental linear measurement} = P_{i+1} - P_i
\]

Equation 4-2

Where:

\[i = 5, 10, 15, \ldots 85 \text{ cm.}\]

P = scalar sensor position;

The expected value between two subsequent parallel lines was 5 cm, as measured previously with the calliper. For accuracy calculation, the experimental linear measurement (Fastrak™), its standard deviation and the expected value (measured with the calliper) were used for calculating linear accuracy.

4.2.3.2.2 Accuracy of AM

For AM, the angular differences in X axis (global coordinate system) between the three sensors (S1-S2; S1-S3; and S2-S3) were calculated. These values represented the experimental angular measurements for the internal angles of the triangle (as measured by the Fastrak™). The expected values for the internal angles of the triangle were 65.3° (S1-S2, and S1-S3), and 49.3° (S2-S3). The experimental angular measurements, its standard deviation and the true internal angle measurements of the triangle (as measured by trigonometry, previously described) were used as input for calculating angular accuracy.
4.3 Results

4.3.1 Reliability of measurements

Reliability findings for LM and AM with or without the inclusion of Spineangel® in the data collection field are reported in Table 4-1. The ME and CV_{ME} were found to be less than one degree and one percentage, respectively. The agreement between measurements in Bland and Altman plots of differences versus means is presented at Figures 4-3 to 4-10 (Bland and Altman, 1999).

Table 4-1. Reliability for linear measurements (LM) and angular measurements (AM).

<table>
<thead>
<tr>
<th>Condition</th>
<th>ICC (2,1)</th>
<th>95% Confidence Interval</th>
<th>ME</th>
<th>CV_{ME} (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LM without SA</td>
<td>0.96</td>
<td>0.89 to 0.99</td>
<td>0.02 cm</td>
<td>0.03</td>
</tr>
<tr>
<td>LM with SA</td>
<td>0.96</td>
<td>0.90 to 0.99</td>
<td>0.03 cm</td>
<td>0.06</td>
</tr>
<tr>
<td>AM without SA</td>
<td>1.00</td>
<td>1.00 to 1.00</td>
<td>0.22°</td>
<td>0.51</td>
</tr>
<tr>
<td>AM with SA</td>
<td>1.00</td>
<td>1.00 to 1.00</td>
<td>0.22°</td>
<td>0.07</td>
</tr>
</tbody>
</table>

SA = Spineangel®; ME = method error; CV_{ME} = coefficient of variation of method error.

4.3.1.1 Linear measurement reliability

4.3.1.1.1 Consistency of LM without the Spineangel®

The mean difference between LM1 and LM2 was found to be close to 0.003 cm (SD = 0.02 cm) (Figure 4-4).

Figure 4-4. Agreement between linear measurements without the Spineangel®. LM1 = first linear measurement; LM2 = second linear measurement.
4.3.1.1.2 Consistency of LM with the Spineangel®

The mean difference between LM1 and LM3 was found to be 0.016 cm (SD = 0.04 cm) (Figure 4-5).

4.3.1.2 Angular measurement reliability

4.3.1.2.1 Consistency of AM without the Spineangel®

Differences between sensors (S1-S2; S1-S3, and S2-S3) for AM1 and AM2 are illustrated in Figure 4-6, Figure 4-7, and Figure 4-8, respectively. The mean difference between S1-S2 was 0.10° (SD = 0.47°); between S1-S3, 0.02° (SD = 0.15°); and between S2-S3, 0.10° (SD = 0.32°). The largest angular difference (1.18°) was found for S1-S2 (Figure 4-6).
Figure 4-6. Agreement between measurements without the Spineangel®. AM1 = first angular measurement; AM2 = second angular measurement; S1 = sensor 1; S2 = sensor 2.

Figure 4-7. Agreement between measurements without the Spineangel®. AM1 = first angular measurement; AM2 = second angular measurement; S1 = sensor 1; S3 = sensor 3.
4.3.1.2.2 Consistency of AM with the Spineangel®

Differences between sensors (S1-S2; S1-S3; and, S2-S3) for AM1 and AM3 are illustrated in Figure 4-9, Figure 4-10 and Figure 4-11, respectively. The mean difference between S1-S2 was 0.12° (SD = 0.47°); between S1-S3, 0.08° (SD = 0.16°); and between S2 and S3, 0.03° (SD = 0.32°). The largest difference was equivalent to -1.16° for angular measurements between S1-S2 (Figure 4-9). All remaining differences between sensors for AM1-AM2 and AM1-AM3 had magnitudes of less than 1° (Figure 4-6 to Figure 4-11).
Figure 4-9. Agreement between measurements without (AM1) and with (AM3) the Spineangel®. AM1 = first angular measurement; AM2 = second angular measurement; AM3 = third angular measurement; S1 = sensor 1; S2 = sensor 2.

Figure 4-10. Agreement between measurements without (AM1) and with (AM3) the Spineangel®. AM1 = first angular measurement; AM2 = second angular measurement; AM3 = third angular measurement; S1 = sensor 1; S3 = sensor 3.
4.3.2 Accuracy of measurements

4.3.2.1 Linear measurements

The linear accuracy changed according to the distance between sensor and transmitter. The accuracy values were less than 0.05 cm for sensor placements between 10 and 65 cm (Figure 4-12). Higher accuracy magnitudes were found for scalar distance between sensor placement at 5-10 cm and sensor placement at 35-40 cm. The accuracy deteriorated as the sensor was placed at 65 cm from the transmitter (Figure 4-12). Nonetheless, the least accurate measurement discrepancies were found to be less than 0.35 cm.
4.3.2 Angular measurements

Angular accuracy deteriorated as the plastic triangle was placed distant from the transmitter (Figure 4-13 and Figure 4-14). Angular accuracy values for experimental angular measurements between S2-S3 were found to be worse than those for S1-S2 and S1-S3. Nonetheless, all angular accuracy values were found to be below 2.33° (for AM1) and 3.46° (for AM3).
4.4 Discussion

4.4.1 Reliability of measurements

The ICC (2,1) for linear and angular measurements confirmed that the experimental procedure (both with and without the Spineangel®) allowed for consistent measurements and thus could be used to assess the consistency of linear and angular data, at least within these experimental conditions. Values for ME and CVME were found to be extremely low (Table 4-1). Previous research has assessed the influence of metals on the Fastrak™ outcomes (McGill et al., 1997). Those authors concluded that by avoiding placement of metal objects between the transmitter and sensor, measurement accuracy did not deteriorate. Saber-Sheikh et al. (2010) found no magnetic distortion when Fastrak™ was used conjointly with inertial sensors (Xsens Technology). Nonetheless, the authors did not assess the accuracy of measurements for both devices (Saber-Sheikh et al., 2010). It is likely that measurement distortions will increase as the distance between the sensor and transmitter increases (Bull and McGregor, 2000). The present findings suggest this and show, particularly, that such distortion was not amplified by the presence of the Spineangel® device (Figure 4-12 to Figure 4-14).
4.4.2 Accuracy of measurements

It is not clear why linear accuracy was found to be worse for scalar differences between sensor placement at 5-10 cm and sensor placement at 35-40 cm (Figure 4-12). Nonetheless, the linear accuracy can be considered to be very good in both situations, as these values were below 0.05 cm. Previous research, using the same method to quantify measurement accuracy, has found similar accuracy values (Ribeiro and Loss, 2010, Sarro et al., 2009). For example, Ribeiro and Loss (2010) found linear accuracy of 0.17 cm using a video-based system for upper-limb kinematic analysis, Sarro et al. (2009) measured rib motion during breathing with a video-based system and found linear accuracy of 0.26 cm. The reason for declined angular accuracy between S2-S3 is also unclear (Figure 4-13 and Figure 4-14). Nevertheless, these sensors provided accurate angular measurements, with angular accuracy magnitude less than 3.46° in error.

The present findings suggest that the Spineangel® device can be used concurrently with the Fastrak™, without resulting in any deterioration in measurement accuracy from Fastrak™. These findings are limited to the placement conditions studied in the current protocol: in the present study, the Spineangel® was not placed directly between the transmitter and the sensor and therefore it is not possible to make any statement regarding the potential effect in that condition.

4.5 Limitations

This study has limitations. For instance, the present study did not assess the effect of the Spineangel® movement within the sensor-transmitter magnetic field on the signal. However, considering the Spineangel® did not affect the accuracy of the Fastrak™ measurements under static conditions, it is reasonable to assume the Spineangel® would not interfere with Fastrak™ measurements, if it was moved through the magnetic field.

4.6 Implications for the validity study (Chapter 5)

This study demonstrated that placing the Spineangel® within the electromagnetic field of the Fastrak™ does not distort or bias the latter’s data. These results indicated that the Fastrak™ could be used as a ‘gold standard
instrument’ when assessing the validity of the Spineangel® as a lumbo-pelvic monitor device. Chapter 5 will describe and discuss such study.
5 The concurrent validity and reliability of the Spineangel® as a lumbo-pelvic postural monitor device

5.1 Overview

In this Chapter, concurrent validity and reliability of Spineangel® as a lumbo-pelvic postural monitor device when fixed to the waistband or belt is evaluated during a range of functional tasks. Lumbo-pelvic movements were measured with two different instruments: the Spineangel® and the Fastrak™. Findings from this study provided relevant information with regards to how Spineangel® measurements should be interpreted in later chapters (Chapter 6 and 7).

5.1.1 Background

A complex interaction between mechanical and psychosocial factors can contribute towards the onset and maintenance of NSLBP (Nicholas et al., 2011, Vandergrift et al., 2012, Jansen et al., 2004). Workplace posture is one of a number of mechanical factors that may be associated with NSLBP (Harcombe et al., 2009, Punnett and Wegman, 2004, Harkness et al., 2003, Teschke et al., 2009). Findings from the systematic review described in Chapter 2 suggest limited evidence is available for ROM and duration of trunk flexion and no evidence was found regarding repetitive trunk flexion as risk factor for NSLBP. On the other hand, laboratory studies have repeatedly reported sustained or repetitive trunk flexion to be associated with deleterious effects on spinal neuromuscular functioning (Olson et al., 2009, Shin and Mirka, 2007), and to be associated with perturbed lumbar position sense in a healthy population (Dolan and Green, 2006, Wilson and Granata, 2003). Similarly, patients with NSLBP may present with reduced postural awareness and reduced lumbar position sense (Newcomer et al., 2000, Gill and Callaghan, 1998, O'Sullivan et al., 2003). It has been also shown that changing patient's spinal postural alignment can reduce symptoms in a sub-group of patients presenting with NSLBP (Van Dillen et al., 2003, Van Dillen et al., 2005, O'Sullivan, 2005). The literature suggests that altered lumbo-pelvic proprioception may play a role in the maintenance of symptoms in a sub-group of patients with NSCLB (O'Sullivan, 2005). Consequently, prevention programmes have focused on
reducing exposure to flexed spinal postures and clinicians often include postural re-education as part of the intervention protocol (Van Dillen et al., 2007, Van Dillen et al., 2003).

Different methods for measuring posture have been reported in the literature (Allread et al., 2000, Wong and Wong, 2008, Sheeran et al., 2010, O'Sullivan et al., 2011, David, 2005, Freitag et al., 2007, Teschke et al., 2009, Xu et al., 2011). Visual assessment is commonly used in clinical practice and for work-risk assessment, while more robust and complex methods such as the use of real-time motion capture systems are used for laboratory studies (Intolo et al., 2010, Straker et al., 2010). The disadvantage of laboratory-based systems is the technical complexity requiring time consuming methods for assessing posture (Straker et al., 2010). Self-reports are also common ways of estimating work-related postural exposure; however, they were found to underestimate certain postures and overestimate duration of recalled ones (Teschke et al., 2009, Unge et al., 2005). The use of direct assessment of working posture provides precise, accurate and depth information about postural exposure, as long as the measuring device provides valid data (Teschke et al., 2009). The findings from the systematic review described in Chapter 2 suggested that postural exposure outcome measures need to be assessed in a more systematic and standardized way. A number of portable devices that provide alternatives for monitoring posture during real-life activities have recently been reported and have the potential to improve postural exposure measurements (Dean and Dean, 2006, Horton and Abbott, 2008, O'Sullivan et al., 2011, Donatell et al., 2005, Teschke et al., 2009). As discussed in Chapter 3, from a clinical perspective, the ideal instrument should be capable of monitoring posture, while also providing postural feedback for the user. The combination of postural monitoring and feedback is considered clinically relevant for patients with NSLBP as this could help to avoid pain-provoking postures during daily-life activities. From a prevention perspective, postural monitor and feedback devices could be used to assess and minimize exposure to higher risk postures. In order to monitor and provide such postural feedback reliable devices are required.

The Spineangel® was developed to be attached to the belt or waistband while the user performs daily activities. The device has been shown to be a valid instrument for monitoring pelvic movements during forward bending in a
controlled laboratory setting and while adhered directly to the skin (Intolo et al., 2010); however its validity when clipped to the belt or waistband is unknown. Intolo et al. (2010) assessed the Spineangel® in sagittal plane for bending tasks but did not examine the performance of this device during a range of different functional tasks that are likely to be performed by users during daily-life activities, for example: lifting, sitting posture or squatting.

Before exploring the use of the device in the workplace, it was necessary to explore the measurement properties of the device during a range of occupational activities while clipped to the belt or waistband. The aims of this study were twofold: firstly, to determine the within-session, within-task, and between-day reliability of the device; secondly to determine the concurrent validity of the Spineangel® as a lumbo-pelvic postural monitor when clipped on the belt or waistband for the measurement of lumbo-pelvic movements during a range of occupational activities.

5.2 Methods

5.2.1 Study Design

This was a cross-sectional study design with a convenience sample of twenty-five. All participants provided informed written consent (Appendix B). This study was approved by the Human Ethics Committee of the University of Otago – Reference number: 10-035 (Appendix B).

5.2.2 Recruitment of participants

Posters, on notice boards at the School of Physiotherapy, and all-department email were used to inform staff and students from the University of Otago about the study.

5.2.2.1 Inclusion and exclusion criteria

Participants were invited to take part in the study irrespective of any history of back symptoms. Participants were excluded if they were unable to undertake regular daily activities due to back pain (such as study, sports activities and work related tasks).
5.2.3 *Instrumentation*

Comparative kinematic data were monitored by means of the Spineangel® device (Movement Metrics, Hamilton, New Zealand) and 3-Space Fastrak™ (Polhemus, Colchester - Vermont, USA).

5.2.3.1 *Spineangel®*

For the purpose of this study, the Spineangel® was used in the continuous recording mode and no audio-feedback was provided to participants. When turned on, the Spineangel® records the participant’s standard upright posture, which is then accepted as the zero value. Forward inclinations of the device are then recorded as negative angular values while backwards inclinations are recorded as positive values. As a result, any trunk flexion, anterior pelvic tilt or hip flexion in a closed kinetic chain is likely to lead the device to tilt forward (i.e. negative recording values) while trunk extension, posterior pelvic tilt and hip extension in a closed kinetic chain is likely to induce the device to tilt backwards (i.e. positive recording values). When sitting in a slumped posture, the Spineangel® tilts backwards with the pelvis, recording positive values.

5.2.3.2 *3 Space Fastrak™*

Lumbo-pelvic and hip movements were recorded using 3 Space Fastrak™ (Polhemus, Colchester - Vermont, USA) at a frequency sample of 10 Hz. The Fastrak™ is an electromagnetic device designed to measure position and orientation of a sensor. For this study, one source and four sensors were used. The sensors detect a low frequency magnetic field generated by the source and six degree-of-freedom data are generated for each sensor. One global coordinate system (GCS) was defined by the Fastrak™ source’s Cartesian coordinate system with X (medio-lateral), Y (posterior-anterior) and Z (inferior-superior). The Cartesian coordinate system of each sensor defined the local coordinate system (LCS) of the twelfth thoracic (T12), third lumbar (L3) and first sacral (S1), and femur. For each sensor, three translations (X, Y and Z) and three rotations (azimuth (θ), elevation (φ) and roll (Ψ)) are described with regards to the GCS. The orientation data are described in Cardan angles (Woltring, 1994). The 3 Space Fastrak™ has demonstrated reliability and validity as an instrument for lumbar spine kinematic measurement (Pearcy and Hindle, 1989, Jordan et al., 2004) and has a reported accuracy of 0.2° (Pearcy and Hindle, 1989).
To monitor lumbo-pelvic movements, three sensors were placed on the skin at the spinous process of the T12, L3 and S1 using double-sided adhesive tape. The sensor placed at T12 allowed monitoring movements at the total lumbar (TL) spine, the L3 sensor the lower lumbar (LL) spine and the S1 pelvic movement. An additional sensor was strapped to the lateral femoral condyle of the right knee to monitor hip movements. Kinematic data from hip movements were used for reference purposes only during data processing. This allowed identifying when each subject adopted sitting or standing postures. All sensors were placed by the same researcher (DCR). Sensors placed at the vertebral column defined a right-handed coordinate system. The x, y and z represented inferior-superior, medio-lateral, and posterior-anterior axes respectively. As a result, rotations occurring about the x axis (ψ) described right (-) and left (+) axial rotation; about the y axis (ϕ) described flexion (-) and extension (+); and about the z axis (θ) described left (-) and right (+) lateral flexion (Burnett et al., 1998). For the purpose of this study, only rotations around the y axis (flexion and extension) were analysed. As described in Chapter 4, placing the Spineangel® device close to Fastrak™ sensors and source does not alter Fastrak™ measurements.

5.2.4 Procedures

Participants’ mass and height were recorded. They were familiarised with the testing procedures and performed up to 5 repetitions of each task before placing the sensors. To enhance external validity of this research, participants wore their normal daily clothes during testing with the Spineangel® device attached to their trouser belt or waistband, as recommended by the manufacturer (Figure 5-1a). In order to pragmatically capture between-subject variability, we did not control for the height of the waistband or belt position, and the use of a belt was not mandatory.

With the intention of describe kinematic data relative to a zero reference, participants were instructed to assume a natural, neutral posture standing comfortably for five seconds. The orientation of each sensor was recorded during this period and the mean orientation value calculated for each sensor was used as the zero reference (Burnett et al., 1998, Mitchell et al., 2008).
Seven tasks were performed by participants. In order to reduce the risk of sequence effects, tasks were performed in random order:

1. Flex-to-knee: forward trunk flexion with fingers reaching to the knees (knees maintained in full extension) (Figure 5-1b);

2. Flex mid-lower leg: forward trunk flexion with fingers reaching to the mid-shin (knees maintained in full extension) (Figure 5-1c);

3. Full trunk flex: full trunk flexion (knees maintained in full extension) (Figure 5-1d);

4. Sitting (neutral as starting posture) (Figure 5-1e): participants were instructed to “arch the lower back” and “flatten the lower back”. To identify neutral sitting position, participants were asked to identify the mid-point between the maximum anterior and posterior pelvic rotation.
   a. anterior pelvic rotation (Figure 5-1f);
   b. posterior pelvic rotation (Figure 5-1g);

5. Squatting: starting from a sitting posture (Figure 5-1h), participants were asked to squat, which was defined as the minimum range of motion required to have their buttocks no longer touching the stool, while keeping their balance (Figure 5-1i);

6. Lifting: lifting an empty box placed on the floor next to the participants’ right side, placing it on a table at waist height, and returning it to the floor (Figure 5-1j and Figure 5-1k);

7. Repeating the first task (as allocated by the randomization procedure).
a) Fastrak™ sensors and Spineangel® placements

b) Flex-to-knee

c) Flex-to-mid-shin

d) Full trunk flexion
e) Sitting: neutral posture

f) Sitting: anterior pelvic tilt

g) Sitting: posterior pelvic tilt

h) Squatting: starting posture
For ‘Flex-to-knee’ and ‘Flex mid-lower leg’ tasks, a horizontal board was placed at the knee and mid-lower leg height, respectively for each participant (Figure 5-1). Participants were requested to reach the horizontal board with their hands while keeping fingers flexed. They were then allowed to perform lifting using their preferred lifting/lowering strategy while, maintaining feet position. The first task was repeated as the seventh (Task-7) to allow assessing the within-session reliability of measurements. Each movement was performed five times and the targeted posture was maintained for 5 s. This procedure was adopted as it was
not possible to electronically synchronize the Spineangel® with the Fastrak™ equipment. Those tasks were selected as they were considered to reflect the variability of typical movements performed during a working day.

When using the Spineangel® as a monitor device for postural measurements on different days and over a number of weeks, its measurements can be influenced by the use or not of a belt, the type of trousers worn, a loss or gain in body mass, and the way it is clipped to the belt or waistband. In order to assess for the between-day reliability of the Spineangel® measurements, a sub-group of 10 participants were randomly selected to attend a second data collection session, within three months of the first. This period of time between measurements was elected to enhance external validity of the findings, as the Spineangel® is likely to be used in field research in longitudinal studies, and potentially in successive phases of a rehabilitation programme.

5.2.5 Data processing and analysis

Kinematic data were analysed using a customised code written in Matlab® software (MathWorks, Inc., Natick, MA). Raw kinematic data were digitally filtered using a low-pass third-order Butterworth filter. The cut-off frequency was determined by the Residual Analysis Method (Winter, 2005) and was set at 1 Hz.

5.2.6 Data reduction and transformation

For kinematic data to have anatomical meaning, Fastrak™ raw data were processed and transformed. Direction cosine matrices for each sensor were structured by converting the three Cardan angles (Z, Y, X) from the raw data into elements of their respective matrices (Burnett et al., 1998). For each sensor, the direction cosine matrix \( R \) was defined as:

\[
R = \begin{bmatrix}
  R_{11} & R_{12} & R_{13} \\
  R_{21} & R_{22} & R_{23} \\
  R_{31} & R_{32} & R_{33}
\end{bmatrix}
\]

Where:

\( R_{11} \) = the direction cosine formed by the first axis of GCS and the first axis of LCS;
\( R_{12} \) = the direction cosine formed by the first axis of GCS and the second axis of LCS;

\( R_{13} \) = the direction cosine formed by the first axis of GCS and the third axis of LCS;

\( R_{21} \) = the direction cosine formed by the second axis of GCS and the first axis of LCS;

\( R_{22} \) = the direction cosine formed by the second axis of GCS and the second axis of LCS;

\( R_{23} \) = the direction cosine formed by the second axis of GCS and the third axis of LCS;

\( R_{31} \) = the direction cosine formed by the third axis of GCS and the first axis of LCS;

\( R_{32} \) = the direction cosine formed by the third axis of GCS and the second axis of LCS;

\( R_{33} \) = the direction cosine formed by the third axis of GCS and the third axis of LCS;

To achieve that, the following equations were used:

\[
R_{11} = \cos \theta \cdot \cos \phi \quad \text{Equation 5-2}
\]

\[
R_{12} = \cos \theta \cdot \sin \phi \cdot \sin \psi - \sin \theta \cdot \cos \psi \quad \text{Equation 5-3}
\]

\[
R_{13} = \cos \theta \cdot \sin \phi \cdot \cos \psi + \sin \theta \cdot \sin \psi \quad \text{Equation 5-4}
\]

\[
R_{21} = \sin \theta \cdot \cos \phi \quad \text{Equation 5-5}
\]

\[
R_{22} = \sin \theta \cdot \sin \phi \cdot \sin \psi + \cos \theta \cdot \cos \psi \quad \text{Equation 5-6}
\]

\[
R_{23} = \sin \theta \cdot \sin \phi \cdot \cos \psi - \cos \theta \cdot \sin \psi \quad \text{Equation 5-7}
\]

\[
R_{31} = -\sin \phi \quad \text{Equation 5-8}
\]

\[
R_{32} = \cos \phi \cdot \sin \psi \quad \text{Equation 5-9}
\]

\[
R_{33} = \cos \phi \cdot \cos \psi \quad \text{Equation 5-10}
\]
Where:

\( \cos = \) cosine;

\( \sin = \) sine;

\( \theta = \) rotation around the Z axis;

\( \phi = \) rotation around the Y axis;

\( \Psi = \) rotation around the X axis.

To describe kinematic data with regards to the neutral posture, kinematic data was transformed using the following equation:

\[
\mathbf{R}_r \mathbf{N} = \mathbf{R}_N^T \mathbf{R}_r
\]

\text{Equation 5-11}

Where:

\( \mathbf{R}_r \mathbf{N} = \) direction cosine matrix of raw kinematic data relative to the neutral posture;

\( \mathbf{R}_N^T = \) transpose cosine matrix of neutral posture;

\( \mathbf{R}_r = \) direction cosine matrix of raw kinematic data;

\textbf{5.2.6.1 Joint Coordinate System (JSC)}

Joint movement was described by the use of JCS, as recommended by the International Society of Biomechanics (Wu et al., 2002). In order to establish the JCS, two LCS are used. Two axes of the JCS are embedded at the body segment and one is a floating axis (Figure 5-2):
1. The first axis (e1) is embedded at the proximal segment and has a medio-lateral orientation;

2. The second axis (e2) is the ‘floating’ one and is a common axis perpendicular to the medio-lateral and longitudinal axes (e3). This axis (e2) is defined by the cross product of the first and third axis;

3. The third axis is embedded longitudinally at the distal segment and has an inferior-superior orientation.

After defining the JCS for kinematic description of each body segment, the three rotational movements are described based on the JCS (Zatsiorsky, 1998). The angle $\alpha$ describes the rotation around the medio-lateral axis of the proximal segment, corresponding to flexion/extension. The angle $\gamma$ describes the rotation around the longitudinal axis fixed at the distal segment, corresponding to axial rotation. The angle $\beta$ describes rotation around the floating axis, corresponding to lateral flexion (for the spine) or abduction-adduction (for the hip joint) (Wu et al.,...
These angles were calculated based on the $R_{rn}$ matrix (see Equation 5 - 11) and using the following equations (Burnett et al., 1998):

$$\alpha = \tan^{-1}\left(\frac{R_{rn\ 31}}{R_{rn\ 11}}\right) \quad \text{Equation 5-12}$$

$$\beta = \tan^{-1}\left(\frac{R_{rn\ 21}}{\sqrt{R_{rn\ 31}^2 + R_{rn\ 11}^2}}\right) \quad \text{Equation 5-13}$$

$$\gamma = \tan^{-1}\left(\frac{-R_{rn\ 23}}{R_{rn\ 22}}\right) \quad \text{Equation 5-14}$$

Where:

$\alpha$ = describes flexion (-) and extension (+);

$\beta$ = describes right lateral flexion (+) and left lateral flexion (-);

$\gamma$ = describes left axial rotation (+) and right left axial rotation (-);

$[R_{rn}]$ = direction cosine matrix of raw kinematic data relative to the neutral posture;

5.2.6.2 Lumbar kinematics

Lumbar movements were defined by the three sensors placed at T12, L3 and S1. Total lumbar (TL) movements were defined by the relative movements of the sensor placed at T12 with regards to the sensor placed at S1. Lower lumbar (LL) movements were defined by the relative movements of the sensor placed at L3 with regards to the sensor placed at S1. Kinematic data for L3 and T12 sensors were described with regards to the neutral orientation of the sensor placed at S1. This allowed for quantification of regional lumbar movement (L3-S1) and total lumbar movement (T12-S1).

The first rotation ($\alpha$) is around the medio-lateral axis of the proximal segment (S1) and describes flexion(-) and extension(+). The second rotation ($\gamma$) is around the longitudinal axis fixed at the distal segment (L3, T12 or Femur) and describes left axial rotation(+) and right left axial rotation(-). The third rotation ($\beta$) is around the floating axis and describes right lateral flexion(+) and left lateral flexion(-) (Wu et al., 2002).
5.2.6.3 Pelvic kinematics

Pelvic movements were defined by the rotation of the sensor placed at S1, with regards to its initial position. The first rotation ($\alpha$), around the medio-lateral axis of the S1, described posterior pelvic tilt (+)/anterior pelvic tilt (-). The second rotation ($\gamma$), around the longitudinal axis of S1, described left axial rotation (+)/right axial rotation (-). The third rotation ($\beta$), around the floating axis, described right lateral flexion (+)/left lateral flexion (-) (Wu et al., 2002).

5.2.6.4 Hip kinematics

As stated before, hip joint angles were used for reference purposes, so it was possible to identify when the subject was sitting or standing. For monitoring hip movements, one sensor was placed at the lateral femoral condyle. The LCS of this sensor had the z axis pointing lateral-medially, y axis pointing posterior-anteriorly, and x axis pointing inferior-superiorly. In order to correctly quantify hip movements, a specific data transformation was required. For data processing purposes, the z axis orientation was inverted. As a result, the LCS for the sensor S1 had its z axis pointing medial-laterally (Figure 5-2). The first rotation ($\alpha$), around the medio-lateral axis of the proximal segment (S1), described flexion (+) / extension (-). The second rotation ($\gamma$), around the longitudinal axis fixed at the distal segment (femur), described medial hip rotation (+) / lateral hip rotation (-). The third rotation ($\beta$), around the floating axis, described adduction (+) / abduction (-) (Wu et al., 2002).

As illustrated in Figure 5-3, by analysing hip joint angles, it was possible to identify upright and sitting postures. Prior to task execution, the participants held an upright posture and hip joint angles were approximately 0°. Then, participants were requested to sit in a stool and the hip joint angles increased to approximately 70° (Figure 5-3).
5.2.7 Statistical analysis

All statistical analysis were performed with the use of the Matlab® software (MathWorks, Inc., Natick, MA) and the R® statistical software (version 2.12.1) (R_Core_Team, 2008). Data distribution was assessed by means of kurtosis, skewness, graphical analysis of Q-Q plots and histograms (Peat and Barton, 2008). The Spineangel® and Fastrak™ (TL, LL and Pelvic) mean value of measurements obtained during the sustained postures were used as outcome measures.

5.2.7.1 Within-task reliability of Spineangel® and Fastrak™

The within-task reliability for each instrument (i.e. Spineangel® and Fastrak™) was assessed by means of the Intraclass Correlation Coefficient (two-way mixed model, consistency definition, ICC (3,1)). The five repetitions of each task were used as input in the model, assuming the Spineangel® as a single rater. Response stability was assessed by the Standard Error of Measurements (SEM) across the five repetitions of each analysed task. The SEM was calculated by extracting the square root of the error mean square term from the ANOVA test (Weir, 2005). This method has the advantage of estimating the SEM independently from the ICC magnitude (Weir, 2005).
5.2.7.2 Within-session reliability of Spineangel® and Fastrak™

Within-session reliability, comparing data of the first (Task-1) and last task (Task-7), was assessed with the ICC (3,5) (two-way mixed model, consistency definition). The mean value of the five repetitions for both Task-1 and Task-7 were used as input data for this model, assuming the Spineangel® as a single rater. The ME and the CV<sub>ME</sub> were also calculated (Portney and Watkins, 2009). The ME reflects the difference between the two measurements (Task-1 and Task-7) while the CV<sub>ME</sub> represents the ME with regards to the size of the mean differences (Portney and Watkins, 2009). Systematic bias between Task-1 and Task-7 was assessed by performing a two-tailed paired t-test with alpha level of 0.05 (Portney and Watkins, 2009). It was hypothesized there would be no differences between Task-1 and Task-7.

5.2.7.3 Between-day reliability of Spineangel® measurements

The between-day reliability for the Spineangel® measurements was assessed by means of the Intraclass Correlation Coefficient (two-way mixed model, agreement definition, ICC(2,5)). The mean values of the five repetitions for both Day-1 and Day-2 measurements were used to calculate the ICC value for each task. The ICC (2,5) allows to generalize findings from this sample to other participants. The ME and CV<sub>ME</sub> were calculated to assess absolute reliability (Portney and Watkins, 2009). The ME represents the difference between measurements (Day-1 and Day-2) and the CV<sub>ME</sub> represents the percentage of ME with regards to the mean difference between measurements (Day-1 and Day-2). Mean body mass difference between Day-1 and Day-2 and the use or not of belt were recorded, to monitor for potential intervening variables.

5.2.7.4 Concurrent validity of measurements

Concurrent validity of the Spineangel® was assessed by comparing TL, LL and pelvic kinematic data measured by the Fastrak™ with kinematic data measured by the Spineangel®. To assess the agreement between the Spineangel® and the 3 Fastrak™ measurements (TL, LL pelvis), limits of agreement were calculated (Portney and Watkins, 2009). When assessing for agreement between two instruments, it is recommended to calculate the difference between measurements. Therefore, the following equation was used to calculate differences between Spineangel® and the Fastrak™ (Bland, 2004):
Difference = Spineangel – Fastrak  \[ \text{Equation 5-15} \]

Thus, positive differences mean the measurements produced by the new method (i.e. the Spineangel®) exceeded those of the gold standard (i.e. Fastrak™), while negative differences suggest the Spineangel® provided conservative estimates of lumbo-pelvic postural movements.

In order to check for systematic bias between measurements (TL x Spineangel®, LL x Spineangel®, and Pelvis x Spineangel®), paired \( t \)-tests were performed for comparison between Spineangel® and Fastrak™ sensors for each task individually as well as collectively with alpha level set at 0.05. To emphasise external validity for occupational field research and intervention research, the primary outcome of interest was the overall (collective) analysis of all movements.

5.2.7.5 Post hoc power analysis

No studies comparing the Spineangel® with the Fastrak™ measurements were found, impeding the estimation of the sample size for this study. Therefore, a post hoc power analysis was conducted to support the interpretation of the concurrent validity results and determine the likelihood of committing a Type II error (Portney and Watkins, 2009). The smallest difference between the Spineangel® and the Fastrak™ measurements, and the correspondent effect size (d) were identified based on the analysis of all tasks collectively. Those variables (i.e. mean difference and effect size) and the sample size were, then, used as input data for the post hoc power analysis.

5.2.7.6 Data handling

Prior to the analysis of covariance between the Spineangel® and Fastrak™ measurements, data distributions were assessed. Data were assessed for conformity to a Gaussian distribution, and for skewness, and kurtosis by means of graphical analysis of Q-Q plots and histograms (Peat and Barton, 2008).

While calculating the Pearson correlation coefficient, its magnitude can be drastically influenced by the range of measurements (Portney and Watkins, 2009). Due to potential clustering of data when analysing each task separately, it was deemed more appropriate to analyse all tasks collectively.
5.2.7.7 Interpretation of results

The validity of the Spineangel® as a monitor device was accepted if a strong Pearson correlation coefficient (>0.8) between the Spineangel® and the Fastrak™ was present; the difference between this device and the Fastrak™ was less than the threshold value of 5.0° (Intolo et al., 2010), and the 95% limits of agreement were narrow (less than 5.0° in either direction).

5.3 Results

Demographic data of the 25 participants are described in Table 5-1.

Table 5-1. Demographic data for the 25 participants.

<table>
<thead>
<tr>
<th>Participants</th>
<th>Mean (SD)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>29.2 (5.1)</td>
<td>21-44</td>
</tr>
<tr>
<td>Height (m)</td>
<td>168.6 (9.5)</td>
<td>152.0-184.5</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>68.2 (10.7)</td>
<td>50-95</td>
</tr>
<tr>
<td>Body Mass Index (kg/m^2)</td>
<td>23.9 (2.3)</td>
<td>19.1-28.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belt (yes/no)</td>
</tr>
<tr>
<td>Gender (M/F)</td>
</tr>
</tbody>
</table>

SD = standard deviation; m = metre; kg = kilogram; M = male; F = female.

5.3.1 Within-task reliability of measurements

5.3.1.1 Spineangel® device

The ICC(3,5) values for within-task reliability for the Spineangel® measurements ranged from 0.97 to 0.99 and the 95% Confidence Intervals (CI) were narrow (Table 5-2). These values fall within the range defined as excellent (Fleiss, 1999). The SEM for the Spineangel® device measurements ranged from 1.0 to 2.1° or 3.2 to 22.7% of the mean measurements (Table 5-2).

5.3.1.2 Fastrak™ device

Within-task reliability for the Fastrak™ measurements ranged from 0.99 to 1.00 with a narrow 95% CI (Table 5-2). These values fall within the range defined as excellent (Fleiss, 1999). The SEM for the Fastrak™ device measurements ranged from 0.9 to 3.6° or 3.9 to 15.6% of the mean measurement (Table 5-2).
Table 5-2. Within-task reliability for Spineangel® and Fastrak™ measurements.

<table>
<thead>
<tr>
<th>Task</th>
<th>Instrument</th>
<th>Body segment</th>
<th>ICC(3,5)</th>
<th>95% CI</th>
<th>SEM</th>
<th>SEM (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flex-to-knee</td>
<td>Spineangel®</td>
<td>--</td>
<td>0.97</td>
<td>0.95 to 0.98</td>
<td>1.5</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>Fastrak™</td>
<td>Total lumbar</td>
<td>0.99</td>
<td>0.99 to 1.00</td>
<td>1.5</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower lumbar</td>
<td>1.00</td>
<td>0.99 to 1.00</td>
<td>0.9</td>
<td>3.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pelvis</td>
<td>0.99</td>
<td>0.99 to 1.00</td>
<td>1.7</td>
<td>7.3</td>
</tr>
<tr>
<td>Flex-to-mid-lower-leg</td>
<td>Spineangel®</td>
<td>--</td>
<td>0.98</td>
<td>0.98 to 0.99</td>
<td>1.0</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>Fastrak™</td>
<td>Total lumbar</td>
<td>0.99</td>
<td>0.99 to 1.00</td>
<td>1.2</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower lumbar</td>
<td>1.00</td>
<td>0.99 to 1.00</td>
<td>1.0</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pelvis</td>
<td>0.99</td>
<td>0.99 to 1.00</td>
<td>1.4</td>
<td>4.4</td>
</tr>
<tr>
<td>Full trunk flex</td>
<td>Spineangel®</td>
<td>--</td>
<td>0.99</td>
<td>0.98 to 0.99</td>
<td>1.2</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>Fastrak™</td>
<td>Total lumbar</td>
<td>1.00</td>
<td>0.99 to 1.00</td>
<td>1.1</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower lumbar</td>
<td>1.00</td>
<td>0.99 to 1.00</td>
<td>1.3</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pelvis</td>
<td>0.99</td>
<td>0.99 to 1.00</td>
<td>1.6</td>
<td>3.6</td>
</tr>
<tr>
<td>Sit ant</td>
<td>Spineangel®</td>
<td>--</td>
<td>0.98</td>
<td>0.97 to 0.99</td>
<td>1.6</td>
<td>9.3</td>
</tr>
<tr>
<td></td>
<td>Fastrak™</td>
<td>Total lumbar</td>
<td>1.00</td>
<td>0.99 to 1.00</td>
<td>2.3</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower lumbar</td>
<td>0.99</td>
<td>0.99 to 1.00</td>
<td>1.3</td>
<td>5.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pelvis</td>
<td>1.00</td>
<td>0.99 to 1.00</td>
<td>2.5</td>
<td>10.8</td>
</tr>
<tr>
<td>Sit post</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task</td>
<td>Instrument</td>
<td>Body segment</td>
<td>ICC(3,5)</td>
<td>95% CI</td>
<td>SEM</td>
<td>SEM (%)</td>
</tr>
<tr>
<td>--------</td>
<td>------------</td>
<td>--------------</td>
<td>----------</td>
<td>----------------</td>
<td>------</td>
<td>---------</td>
</tr>
<tr>
<td></td>
<td>Spineangel®</td>
<td>--</td>
<td>0.99</td>
<td>0.98 to 0.99</td>
<td>1.5</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>Fastrak™</td>
<td>Total lumbar</td>
<td>1.00</td>
<td>0.99 to 1.00</td>
<td>1.5</td>
<td>6.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower lumbar</td>
<td>1.00</td>
<td>0.990 to 1.000</td>
<td>1.1</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pelvis</td>
<td>0.99</td>
<td>0.99 to 1.00</td>
<td>1.6</td>
<td>7.8</td>
</tr>
<tr>
<td>Squat</td>
<td>Spineangel®</td>
<td>--</td>
<td>0.98</td>
<td>0.97 to 0.98</td>
<td>2.1</td>
<td>22.7</td>
</tr>
<tr>
<td></td>
<td>Fastrak™</td>
<td>Total lumbar</td>
<td>0.99</td>
<td>0.99 to 1.00</td>
<td>3.2</td>
<td>11.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower lumbar</td>
<td>0.997</td>
<td>0.99 to 1.00</td>
<td>2.4</td>
<td>10.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pelvis</td>
<td>0.99</td>
<td>0.98 to 0.99</td>
<td>2.4</td>
<td>13.3</td>
</tr>
<tr>
<td>Lifting</td>
<td>Spineangel®</td>
<td>--</td>
<td>0.97</td>
<td>0.96 to 0.98</td>
<td>1.8</td>
<td>6.6</td>
</tr>
<tr>
<td></td>
<td>Fastrak™</td>
<td>Total lumbar</td>
<td>0.99</td>
<td>0.99 to 0.99</td>
<td>2.3</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower lumbar</td>
<td>0.99</td>
<td>0.99 to 0.99</td>
<td>1.7</td>
<td>5.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pelvis</td>
<td>0.99</td>
<td>0.98 to 0.99</td>
<td>3.6</td>
<td>15.6</td>
</tr>
</tbody>
</table>

ICC = Intraclass correlation coefficient; CI = confidence interval; SEM = standard error of measurement.
5.3.2 Within-session reliability

5.3.2.1 Spineangel®

Excellent within-session reliability was found for Spineangel® measurements (ICC = 0.98) with a narrow 95% CI (Table 5-3). The ME and CVME were 2.0° and 9.4% respectively (Table 5-3). The mean difference between Task-1 and Task-7 was -0.1° (SD=6.6) with a 95% CI from -2.6 to 2.4° (Table 5-4). Four participants performed the sitting task at T1 and T7. That task involved two movements (i.e. anterior and posterior pelvic tilt), so those were considered as separate tasks for the t-test. As a result, the total number of samples included for the paired t-test was 29. The t-test statistics were -0.08°, with 28 degrees of freedom and an associated p value of 0.93.

5.3.2.2 Fastrak™ measurements

Excellent within-session reliability was found for Fastrak™ measurements® (Total lumbar ICC = 0.97; Lower Lumbar ICC = 0.87; Pelvis ICC = 0.96) with a narrow 95% CI (Table 5-3). The ME was equivalent to 2.0° for the lumbar sensor placed at T12, 4.0° for the lower lumbar sensor and 4° for Pelvic sensor (Table 5-3) and the CVME was equivalent to 5.7, 16.6 and 13.4% for the upper, lower lumbar and pelvic sensors, respectively. The mean difference between Task-1 and Task-7 for the lumbar sensor placed at T12 was equivalent to -2.8° (95% CI: -5.9 to 0.2°, p value = 0.06), for the lower lumbar sensor 2.8° (95% CI: -2.2 to 7.7°, p value = 0.26) and for the pelvic sensor -0.5 (95% CI: -4.54 to 3.5°, p value = 0.79) (Table 5-4).

Table 5-3. Within-session reliability (Task-1 and Task-7) for Spineangel® and Fastrak™ measurements.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Segment</th>
<th>ICC(3,2)</th>
<th>95% CI</th>
<th>ME (degrees)</th>
<th>CVME (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spineangel®</td>
<td>--</td>
<td>0.98</td>
<td>0.96 to 0.99</td>
<td>2.0</td>
<td>9.4</td>
</tr>
<tr>
<td>Fastrak™</td>
<td>Total Lumbar</td>
<td>0.97</td>
<td>0.95 to 0.99</td>
<td>2.0</td>
<td>5.7</td>
</tr>
<tr>
<td></td>
<td>Lower Lumbar</td>
<td>0.87</td>
<td>0.72 to 0.93</td>
<td>4.0</td>
<td>16.6</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>0.96</td>
<td>0.93 to 0.98</td>
<td>4.0</td>
<td>13.4</td>
</tr>
</tbody>
</table>

ICC = Intraclass correlation coefficient; CI = confidence interval; ME = Method Error; CVME = coefficient of variation of method error.
Table 5-4. Comparison between measurements (Task-1 and Task-7) for assessment of systematic bias for the Spineangel® and the FastrakTM measurements (degrees).

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Body Segment</th>
<th>Mean</th>
<th>SD</th>
<th>95% CI</th>
<th>t value</th>
<th>Df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spineangel®</td>
<td>--</td>
<td>-0.1</td>
<td>6.6</td>
<td>-2.6 to 2.4</td>
<td>-0.08</td>
<td>28</td>
<td>0.93</td>
</tr>
<tr>
<td>FastrakTM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total lumbar</td>
<td>-2.8</td>
<td>8.0</td>
<td>-5.9 to 0.2</td>
<td>-1.91</td>
<td>28</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>Lower</td>
<td>2.8</td>
<td>13.1</td>
<td>-2.2 to 7.7</td>
<td>1.13</td>
<td>28</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>Pelvis</td>
<td>-0.5</td>
<td>10.4</td>
<td>-4.5 to 3.5</td>
<td>0.25</td>
<td>28</td>
<td>0.79</td>
<td></td>
</tr>
</tbody>
</table>

SD = standard deviation; CI = confidence interval; Df = degrees of freedom.

5.3.3 Between-day reliability for Spineangel® measurements

For between-day reliability assessment of Spineangel® measurements, lumbo-pelvic posture data was collect from seven male and three female participants. Information about participants' body mass and about the use or not of belt at Day-1 and Day-2 is presented in Table 5-5. There was no difference in body mass between Day-1 and Day-2 measurements (Table 5-5). Between-day reliability for the Spineangel® measurements was found to be excellent (ICC = 0.93, 95% CI: 0.89 to 0.95). The ME was equivalent to 8.0° and the CV<sub>ME</sub> to 34.4%.

Table 5-5. Spineangel® between-day reliability measurements: participants' mean (SD) body mass, mean difference and 95% confidence interval (CI) and use of belt.

<table>
<thead>
<tr>
<th></th>
<th>Day-1</th>
<th>Day-2</th>
<th>Mean difference (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body mass (kg)</td>
<td>66.8 (11.2)</td>
<td>67.2 (11.0)</td>
<td>-0.4 (-1.5 to 0.67)</td>
</tr>
<tr>
<td>Belt (yes/no)</td>
<td>8/2</td>
<td>4/6</td>
<td>--</td>
</tr>
</tbody>
</table>

SD = standard deviation.

5.3.4 Concurrent validity of measurements

Agreement and systematic bias between Spineangel® and FastrakTM measurements are described in Table 5-6. Mean difference estimates varied widely between tasks performed and segments compared. Generally, all 95% limits of agreement were wide (Table 5-6). Mean differences and 95% CI between Spineangel® and FastrakTM measurements are described in Table 5-7.
Table 5-6. Limits of agreement between Spineangel® and Fastrak™ measurements (degrees).

<table>
<thead>
<tr>
<th>Task</th>
<th>Spineangel® x Fastrak™</th>
<th>Mean Difference</th>
<th>95 % Limits of Agreement</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lower Limit</td>
<td></td>
</tr>
<tr>
<td>All movements analysed</td>
<td>Total lumbar</td>
<td>31.2</td>
<td>-22.0</td>
<td>84.5</td>
</tr>
<tr>
<td></td>
<td>Lower lumbar</td>
<td>12.2</td>
<td>-45.9</td>
<td>70.2</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>5.9</td>
<td>-30.3</td>
<td>42.1</td>
</tr>
<tr>
<td>Flex-to-knee</td>
<td>Total lumbar</td>
<td>30.0</td>
<td>-5.7</td>
<td>65.6</td>
</tr>
<tr>
<td></td>
<td>Lower lumbar</td>
<td>-0.7</td>
<td>-34.0</td>
<td>32.5</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>-0.1</td>
<td>-19.9</td>
<td>19.8</td>
</tr>
<tr>
<td>Flex-to-mid-lower-leg</td>
<td>Total lumbar</td>
<td>30.4</td>
<td>-6.0</td>
<td>66.7</td>
</tr>
<tr>
<td></td>
<td>Lower lumbar</td>
<td>-0.8</td>
<td>-40.4</td>
<td>38.7</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>2.5</td>
<td>-21.2</td>
<td>26.1</td>
</tr>
<tr>
<td>Full trunk flex</td>
<td>Total lumbar</td>
<td>26.4</td>
<td>-18.5</td>
<td>71.2</td>
</tr>
<tr>
<td></td>
<td>Lower lumbar</td>
<td>-7.6</td>
<td>-61.0</td>
<td>45.8</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>6.4</td>
<td>-23.8</td>
<td>36.7</td>
</tr>
<tr>
<td>Sit ant</td>
<td>Total lumbar</td>
<td>22.8</td>
<td>-28.1</td>
<td>73.7</td>
</tr>
<tr>
<td></td>
<td>Lower lumbar</td>
<td>26.3</td>
<td>-14.5</td>
<td>67.1</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>20.7</td>
<td>-14.1</td>
<td>55.5</td>
</tr>
<tr>
<td>Sit post</td>
<td>Total lumbar</td>
<td>56.9</td>
<td>-15.6</td>
<td>129.5</td>
</tr>
<tr>
<td></td>
<td>Lower lumbar</td>
<td>53.2</td>
<td>10.5</td>
<td>95.8</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>6.8</td>
<td>-45.6</td>
<td>59.3</td>
</tr>
<tr>
<td>Squat</td>
<td>Total lumbar</td>
<td>19.8</td>
<td>-28.9</td>
<td>68.6</td>
</tr>
<tr>
<td>Task</td>
<td>Spineangel® x Fastrak™</td>
<td>Mean Difference</td>
<td>95% Limits of Agreement</td>
<td>p-value</td>
</tr>
<tr>
<td>--------------</td>
<td>------------------------</td>
<td>-----------------</td>
<td>--------------------------</td>
<td>---------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lower Limit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lower lumbar</td>
<td>12.8</td>
<td>-34.6</td>
<td>60.1</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>9.3</td>
<td>-25.5</td>
<td>44.0</td>
</tr>
<tr>
<td>Lifting</td>
<td>Total lumbar</td>
<td>19.5</td>
<td>-26.6</td>
<td>65.6</td>
</tr>
<tr>
<td></td>
<td>Lower lumbar</td>
<td>12.8</td>
<td>-34.6</td>
<td>60.1</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>9.3</td>
<td>-21.0</td>
<td>39.5</td>
</tr>
</tbody>
</table>

Table 5-7. Mean differences between Spineangel® and Fastrak™ measurements (total lumbar, lower lumbar and pelvic sensors), standard deviation (SD), 95% Confidence Interval (CI) and p-value.

<table>
<thead>
<tr>
<th>Task</th>
<th>Segment</th>
<th>Mean Difference (degrees)</th>
<th>95% CI (degrees)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>All movements analysed</td>
<td>Total lumbar</td>
<td>31.2</td>
<td>27.1 to 35.4</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Lower lumbar</td>
<td>12.2</td>
<td>7.7 to 16.7</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>5.9</td>
<td>3.3 to 8.6</td>
<td>0.00</td>
</tr>
<tr>
<td>Flex-to-knee</td>
<td>Total lumbar</td>
<td>30.0</td>
<td>22.3 to 37.6</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Lower lumbar</td>
<td>-0.7</td>
<td>-7.9 to 6.4</td>
<td>0.83</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>-0.1</td>
<td>-4.3 to 4.2</td>
<td>0.97</td>
</tr>
<tr>
<td>Flex-to-mid-lower-leg</td>
<td>Total lumbar</td>
<td>30.4</td>
<td>22.7 to 38.0</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Lower lumbar</td>
<td>-0.8</td>
<td>-9.2 to 7.5</td>
<td>0.83</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>2.5</td>
<td>-2.5 to 7.5</td>
<td>0.31</td>
</tr>
<tr>
<td>Full trunk flex</td>
<td>Total lumbar</td>
<td>26.4</td>
<td>16.9 to 35.8</td>
<td>0.00</td>
</tr>
<tr>
<td>Task</td>
<td>Segment</td>
<td>Mean Difference (degrees)</td>
<td>95% CI (degrees)</td>
<td>p-value</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
<td>---------------------------</td>
<td>------------------</td>
<td>---------</td>
</tr>
<tr>
<td></td>
<td>Lower lumbar</td>
<td>-7.6</td>
<td>-18.9 to 3.7</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>6.4</td>
<td>0.1 to 12.8</td>
<td>0.04</td>
</tr>
<tr>
<td>Sit ant</td>
<td>Total lumbar</td>
<td>22.8</td>
<td>7.4 to 26.6</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Lower lumbar</td>
<td>26.3</td>
<td>13.9 to 27.1</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>20.7</td>
<td>8.5 to 21.3</td>
<td>0.00</td>
</tr>
<tr>
<td>Sit post</td>
<td>Total lumbar</td>
<td>56.9</td>
<td>48.8 to 76.6</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Lower lumbar</td>
<td>53.2</td>
<td>50.4 to 67.4</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>6.8</td>
<td>2.4 to 22.8</td>
<td>0.01</td>
</tr>
<tr>
<td>Squat</td>
<td>Total lumbar</td>
<td>19.8</td>
<td>9.6 to 30.1</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Lower lumbar</td>
<td>12.8</td>
<td>2.8 to 22.7</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>9.3</td>
<td>1.9 to 16.6</td>
<td>0.01</td>
</tr>
<tr>
<td>Lifting</td>
<td>Total lumbar</td>
<td>19.5</td>
<td>9.6 to 30.1</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Lower lumbar</td>
<td>12.8</td>
<td>2.8 to 22.7</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>9.3</td>
<td>1.9 to 16.6</td>
<td>0.02</td>
</tr>
</tbody>
</table>
5.3.4.1 Lumbar movements

For all tasks collectively, the mean difference between TL or LL sensors and the Spineangel\textregistered measurements were 31.2 and 12.2°, respectively (Table 5-6). The 95\% Limits of agreement for TL x Spineangel\textregistered and LL x Spineangel\textregistered were wide (larger than 5° for either side of the estimate); these are also presented in Table 5-6. The mean difference between LL x Spineangel\textregistered was approximately 12.0° (95\% CI: 7.7 to 16.6°). The Pearson correlation coefficients for TL or LL sensors and Spineangel\textregistered for all tasks collectively were found to be moderate ($r_s = 0.52$) and fair ($r_s = 0.16$), respectively (Table 5-8) (Portney and Watkins, 2009).

When analysing tasks separately, the differences between the LL sensor and the Spineangel\textregistered were found to be smaller than the threshold value of 5° for two tasks (i.e. Flex-to-knee and Flex-to-mid-lower-leg) (Table 5-7). For all other tasks, the differences between the LL sensor and the Spineangel\textregistered were larger than the critical value of 5°.

5.3.4.2 Pelvic movements

When all tasks were collectively analysed, the mean difference between Spineangel\textregistered and pelvic sensor (Fastrak™) was approximately 6.0° (95\% CI = 3.2 to 8.7). The 95\% Limits of agreement for the Spineangle\textregistered and Pelvic sensor were wide (larger than 5°) and are presented in Table 5-6. The mean difference between Pelvic sensor and Spineangel\textregistered was approximately 6.0° (95\% CI: 3.3 to 8.5°). Good correlation coefficient was found between the Spineangel\textregistered and the pelvic sensor ($r_s = 0.77$, p value < 0.001) (Table 5-8) (Portney and Watkins, 2009).

<table>
<thead>
<tr>
<th>Task</th>
<th>Segment</th>
<th>Pearson Correlation Coefficient</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>All movements analysed</td>
<td>Total lumbar</td>
<td>0.52</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Lower lumbar</td>
<td>0.16</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>0.77</td>
<td>0.00</td>
</tr>
</tbody>
</table>

When analysing tasks separately, the differences between the Pelvic sensor and the Spineangel\textregistered were found to be smaller than the threshold value of 5° for the Flex-to-knee and Flex-to-mid-lower-leg tasks (Table 5-7). For all other tasks, the differences between the Pelvic sensor and the Spineangel\textregistered were larger than the critical value of 5°.
5.3.5 Post hoc power analysis

The smallest difference between the Spineangel® and the Fastrak™ measurements was found when comparing the Pelvic sensor and the Spineangel® (mean difference = 5.9°, Table 5-7). The post hoc power analysis revealed that based on the mean, sample size (n = 25) and the between-instrument comparison effect size observed in this study (d = 0.33), this study had a statistical power level of 0.37.

5.4 Discussion

5.4.1 Within-task reliability of Spineangel® and Fastrak™

Within-task reliability can be affected by small variations between trials as well as measurement error associated with the Spineangel® or Fastrak™ device. These results suggest both the Spineangel® and the Fastrak™ measurements provide stable measurements throughout the trials. Intolo et al. (2010) measured lumbo-pelvic postures with the Spineangel® fixed to the skin, assessing the reliability of angular data obtained from the Spineangel® by calculating the repeatability coefficient. The authors reported such coefficient to range from 3.0 to 5.0°, or a SEM of approximately 1.5 to 2.5, respectively. In the present study, the Spineangel® was clipped to the belt or waistband to enhance the external validity. These findings indicate that this did not increase the within-task measurement variability compared to attaching it to the skin. The present findings suggest the SEM ranged from 1.0 to 2.0°. Such values are similar to those previously reported in the literature (Intolo et al., 2010). Teyhen et al. (2005) measured lumbar spinal movement in the sagittal plane using digital fluoroscopic video (DFV), an expensive and non-portable technology that exposes participants to ionizing radiation. These authors found between trials SEM ranging from 0.7° to 1.4°. The smaller of these values from DFV is comparable to the SEM magnitude found for the Spineangel® in the present study, indicating the Spineangel® device demonstrates strong within-task reliability.

5.4.2 Within-session reliability of Spineangel® and Fastrak™

Excellent within-session reliability was found for Spineangel® and Fastrak™ measurements (Table 5-3). The ME was low for the Spineangel® (2.0°) and ranged from 2 to 4.0° for Fastrak™ measurements. It was found no
statistically significant differences between Task-1 and Task-7, indicating that there was no significant systematic bias for the Spineangel® and the Fastrak™ measurements. Measurement error of up to 5.0° was considered as acceptable by previous reliability study assessing scapulohumeral kinematics (Barnett et al., 1999). Considering the intended use of the Spineangel®, it could be argued that the same cut-off value could be used when assessing the reliability of the Spineangel® measurements. The findings reported by Intolo et al. (2010) and the present study suggest the Spineangel® is a reliable tool for monitoring lumbo-pelvic posture.

5.4.3 Between-day reliability for Spineangel® measurements

Between-day measurements can be affected by different factors, such as accuracy of the Spineangel® device, the use or not of a belt, the use of a different type of belt between the testing days, the type of trousers, changes in body mass, and the way the Spineangel® is clipped to the belt or waistband, and the tasks being undertaken on the second day of measurement. For this study, none of these variables were controlled in order to maximise the external validity of the results.

Sheeran et al. (2010) assessed between-day measurement error for the spine wheel device and found errors ranging from 4.0° to 7.4°. O’Sullivan et al. (2011) found the SEM for between-day reliability for the Body-Guard monitor device to be equivalent to 4°. Since this device monitors specific lumbar segment movements, it is expected such an instrument will present with a lower SEM than the Spineangel®, which monitors gross lumbo-pelvic movement. Between-day reliability for Spineangel® measurements was excellent (ICC = 0.93) and the ME was equal to 8.0° (CV_ME: 34.4%). These findings suggest that when monitoring for within-subjects lumbo-pelvic posture differences, an error of 8.0° can be expected, but this will be consistent between days, as indicated by the high ICC of 0.93.

5.4.4 Concurrent validity of measurements

5.4.4.1 Lumbar movements

The agreement between the Spineangel® and TL sensor was poor. When analyzing all movements, the mean difference between measurements (Spineangel® x TL) was approximately 31.2° (95% Limits of agreement = -22.0 to
When assessing the agreement between Spineangel® and LL sensor for all movements, the present findings suggest the Spineangel® provides conservative estimates for the lower lumbar movements (mean difference: 12°, 95% CI: 7.7 to 16.6, p = 0.00). Differences between the Spineangel® and TL or LL sensors were expected, as the former was clipped at the belt or waistband, i.e., far from L3 or T12 vertebrae. More importantly, the differences between measurements were expected to be consistent.

When analyzing tasks separately (specifically Flex-to-knee and Flex-to-mid-lower-leg tasks), the mean difference between the LL sensor and the Spineangel® was found to be close to zero (Table 5-7). However, for these same tasks (Flex-to-knee and Flex-to-mid-lower-leg), the 95% limits of agreement were wide for the comparison between the LL sensor and the Spineangel® (95% Limits of agreement: -33.9 to 32.5°; and -40.4 to 38.7°, respectively). These results suggest there is not a significant systematic bias for Spineangel® when compared to the LL sensor, when analysing trunk flexion with hands reaching the mid-lower-leg.

### 5.4.4.2 Pelvic movement

When analysing all tasks collectively, the present findings suggest the Spineangel® can monitor pelvic movements quite well ($r_s = 0.77$), albeit with some systematic bias (mean difference = 6°, 95% CI = 3.2 to 8.7°, p = 0.00), when compared to the Fastrak™ pelvic sensor. This suggests the Spineangel® tends to systematically measure slightly smaller values, on average, for pelvic movements during a range of functional tasks (i.e. flex-to-knee, flex-to-mid-lower-leg, trunk flexion, sitting, squatting and lifting). As presented in Table 5-6, the 95% Limits of Agreement were wide, suggesting differences in measurements between the Spineangel® and the Pelvic sensor could reach approximately 36.0° in either direction. Of particular note, no systematic bias were found for Spineangel® measurements when compared to the Pelvic sensor during Flex-to-knee (mean difference: -0.06°, 95% CI: -4.3 to 4.2°, p = 0.97) and Flex-to-mid-lower-leg (mean difference: 2.5°, 95% CI: -2.5 to 7.5°, p = 0.31) tasks.

For measurement of posture in field research, there is always a trade-off between portability, simplicity, compliance and measurement accuracy. The Spineangel® has been found to provide valid measurements for the pelvis during forward bending with hands reaching the knee, when the device was fixed to the
skin (Intolo et al., 2010). When attached to the belt or waistband, the Spineangel® did not meet the requirements to be considered as a valid instrument for measuring pelvic or lumbar movements, in terms of accuracy for depicting degrees of movement across all individual movements tested, at each of the lumbo-pelvic segments. The correlation between the Spineangel® and the Fastrak™ pelvic sensor was found to be good ($r_s = 0.77$), the ICC values for the Spineangel® measurements were excellent and no statistically significant differences were found between the Spineangel® x LL-sensor and the Spineangel® x Pelvic-sensor during Flex-to-knee and Flex-to-mid-lower-leg tasks. It is probably that these tasks recorded the best results as those tasks are simple movements (if compared to more complex task as lifting) which can be accomplished with little movements at the pelvis and the lumbar spine. Together, these results indicate that this device is capable of approximating exposure to changes in lumbo-pelvic postures. As the Spineangel® was developed to be attached to the belt or waistband; it makes sense that it does not provide accurate measurement of all of the assessed segments (TL, LL and pelvis). Attaching the Spineangel® to the belt or waistband is likely to increase variability between subjects, compared with direct adhesion to the skin; however, measurements are reliable for monitoring a wide range of within-subject postural changes. These results suggest the Spineangel® is monitoring a combination of LL and pelvic movements and has the potential to be used as a monitor device for recording general lumbo-pelvic postural behaviour, the purpose for which it was designed.

5.4.5 Post hoc power analysis

As previously described, non-significant differences were found when comparing the LL or Pelvic sensors with the Spineangel® during the Flex-to-knee and Flex-to-mid-lower-leg tasks. The post hoc power analysis indicated a limited statistical power due to modest sample size ($n = 25$). These findings suggest it is not possible to rule-out the presence of a Type II error for non-significant differences findings between the Spineangel® and the Fastrak™ sensors.

Some authors suggest the concept of power is important only at the planning phase of a study (Swinscow and Campbell, 2002). Once a study has been completed, researchers should not discuss hypothetical alternative hypotheses, but the current data (Swinscow and Campbell, 2002). It is recommended that the
best way of doing so, is to analyse the data based on the sample mean difference
values and its respective confidence intervals (Altman et al., 2000, Hoenig and

Relatively narrow 95% CIs were found for the differences between LL or Pelvic sensors and the Spineangel® during the Flex-to-knee and Flex-to-mid-
lower-leg tasks (Table 5-7). The narrowest 95% CI was found when comparing the
Pelvic sensor with the Spineangel® measurements during the Flex-to-knee task.
The present results suggest the true difference between the Pelvic sensor and the
Spineangel® lie within the scores of -4.3° to 4.2° (Table 5-7). Such 95% CI was the
only one presenting smaller magnitude than the threshold of 5°. Therefore, the
95% CI analysis support the lack of significant difference between the Pelvic
sensor and the Spineangel® at least for the Flex-to-knee task.

5.4.6 Practical implications

There needs to be a balance between portability, measurement reliability,
accuracy and validity when using a device for functional postural monitoring and
feedback in the daily workplace. These results support the use of the Spineangel®
as a lumbo-pelvic postural monitor device for measuring exposure to postural
movements, but with limited validity for accurate measurement of movement in
degrees. The Spineangel® was developed to monitor daily-life postures over time,
and to provide audio-feedback whenever a specific postural threshold is exceeded.
The present findings confirm the device is reliable for measuring threshold angles
consistently, but not accurately in terms of degrees. For the purpose of postural
feedback, validity of measurements is not essential, but consistency of
measurements is. Additionally, because the Spineangel® measurements are
consistent, the postural threshold can be adjusted to the systematic bias reported
in this study. Such postural audio-feedback could help patients with NSLBP to
change postural behaviour. The results of this and previous studies (Intolo et al.,
2010) suggest the Spineangel® can approximate postural movement activity. As a
result, although this device may not provide valid lumbar or pelvic measurements
(in terms of accuracy), per se, it is capable of reliably monitoring lumbo-pelvic
posture changes and it could be used to measure pre-post intervention within-
subject differences in postural movement behaviour. Since it is a reliable postural
monitor device, its postural threshold can be adjusted according to individual-level factors; for example, postures that trigger each patient’s low back symptoms.

It is important to highlight that when performing daily-life activities, each patient may have a different lumbo-pelvic movement strategy (Pal et al., 2007), and the Spineangel® was shown to be capable of reliably monitoring the general/gross lumbo-pelvic movement pattern. As program feedback (i.e. the feedback focused on the general pattern of the movement) may be an effective way of instructing patients with NSLBP to change postural behaviour (Chapter 3), the Spineangel® has the potential to be used as a clinical tool to help patients to avoid pain-provoking postures. However, future research is warranted to assess its use as a clinical tool.

5.4.7 Limitations

This study presents with some limitations. Firstly, Fastrak™ sensor placement was based on manual palpation, which may be a source of between-subject error. To minimize this, all sensors for all participants, were placed by a single researcher (DCR). Secondly, work-related and daily living activities entail more postures and movements than those included in this study. It is likely, however, that the postures performed for this study represent a range of different possible tasks to be performed in real life. Thirdly, Fastrak™ measurements are also associated with some error and those could influence the validity results. As previously discussed, within-task SEM can be affected by minor changes in movement pattern between each repetition as well as measurement error associated with each instrument (i.e. Spineangel® and Fastrak™). Differences in movement pattern are likely to affect both instruments (Spineangel® and Fastrak™). The within-task SEM findings for Fastrak™ measurements were small (less than 3.6°); therefore it is unlikely those errors could have influenced the comparisons between the two instruments. Fourthly, repeated t-tests were performed, for each task and collectively, for comparison between the Spineangel® and the Fastrak™. Theoretically, this could increase the chance of Type I error. Fifthly, it is possible that non-significant differences between the Spineangel® and the Fastrak™ sensors were found due Type II error. To minimize such limitation, during the planning phase of the present study, the targeted sample size was set as 25 participants. Such sample size is larger than previous
ones assessing the validity or reliability of instruments used to measure lumbar posture and movement (O’Sullivan et al., 2011, Intolo et al., 2010, Mannion and Troke, 1999, Ng et al., 2001). However, the post hoc power analysis revealed that based on the mean, and the between-group comparison effect size observed in this study (d = 0.33), statistical power was lower than expected, raising the probability of Type II error. For future studies replicating this design, approximately 70 participants would be required to obtain statistical power at the recommended 0.80 level (Portney and Watkins, 2009). Finally, further clinical trials are necessary to assess whether the Spineangel® is a clinically relevant and applicable device.

5.5 Implications for field study (Chapter 6) and feasibility RCT (Chapter 7)

The Spineangel® is a reliable tool when attached to the belt or waistband for monitoring lumbo-pelvic postures during different functional tasks. These results suggest it is capable of monitoring gross postural activity in a range of functional movements, but not for accurately measuring magnitude of movement in degrees, except for pelvic and LL movements when flexing the trunk with hands reaching the knee or the mid-lower-leg. The Spineangel® is accurate, precise and reliable for measuring pelvic angular movements (especially from neutral to knee or mid-shin levels), after adjustment is made for known bias revealed in the present results. The potential of the Spineangel® as a biofeedback device in the daily workplace for patients with NSLBP, or for workers at risk of developing NSLBP, needs to be further explored. This Chapter presented relevant information about how to interpret postural data gathered with the Spineangel® for the studies described in the following chapters 6 and 7.
6 Cumulative postural exposure measured by the Spineangel®: a cross-sectional field study

6.1 Overview

In Chapter 2, the level of evidence for three cumulative postural domains as risk factors for NSLBP was assessed. The reason for conducting this systematic review was to identify postural threshold values for ROM, duration and frequency to be used in the field study (Chapter 7). Findings from this review suggested limited evidence regarding ROM and duration of trunk flexion as risk factors for NSLBP, and no evidence for frequency of trunk flexion as risk factor for NSLBP. The evidence available was considered insufficient for defining postural threshold values for postural EF provision for the feasibility randomized trial. As a result, a cross-sectional study, described in this chapter, was conducted to gather additional information about postural exposure in a group of aged care rest home workers and to explore measurement properties of the Spineangel® in a field-based study.

6.1.1 Background

Sustained and/or repetitive trunk flexion are known to either increase the risk of future NSLBP (Parkinson et al., 2004, Parkinson and Callaghan, 2009) or maintain NSLBP symptoms (Comerford and Mottram, 2001). Cumulative lumbo-pelvic forward flexion can lead to neuromechanical changes, such as creep of spinal tissues, ligament inflammation, increased lumbar instability, altered spinal muscle reflexive-response and reduced postural awareness (Shin and Mirka, 2007, Dolan and Green, 2006). The cumulative effect of postural exposure is dependent on three mechanical domains: magnitude (range of motion - ROM), duration, and frequency in which postures are adopted (Burdorf and van der Beek, 1999). The interplay between these domains leads to an exponential decrease of tissue load-tolerance over time (Waters et al., 2006). One of the challenges to improve both prevention and rehabilitation programmes is to identify the threshold limit for cumulative postural exposure within each of the three postural domains for trunk postures.

Patients with NSLBP were found to have altered feedback (Brumagne et al., 2000) and feedforward postural control mechanisms compared to controls
Similarly, healthy subjects exposed to prolonged slouched posture have reduced lumbar proprioceptive control (Dolan and Green, 2006). Ergonomic and rehabilitation interventions commonly target postural re-education. Since exposure to repetitive trunk flexion (Wilson and Granata, 2003) or the presence of low back symptoms can reduce lumbar proprioception (O’Sullivan et al., 2003), the provision of feedback might help people to avoid risk postures and improve postural awareness. In order to provide such feedback, a reliable postural monitor should be used (Sheeran et al., 2010).

The intended purpose of the Spineangel® is to provide the wearer with audio-feedback when postural thresholds are exceeded. Thresholds can be adjusted to lumbo-pelvic forward flexion ROM (magnitude domain), duration of sustained flexion and the interval between subsequent lumbo-pelvic forward flexion (frequency). The Spineangel® was shown to provide valid and reliable measurements for lumbo-pelvic gross movement during a range of functional tasks (Chapter 5). Prior to use in field research, it was necessary to assess its reliability as a device to monitor cumulative workplace posture and to gather preliminary information about postural exposure in a group of workers from a health care institution. The aim of the present study was to examine the within-day reliability of the Spineangel® for monitoring daily posture and to develop preliminary estimates of cumulative postural exposure of health care workers at a residential home for the elderly.

6.2 Methods

6.2.1 Participants

This is a cross-sectional repeated measures study design in a convenience sample of aged care rest home workers. This study was approved by the University of Otago Human Ethics Committee (Appendix B). Twenty-one workers took part in this study and all participants provided informed written consent.

6.2.1.1 Inclusion criteria

Workers (with or without low back symptoms) who were performing their regular work activities without any limitations were included.
6.2.1.2 Exclusion criteria

Workers who were unable to undertake their regular work-related activities due to NSLBP were excluded from this study.

6.2.2 Instrumentation

For the present study, the Spineangel® was set at continuous recording mode, so different estimates of postural exposures could be calculated by using a customised code written using Octave software (please refer to 6.2.5.3). Based on the results described at Chapter 5, the Spineangel® tracks lumbo-pelvic movements, although it does not provide accurate measurements for the precise magnitude of pelvic or lumbar segments, per se, it is capable of monitoring the general/gross lumbo-pelvic movement pattern.

6.2.3 Procedures

Demographic and work-related information were gathered by means of self-administered questionnaire (Appendix C). Workers were requested to wear the Spineangel® during part of the work shift. Each worker secured their Spineangel® to the waistband or belt, using the purpose designed clip and following standard instructions (Figure 6-1). In order to pragmatically capture between-worker variability, the height of the waistband or belt position was not controlled for.

To assess the within-day reliability of measurements, a sub-group of 11 workers performed two sets of three lumbo-pelvic forward flexion to place their forearms and hands on one table (80cm height) and sustained this position for 5 s, at the beginning (first measurement, M1) and at the end (second measurement, M2) of the work shift. This posture was accepted as reaching mid-range lumbo-pelvic forward flexion (as per visual subjective assessment by the researcher). It was decided to limit the number of workers participating in the reliability study to minimise workplace disruption.
Figure 6-1. The Spineangel ® device worn on a worker’s waistband or belt.

6.2.4 Data processing

Octave software was used for data processing and filtering (http://www.octave.org) (Eaton, 2002). In order to determine filter cut-off frequency, frequency-domain analyses of kinematic data were performed. Before selecting the ideal cut-off frequency, an interactive process of filtering the data and analysing it through frequency and time-domain was adopted (Bogert, 1996). Kinematic data were digitally filtered with third-order low pass Butterworth filter set to a cut-off frequency of 1 Hz. The cut-off frequency was determined by the Residual Analysis Method (Winter, 2005). A power spectrum illustrating the relative frequency domain of a signal captured from the Spineangel® is illustrated in Figure 6-2. Cumulative postural exposure, postural threshold and lumbo-pelvic postural pattern were calculated through customized routines using Octave software.
6.2.5 Statistical and data analysis

Statistical analyses were performed by means of the Statistical Package for the Social Science (V.16, SPSS Inc., Illinois USA). Data distribution for the difference between measurements (M1 and M2) was assessed by means of skewness, kurtosis and graphical analysis of Q-Q plots and histograms (Peat and Barton, 2008).

6.2.5.1 Within-day reliability

The reliability of measurements was assessed by means of the Intraclass Correlation Coefficient (two-way mixed model, consistency definition, ICC (3,3)). The CVMe was calculated to assess the percentage of variation from trial to trial, as the ICC(3,3) does not account for this (Portney and Watkins, 2009). Finally, to assess for systematic bias between M1 and M2, a two-tailed paired t-test between M1 and M2 was performed with alpha level of 0.05 (Portney and Watkins, 2009).

No studies assessing the Spineangel® within-day reliability were found, hindering the estimation of the sample size for this study. Hence, a post hoc power analysis was conducted to support the interpretation of data, when comparing M1 and M2 measurements, and to assess the likelihood of committing a Type II error (Portney and Watkins, 2009). The mean difference between M1 and M2, and the correspondent effect size (d) and the sample size were used as input data for the post hoc power analysis.
6.2.5.2 Cumulative postural exposure

Cumulative postural exposure was defined as the cumulative time spent in specified ranges of motion for forward and backward inclination; these were analysed as lumbo-pelvic flexion greater than:

- 20° of forward flexion (i.e. from 20 degrees to the maximum lumbo-pelvic flexion recorded);
- 30° of forward flexion (i.e. from 20 degrees to the maximum lumbo-pelvic flexion recorded);
- 40° of forward flexion (i.e. from 20 degrees to the maximum lumbo-pelvic flexion recorded);
- 60° of forward flexion (i.e. from 20 degrees to the maximum lumbo-pelvic flexion recorded).

6.2.5.3 Postural threshold

Postural thresholds were established considering the combination of three domains of cumulative exposure: ROM (magnitude), frequency and duration in which forward postures were adopted. Regarding ROM, one threshold was set at 30°, another at 45° and a third at 60° (Jansen et al., 2004; Hoogendoorn et al., 2000a). These values were based on the risk thresholds identified at the systematic review on posture as a risk factor for NSLBP described in Chapter 2. The frequency and duration limits were the same for all three cumulative postural exposures thresholds, at a maximum frequency of two forward flexion postures within any 60 second period. According to published guidelines (CEN, 2008), static posture is defined as those maintained for longer than 4 s. As the Spineangel® resolution is 1 s, the duration threshold was set at 5 s. The minimum interval time between two subsequent lumbo-pelvic forward flexion in a specific ROM (30, 45 or 60°) and sustained for 5 s was set as 25 s (CEN, 2008).

Based on findings from the systematic review described in Chapter 2, it was not possible to define postural threshold values due to lack of consensus on postural outcome measures for ROM. Then, this study was conducted to develop preliminary estimates of cumulative postural exposure of health care workers at a residential home for the elderly. In an attempt to explore different preliminary
estimates of cumulative postural exposure, it was opted to use different cut-off values of ROM for the cumulative postural exposure (i.e. 20°, 40°, and 60° of forward flexion) and for the postural thresholds (i.e. $30^\circ \pm ME = 8^\circ$, $45^\circ \pm ME = 8^\circ$, and $60^\circ \pm ME = 8^\circ$).

6.2.5.4 Lumbo-pelvic postural pattern

For the purpose of this study, lumbo-pelvic postural pattern was defined as the number of times workers exceeded each cumulative postural threshold. The Spineangel® has a frequency sample of 10 Hz. Therefore, lumbo-pelvic postural pattern was calculated as the number of instant of time (i.e. 0.1 sec) workers exceeded the postural threshold. The number of times the postural thresholds were exceeded was recorded.

6.3 Results

Participants’ demographic data is described at Table 6-1, and their occupations were as follows: carer (n = 7), cleaner (n = 1), cooking (n = 1), laundry (n = 1), manager assistant (n=2), nurse (n = 6), nurse manager (n = 1), occupational therapist (n = 1), physiotherapist (n = 1).

<table>
<thead>
<tr>
<th>Table 6-1. Participants demographic characteristics.</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>46.3 (15.0)</td>
</tr>
<tr>
<td>Body mass (Kg)</td>
<td>79.0 (18.8)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.64 (0.06)</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>29.3 (6.18)</td>
</tr>
<tr>
<td>Time at the job (months)</td>
<td>90.2 (102.9)</td>
</tr>
<tr>
<td>Oswestry Score</td>
<td>4.1 (5.1)</td>
</tr>
<tr>
<td>Total time monitored (hours)</td>
<td>3.9 (1.6)</td>
</tr>
</tbody>
</table>

Kg = kilogram; m = meters; SD = standard deviation.

6.3.1 Within-day reliability

The within-day reliability of the Spineangel® was equal to 0.81 (95% CI = 0.32 to 0.95). This value is considered to reflect an excellent reliability (Fleiss, 1999). The mean values for M1 and M2 were 40.6° and 40.8°, respectively. The mean difference between M1 and M2 was -0.2° (SD = 5.6°) and 95% CI from -3.9° to 3.6°. The paired $t$-test revealed the difference was not statistically significant ($p = 0.918$). The ME was equivalent to 3.9° and the $CV_{ME}$ was 9.75%. The post hoc power analysis revealed that based on the mean, the sample size (n = 21), and the
effect size observed in this study \( (d = 0.03) \), this study had a statistical power level of 0.05.

### 6.3.2 Cumulative postural exposure

The average recording duration was 3.9 hours (SD 1.6) (Table 6-1). On average, workers spent approximately 13\% (SD = 16\%) of work time in lumbo-pelvic posture greater than 20°; 5.0\% (SD = 6.0) of work time in lumbo-pelvic forward flexion postures greater than 30°. Workers spent 2.0\% (SD = 2.5) of total working recorded time in postures greater than 40° of forward flexion, and approximately 0.2\% (SD = 0.2) of total recorded time was spent in postures with more than 60° of lumbo-pelvic forward flexion (Table 6-2).

Table 6-2. Mean and standard deviation (SD) for cumulative time spent in different lumbo-pelvic postures.

<table>
<thead>
<tr>
<th>Duration (% monitored time)</th>
<th>Flexion ≥20°</th>
<th>Flexion ≥30°</th>
<th>Flexion ≥40°</th>
<th>Flexion ≥60°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration (min)</td>
<td>13.2 (16.4)</td>
<td>5.0 (6.0)</td>
<td>2.0 (2.5)</td>
<td>0.2 (0.2)</td>
</tr>
</tbody>
</table>

Min = minute.

### 6.3.3 Lumbo-pelvic postural pattern

The number of times per minute the threshold was exceeded decreased as ROM limit increased (Table 6-3). On average, the threshold for 30° of lumbo-pelvic forward flexion was exceeded 12.9 times/min (SD = 22.1); the threshold for 45° of lumbo-pelvic forward flexion was exceeded on average of 1.8 times/min (SD = 2.9); and for 60° of lumbo-pelvic forward flexion, an average of 0.1 times/min (SD = 0.4).

Table 6-3. Lumbo-pelvic postural pattern for each postural threshold (frequency/min).

<table>
<thead>
<tr>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold 30</td>
</tr>
<tr>
<td>Threshold 45</td>
</tr>
<tr>
<td>Threshold 60</td>
</tr>
</tbody>
</table>

Min = minutes; SD = standard deviation.

### 6.4 Discussion

Twenty-one participants took part in this study. The mean Oswestry score was 4.1 (SD = 5.1), indicating participants were minimally disabled (Table 6-1) (Sirvanci et al., 2008). Preliminary estimates of cumulative postural exposure were measured for this group of workers. It is unlikely this is a representative sample of
the health care population in general, due to the small sample size. However, these findings provided relevant preliminary information about demographics, back-related disability and movement patterns on this group of workers.

6.4.1 Within-day reliability

The present results have shown excellent reliability (ICC = 0.81) for the postural measurements during a working day (Fleiss, 1999) at least for this sample of aged care residential workers. The ME was approximately 4° and CVME was low, at less than 10% of the mean values for M1 and M2. This finding suggests that the variability within trials was small. This field-based result is similar to the laboratory-based findings, in which the within-session error was found to be less than 3° (Chapter 5). As presented, differences between M1 and M2 were not statistically significant; indicating that systematic bias M1 and M2 was also low.

The post hoc power analysis indicated a limited statistical power due to small sample size (n = 21). The effect size observed in the present study was small (d = 0.03) (Cohen, 1988), and that decreased the statistical power of the study. These findings would suggest it is not possible to rule-out the presence of a Type II error for non-significant differences findings between M1 and M2. However, the 95% CI for the mean difference between these measurements was very narrow (95% CI = -3.9° to 3.6°). Thus, it is reasonable to assume that there was no significant difference between M1 and M2, based on the 95% CI analysis.

Previous research using the Spineangel® has reported ICC values of 0.90 to 0.97 for measurements in a very controlled laboratory setting (Intolo et al., 2010). The reliability for Spineangel® measurements in a less controlled laboratory setting were also excellent, as reported in Chapter 5. It is expected that clothing, different anthropometric characteristics, such as body mass index, and workplace demands during in-field experiments will lead to decreased repeatability of measurements. However, the present findings suggest that reliable measurements can be obtained for a group of subjects with different anthropometric characteristics with the device attached to the workers own garments, whilst they are performing work-related tasks. Combined, these results indicate good repeatability of lumbo-pelvic measurements.
6.4.2 Cumulative postural exposure

For this study, cumulative postural exposure was quantified for lumbo-pelvic flexion greater than 20°, 30°, 40° and 60°. As previously described in Chapter 5, the Spineangel® monitors gross lumbo-pelvic posture. Previous studies have monitored nursing workplace posture using different instruments and each device has its own measurement characteristics, advantages and weaknesses. For example, the CUELA measurement system has been used to record trunk and legs kinematic data from nurses working at hospital (Freitag et al., 2007, Freitag et al., 2012) and at nursing homes (Freitag et al., 2012). This device is capable of synchronizing the postural monitor device and a video camera recording, allowing for association between recorded postures with performed tasks. Although this is a portable device, it is not as user-friendly as the Spineangel®. Morlock et al. (2000) used an inverse dynamics and force distribution model to record posture and estimate lumbo-sacral forces of a group of nurses working at hospitals. The approach adopted by Morlock et al. (2000) allows for assessing lumbo-sacral forces during different tasks, the drawback is it requires laborious and complex data analysis. Hodder et al. (2010) used an inclinometer placed close to the sternum to monitor posture of a group of nurses at long-term care facilities. This device can also be synchronized with observational software. The main difference between this instrument and the Spineangel® is the former records upper trunk posture, while the Spineangel® records lumbo-pelvic gross posture.

Further differences between the present study and the above described ones are the inclusion criteria (the present study included workers with different job descriptions), differences in work routines between health care facilities, and the device used to monitor posture. Such differences will lead to different outcomes (discussed below); however, it is still possible to compare general findings from this study with the previously published ones (Hodder et al., 2010, Freitag et al., 2007, Freitag et al., 2012, Morlock et al., 2000). When comparing results from the present study with the literature, it is important to bear in mind that, according to the validity and reliability study (described in Chapter 5), the Spineangel® provides conservative estimates of lumbo-pelvic posture, when compared to a kinematic gold standard device (i.e. the Polhemus™). Additionally, differences in work place routine are likely to require different physical and postural demands.
6.4.2.1  *Forward flexion greater than 20°*

Findings from the present study suggested workers spent approximately 13.2% (SD = 16.4) of work recorded time in lumbo-pelvic forward flexed posture greater than 20° (Table 6-2). Previous studies have reported similar findings (Freitag et al., 2007, Freitag et al., 2012, Morlock et al., 2000). For example, Morlock et al. (2000) found nurses spent 35% of work time at greater than 15° of trunk flexion. Freitag et al. (2007) monitored 8 workers (6 nurses and 2 care nurses) and found workers spent 72 min (approximately 22% of total recorded time) in trunk flexed postures greater than 20°. In another study, Freitag et al. (2012) monitored working posture of nurses at nursing homes and hospitals. They recorded an average of 313 min per shift (nursing home workers) and 308 min per shift (hospital workers). The authors found workers at nursing homes spent on average 112 min (approximately 35% of total recorded time) working in trunk flexed posture greater than 20° while nurses at the hospital spent 63 min (around 20% of total recorded time). Those findings for hospital workers were similar to the results from my study (approximately 13%), after taking into account the conservative estimates of lumbo-pelvic flexion magnitude provided by the Spineangel® device.

6.4.2.2  *Forward flexion greater than 30°*

The present results indicate that workers at an aged care health care facility spent 5.0% (SD = 6.0%) of work time in lumbo-pelvic forward flexed postures greater than 30° (Table 6-2). A previous study found nurses spent 11.3% of total recorded time in lumbar flexion greater than 30° (Morlock et al., 2000). When monitoring working posture of personal support workers, Hodder et al. (2010) found 25% of working time was spent in postures with greater than 30° of trunk flexion. One important difference between this study and that of Hodder et al. (2010) is the placement of the monitor device. For the present study, the Spineangel® was attached to the belt or waistband, whereas the inclinometer used by Hodder et al. (2010) was positioned at the sternum. As a result, the Spineangel® is monitoring mainly lumbo-pelvic postures, while the inclinometer used by Hodder et al. (2010) capturing both lumbo-pelvic and upper trunk kinematics, and therefore, greater magnitudes of flexion.
6.4.2.3  **Forward flexion greater than 40°**

Workers spent on average 2.0% (SD = 2.5%) of total recorded time (approximately 4.6 s) in postures greater than 40° of lumbo-pelvic forward flexion (Table 6-2). Morlock et al (2000) reported nurses spent 4.5% (SD = 6.8%) of recorded time in lumbar flexion greater than 45°. Accepting that the Spineangel® provides more conservative measurements for lower lumbar and pelvic movements, these findings seem to be in agreement with those reported by Morlock et al (2000).

6.4.2.4  **Forward flexion greater than 60°**

On average, subjects in this study spent 0.2% of total recorded time (approximately 22.5 s) in postures with greater than 60° of lumbo-pelvic forward flexion (Table 6-2). Morlock et al (2000) reported nurses spent of 1.3% recorded time in postures greater than 60°, while Freitag et al (2007) reported nurses adopted such a posture, on average, for a total of 7 min (approximately 2% of total recorded time). Again, after accounting for the difference in device position, and therefore flexion magnitude recorded, the results reported in the literature are broadly consistent with those of this study.

6.4.3  **Lumbo-pelvic postural pattern**

This study found that the threshold for 30° of lumbo-pelvic forward flexion (i.e. bending >30° for 5 s duration more than twice in a 60 second period) was exceeded, on average, 12.9 times/min; the threshold for 45°, 1.8 times/min; and the threshold for 60° of lumbo-pelvic forward flexion was exceeded on average of 0.1 times/min. According to the European Committee for Standardization (CEN, 2008) recommendations, trunk postures between 20 and 60° should not be adopted more than twice per minute. Freitag et al. (2007) monitored postures adopted by 8 nurses during a work-shift and recorded an average of 5 working hours. These authors found lumbo-pelvic forward flexion above 60° was adopted on average 33 times per hour during a work shift. This study found workers exceeded an average of 8 times per hour. The main differences between the present study and the one presented by Freitag et al. (2007) is that the present included different job tasks (e.g. office workers, nurses, caregivers, physiotherapists, kitchen workers, cleaners, laundry workers), and used a different instrument to monitor posture. Another study found nurses to be highly exposed
to flexed postures and those working at nursing homes had an increased exposure to forward bending posture when compared to those working at the hospital (Freitag et al., 2012). On average, the frequency of trunk flexion greater than 20° for workers at a nursing home was 4.9 per min (95% CI: 4.3 to 5.5), while nurses at the hospital performed 3.8 per min (95% CI: 3.3 to 4.2). These findings suggest nurses working at nursing homes are exposed to increased postural demands (Freitag et al., 2012).

### 6.4.4 Posture and lifting exposure

When analysing the present findings, it is not possible to define the specific tasks participants were performing during their work shift. Previous research indicates that in addition to known risks of lifting, posture adopted during unloaded tasks (tasks not related to lifting and patient transfer) may also be risk factors for NSLBP (Hodder et al., 2010). Nurses, nurse aides and personal support workers have been reported to spend, on average, 85.0% of total working time performing unloaded tasks (Hodder et al., 2010) in extreme trunk postures, potentially exposing themselves to increased lumbar injury risk (Punnett et al., 1991). Similarly, Freitag et al. (2012) suggest the risk associated with postures adopted during tasks that do not involve patient lifting and transfers has been underestimated. These authors (Freitag et al., 2012) have synchronized the postural monitor device with video camera recording, allowing for association between recorded postures with performed tasks. Interestingly, they found that only a small period of working time was spent performing lifting tasks. Lifting or carrying body weight accounted for an average of 88 s (for workers at nursing home) and 16 s (for nurses at hospitals) per shift and each shift lasted approximately 300 min. Similarly, another study has suggested that high compressive forces at lumbo-sacral joint occurred only for short period of time (less than 0.5% of total shift duration) (Morlock et al., 2000). Therefore, ergonomic interventions should focus on postural alignment instead of only reducing the amount of load to be handled (Hoozemans et al., 2008).

Previous research has shown detrimental neuromuscular effects from repetitive trunk forward flexion or sustained forward flexion (Wilson and Granata, 2003, Parkinson et al., 2004). Creep deformation, altered muscle reflexive-response, increased lumbar instability, and acute inflammation of spinal ligaments
are some examples of such effects (Parkinson et al., 2004, Shin and Mirka, 2007, Solomonow et al., 2003a). Despite this, epidemiologic studies have failed to present a clear relationship between posture and NSLBP (Vieira and Kumar, 2004). According to the findings from the systematic review on posture as risk factor for NSLBP (Chapter 2), most of the literature related to posture as a risk factor for NSLBP has failed to assess all three pertinent domains (magnitude, frequency and duration) of cumulative postural exposure. Some studies have quantified magnitude (ROM of adopted postures) and time spent in flexed postures (Jansen et al., 2004, Hoogendoorn et al., 2000a), while others have quantified the time that bending postures were adopted (Harkness et al., 2003, Van Nieuwenhuyse et al., 2006, Josephson and Vingård, 1998), however, such studies have not specified the magnitude of adopted bending postures.

Due to disagreement between epidemiological and laboratory studies, there is debate regarding the dose-response relationship between postural exposure and NSLBP. It has been suggested that imprecise postural assessment at work might be the cause of such uncertainty (Teschke et al., 2009). Different methods to monitor trunk posture have been reported in the literature (Vieira and Kumar, 2004). As a result different implemented approaches (e.g. qualitative, quantitative), as well as diverse outcome measures for assessment of posture as a risk factor for NSLBP and erratic degrees of association between posture and NSLBP have been reported (Wai et al., 2010). In order to improve current understanding about the association between posture and NSLBP, the former needs to be more precisely and systematically measured (Vieira and Kumar, 2004). Efforts have been made to measure work posture in a more consistent way. Recently, different postural monitoring devices have been reported in the literature (Dean and Dean, 2006, Intolo et al., 2010, Hodder et al., 2010, Wong and Wong, 2008, O’Sullivan et al., 2010a, Straker et al., 2010, Freitag et al., 2012, Morlock et al., 2000, Marras et al., 2010). It is possible that novel devices and technology will help researchers to establish the relationship between awkward postures and NSLBP. Additionally, the use of similar postural thresholds in future epidemiologic studies might help to clarify the strength of dose-response relationship between posture and NSLBP.
6.4.5 Future directions

Lifting tasks have been commonly addressed during prevention programs (Martimo et al., 2008) although they account for a small period of time during a work shift. It is possible that excessive focus on lifting tasks has led to the underestimation of postural working positions as a risk factor for NSLBP (Freitag et al., 2012, Hodder et al., 2010). This is in accordance with the findings and suggestions for future research directions presented at Chapter 2. The use of new portable technology such as the Spineangel® may help to improve postural risk estimates.

This study has established three different postural thresholds. Such thresholds are thus recommended for use in future studies to assess relationship between posture and risk of developing NSLBP. The described thresholds could be associated with feedback provision for patients, during the management of NSLBP or workers for NSLBP prevention programmes. Although it is necessary for patients presenting with NSLBP to keep active, prolonged or sustained lumbo-pelvic forward flexion could delay the soft tissue healing process (McKenzie, 2003), deteriorate lumbar proprioception (Brumagne et al., 2000) and lead to altered spinal neuromuscular control (Newcomer et al., 2002). Due to reduced lumbar position sense (O’Sullivan et al., 2003), it is likely that some patients with NSLBP will adopt postures that continue to mechanically stress pain sensitive tissues (O’Sullivan, 2005). Future studies are warranted to assess the relevance of postural feedback provision based on the described postural thresholds.

6.4.6 Limitations

Ideally, it would be appropriate to gather postural data during an entire working day. However, the work schedule at this aged care rest home was hectic. In order to minimize work disruption, it was opted to have all workers starting and finishing data collection at the same time. As a result, postural data was collected during part of a work shift for some of those workers.

It could be argued that non-significant differences between M1 and M2 were found due Type II error. However, the analysis of the 95% CI for the mean difference between the two measurements was narrow and that supports the assumption of lack of significant difference between M1 and M2. In order to
achieve the recommended statistical power of 0.80, future studies replicating this design should consider a sample size of approximately 6155 participants (Portney and Watkins, 2009).

The Spineangel® device records quantitative postural kinematic data, therefore it is not possible to determine specifically what types of tasks were performed without additional qualitative data collection. This instrument does not allow for synchronization with a video recording camera. The Spineangel® data are therefore limited to postural alignment without reference to load on the spine. Results from the validity and reliability laboratory study (Chapter 5) suggest the Spineangel® is a reliable and valid device for monitoring gross lumbo-pelvic posture; however the accuracy of the device for measuring the magnitude of lumbar flexion is conservatively biased. An interaction between cumulative flexed posture and load exposure as risk factors for NSLBP is known (Waters et al., 2006), wherein interaction between such posture and high loads might lead to an even higher risk of developing NSLBP (Le et al., 2007, Solomonow et al., 2003a).

6.5 **Implications for the feasibility RCT (Chapter 7)**

Results from this study suggest the Spineangel® is a reliable device for monitoring posture at the workplace. Three different postural thresholds were assessed: threshold 30, 45 and 60. The ideal postural threshold to be used at the feasibility study should be one in which workers commonly exceed the threshold, but not constantly (Table 6-3) as well as that is considered to be a risk for NSLBP (as discussed in Chapter 2). Receiving frequent postural EF can be perceived by workers as disruptive and this could reduce workers’ adherence to the use of the Spineangel®. Therefore, the Threshold 45 seems to be the ideal one to be used at the feasibility study.

Additionally, collecting data at this aged care rest home revealed that the workers have a busy working-schedule. Thus, data collection during the feasibility RCT needs to be carefully managed, and optimized to collect only relevant information so as to decrease the possible burden for workers and the workplace.
6.6 Final considerations

The Spineangel ® device is shown to be a reliable instrument for monitoring gross lumbo-pelvic posture in a busy health-care working environment. Cumulative postural exposures were measured for three ROM thresholds, surpassing 5 s duration twice or more in any 60 s period. The results from this study combined with the findings from the systematic review on posture as a risk factor for NSLBP (Chapter 2) provide the information required to establish postural threshold values for the field trials of EF as a means of decreasing exposure to cumulative postural loading of the lumbo-pelvic spine, in rest home workers. Such study is described in Chapter 7.
7 The Spineangel® as a postural feedback device to change postural behaviour: a feasibility randomized controlled trial

7.1 Overview

Previous chapters have explored the validity and reliability of the Spineangel® as a postural monitor feedback device in laboratory-based and field-based settings (Chapter 5 and 6, respectively). Based on findings reported in Chapter 5 and 6, it is reasonable to state that the Spineangel® provides reliable and valid postural estimates for gross lumbo-pelvic movements, with a between-day ME of approximately 8° (Chapter 5), and a within-day ME of approximately 5° (Chapter 6). These findings support the further investigation of the Spineangel® as a potential intervention tool for exploring and modifying postural behaviour via an extrinsic feedback pathway. Prior to testing whether the device can minimize the incidence of work-related NSLBP, it was deemed appropriate to conduct a preliminary trial to assess the feasibility of using the Spineangel® in a workplace setting to improve postural behaviour.

7.1.1 Background

One critical point for the provision of EF with the Spineangel® is to determine the postural threshold (i.e. which posture will trigger the audio-feedback). The variables relevant to the threshold are ROM, duration and frequency of lumbo-pelvic forward flexion. The systematic review described in Chapter 2 attempted to identify what is considered to be at risk posture, considering the domains of cumulative postural exposure (i.e. ROM, duration and frequency of forward flexion) (Burdorf and van der Beek, 1999). The results were inconclusive, so a cross-sectional field-study was conducted to estimate postural exposure in a group of health care workers. This study, described in Chapter 6, suggested three different postural thresholds could be used to quantify postural exposure:
1. **Threshold 30**: the ROM threshold set at 30° of forward flexion, with a duration threshold of 5 s and frequency threshold of a maximum of 2 flexed postures with such characteristics per minute;

2. **Threshold 45**: the ROM threshold set at 45° of forward flexion, with a duration threshold of 5 s and frequency threshold of a maximum of 2 flexed postures with such characteristics per minute;

3. **Threshold 60**: the ROM threshold set at 60° of forward flexion, with a duration threshold of 5 s and frequency threshold of a maximum of 2 flexed postures with such characteristics per minute;

As expected, as ROM of forward flexion increased, the number of times workers exceeded the postural threshold decreased. The selection of a threshold for postural EF provision should logically be a posture that is *commonly* adopted, but not *constantly* adopted and should be associated with increased risk of NSLBP. Additionally, the provision of a postural EF, particularly if excessive, could be perceived by workers as interfering with their daily duties (Wickens, 2008).

There are different forms of providing EF; the ideal content and timing characteristics of EF were presented, revised and discussed in Chapter 3. Such characteristics were derived from the motor control and learning research field, however, it is uncertain whether these would apply when providing EF with the Spineangel®. Based on the review described in Chapter 3, the feedback provided by the Spineangel® can be classified as having the following *content characteristics*: program feedback and external focus of attention (depending on how user is instructed to use it); and the following *timing characteristics*: concurrent EF, and constant or reduced frequency (depending on how it is adjusted). Currently, no study has been published on the different forms of EF provision when using the Spineangel® or a similar device for changing lumbo-pelvic postural behaviour.

The Spineangel® was developed to be used during daily life activities and, to help users to avoid potentially hazardous postures during daily life activities, in particular, those associated with work tasks. Prior to conducting an RCT to assess the effectiveness of the Spineangel® as a tool to prevent NSLBP onset or recurrence, it was deemed necessary to conduct a feasibility study to assess the
following: whether people would use the device for a prolonged period; determine the adherence rate; determine what postural behavioural changes occur; determine which types of EF has the strongest effect; and determine participant perception as to the use of this device for monitoring workplace posture. Health care workers are considered to be exposed to hazardous posture (Harcombe et al., 2009, Yalcinkaya et al., 2010). Thus, these workers were determined to be a good sample for running preliminary study using the Spineangel® as a tool for modifying postural behaviour.

Feasibility studies are an essential step on the development and evaluation of complex interventions (MRC, 2008, Thabane et al., 2010). Therefore, the aim of this study was to assess the feasibility of a trial using the Spineangel® as an EF device for modifying daily activity postures. The primary objectives were to: (1) identify recruitment challenges; (2) identify adherence and follow-up rates; (3) identify challenges participating centres may have with managing the study. The secondary objectives were to: (4) gather data to inform sample size for future trial; (5) assess the effectiveness of a lumbo-pelvic monitor and extrinsic feedback device to modify postural behaviour; (6) compare the effectiveness of intermittent postural feedback provision with constant postural feedback provision; and (7) gather participants’ subjective perception on the usefulness of the Spineangel®.

7.2 Methods

7.2.1 Trial design

This is a controlled, single-blinded, feasibility randomized controlled trial. Group allocation was by blocked randomization to ensure an approximately equivalent number of workers in each group. This study was approved by the Ethics Committee of the University of Otago (Appendix B).

7.2.2 Participants

Participants were recruited from a health care organization having four different centres within the Dunedin city boundaries. Managers from each centre were approached to confirm their interest in having their workers participating on this study. Prior to collecting data, a number of meetings were held to present the aim and relevance of the study to managers and workers. Health care as well as
administrative workers were then invited to participate in this study. Workers from this health care organization received ergonomic training in a regular basis. No additional training was provided for this study. All participants provided informed consent prior to participate in this study. Data collection occurred between October 2009 and April 2011 (in two phases with a break period of 4 months between). Prior to enrolling in this study, workers filled a self-administered questionnaire to gather demographic and psychosocial data.

7.2.3 Inclusion criteria

To increase the external validity of this study, workers (with or without low back symptoms) who were performing their regular work activities without any limitations were included. Additionally, workers were required to work a minimum of 20 hours per week.

7.2.4 Exclusion criteria

Workers who were unable to undertake their regular work-related activities due to NSLBP or worked less than 20 hours per week were excluded from this study.

7.2.5 Procedures

All participants completed a self-administered questionnaire that included demographic (age, gender, body mass, height, occupation, smoking habits), functional disability and psychosocial work characteristics. Functional disability was measured with the Oswestry Disability Index (ODI) (Fairbank, 2000). Work-related psychosocial characteristics were gathered by using the second short version of the Copenhagen Psychosocial Questionnaire (COPSOQ II) (Pejtersen et al., 2010). High ODI scores were reported to be associated with fear-avoidance behaviour (Sions and Hicks, 2011) and a moderate correlation between work-related psychosocial factors and physical exposure has been reported (Vandergrift et al., 2012). Therefore, these variables could potentially impact on postural behaviour; and for that reason these were monitored and controlled for.

7.2.5.1 The Oswestry Disability Index (ODI)

The ODI is a validated condition-specific outcome measure for NSLBP research (Fairbank, 2007). It has 10 items related to daily living activities that may
be affected by NSLBP (Appendix C). Each item has six statements with a maximum score of 5. The total score is presented as a percentage and the minimally clinically important change of the ODI is considered to be at least 10% (Ostelo and de Vet, 2005).

### 7.2.5.2 The COPSOQ II questionnaire

The COPSOQ II has been shown to be a reliable and valid instrument for work-related psychosocial factors (Pejtersen et al., 2010, Rugulies et al., 2010, Bjorner and Pejtersen, 2010). This questionnaire was developed under the following principles: (a) to cover all relevant stressors on psychosocial work environment, (b) to be theory-based while not being linked to a unique theory, (c) the included dimensions should be relevant to different working environments and working places (e.g. department, jobs), and (d) it should have a generic structure (Pejtersen et al., 2010). The short-version of COPSOQ II surveys for twenty-three dimensions with a total of forty questions. While collecting data for the cross-sectional field study (Chapter 6), it became obvious that these workers had a busy working schedule. Therefore, a subset of thirteen dimensions was selected from the short version of COPSOQ II, reducing the total number of questions to twenty-five. For the purpose of this study, the following dimensions were considered as the most relevant ones for monitoring work-related psychosocial factors and were included in the final questionnaire that was handed to participants (Appendix C): (1) quantitative demands; (2) work pace; (3) emotional demands; (4) influence at work; (5) skill discretion; (6) meaning of work; (7) commitment to workplace; (8) predictability; (9) rewards; (10) role clarity; (11) quality of leadership; (12) social support from supervisor; and (13) job satisfaction. Each scale is scored in the direction indicated by the scale name. Most questions have 5 point Likert scale. Each answer receives a score and the scoring system ranges from 0 to 4. According to the COPSOQ II, all dimensions are assessed by two items, allowing a maximum score of 8 (4 per item). The only exception is the job satisfaction scale, which is assessed by one question only with a maximum score of 3. Scores are presented as a percentage of the maximum possible score.

### 7.2.5.3 Postural monitoring and feedback

Participants were requested to wear the Spineangel® for a total of 6 weeks during working days only. Twenty-nine devices were made available for this
research by Movement Metrics Ltd (Hamilton, New Zealand). Therefore, data collection took part in several streams with a maximum of 29 workers per stream. Workers received the Spineangel® at the beginning of every week and returned it to the researcher at the last working day of the week. This allowed for downloading the data from the device and preparing it for the next week.

7.2.6 **Postural pattern and postural threshold**

Postural pattern was defined as the number of times workers exceeded the cumulative postural threshold, which was defined by setting threshold values for range of motion, frequency and duration of sustained forward bending. The range of motion threshold was set as 45° of lumbo-pelvic forward bending; the frequency was set at a maximum of 2 lumbo-pelvic forward bending events (at 45°) per minute; and the duration was set at 5 seconds. Thus, an audio stimulus was triggered when the worker flexed forward with lumbo-pelvic bending exceeding 45°; sustaining this posture for longer than 5 seconds provided such movement was performed more than twice/minute. Postural pattern data consists of the number of times (count) workers exceeded the postural threshold. Participants worked differing numbers of hours per day; thus, postural pattern was represented as the average of times workers exceeded the postural threshold per hour. The number of hours worked for each participant, for each day of data collection, was obtained from the health care organization records.

7.2.7 **Postural baseline measurements**

Postural baseline measurements were gathered during the first week. The Spineangel® was used as a postural monitor device only; no postural audio-feedback was provided during this period. The device recorded the number of times workers exceeded the pre-set postural threshold.

7.2.8 **Intervention**

The intervention period consisted of four weeks (from the second to the fifth week of data collection) and participants either received or did not receive postural audio-feedback according to their allocation into one of the following groups: control group, intermittent feedback group and constant feedback group.
7.2.8.1 **Control group (CG):**

During the intervention period, participants allocated to the CG did not receive postural audio-feedback and the Spineangel® was set to simply monitor and record the postural pattern.

7.2.8.2 **Intermittent feedback group (IFG)**

The IFG received postural audio-feedback at an alternating mode (one week “on”/one week “off”) during four weeks. Thus, during the first and third week, the audio-feedback was activated and participants were provided with an audio-feedback, whenever the postural threshold was exceeded. During the second and fourth week, the postural audio-feedback was inactive with the Spineangel® set to only monitor and record the postural pattern.

7.2.8.3 **Constant feedback group (CFG)**

The CFG received postural audio-feedback, whenever the postural threshold was exceeded, during all four weeks of the intervention.

7.2.9 **Extrinsic feedback provision and the Spineangel®**

All participants, regardless of group allocation, received the same instructions for using the Spineangel®. As discussed in Chapter 3, the way EF is provided can have either positive or negative impact on motor performance. The Spineangel® characteristics allow for the following EF content features: program feedback and external focus of attention; and the following timing features: immediate feedback and constant or reduced frequency. When hearing the audio-feedback, participants were instructed to re-arrange their posture in such way that it stopped that beeping. This provided an EF provision with an external focus of attention, as the instruction provided made no reference to spinal angles, and focused on re-arranging the posture to stop the audio-feedback. For the IFG, the timing characteristics were manipulated by reducing the number of weeks the EF was provided (i.e. week on/week off over the intervention period).

7.2.10 **Follow-up**

The follow-up occurred at the sixth week of data collection. The Spineangel® was used as a postural monitor device only recording workers’ postural pattern. At the end of the final week of data collection, participants were
requested to complete a questionnaire on functional status (assessed by means of the ODI) and workers' opinion on the usefulness of the Spineangel® as a postural feedback device. Workers rated their perception of the usefulness of the postural audio-feedback on a 5-point Likert scale with the following scores: ‘strongly agree’, ‘agree’, ‘undecided’, ‘disagree’ and ‘strongly disagree’. At the end of the questionnaire, there was a section where workers could provide any comments with regards to the data collection procedures, the workplace, the Spineangel® device or any other additional comments they found relevant to report.

7.2.11 Outcomes measures

7.2.11.1 Primary outcome measure

The primary outcome measures for this feasibility study were: (1) the identification of recruitment challenges, (2) adherence and follow-up rates, and (3) the challenges participating centres had with managing the study. Each centre’s recruitment rate was calculated as the ratio between the number of eligible workers recruited and the duration of recruitment period, expressed as workers per week. The study recruitment rate was calculated as the mean of all centres’ recruitment rate and the standard deviation about the mean. The number of Spineangel® devices available was 29, which limited the number of participants for this study, so organization-wide, consent rates were not calculated for this study. Non-adherence was assessed by the number of days participants worked without using the Spineangel® and was expressed as a percentage of total working days. Successful follow-up was defined as the percentage of recruited workers who completed the week 6 data collection protocol. The identification of the challenges encountered by the participating centres was identified by discussion and consensus between the principal investigator and managers of each centre. These discussions were directed by problems faced during the data collection period. This feasibility study was considered to be successful, and a larger RCT to be feasible, if adherence and follow-up were greater than 80% (OCEBM, 2012).

7.2.11.2 Secondary outcome measures

The secondary outcome measures were: (1) postural pattern change (participants' response to postural feedback), (2) workers' perception of the usefulness of postural feedback and (3) any additional comments described by the
participants in their own words. These three outcomes are the ones to be used in the design of a future RCT. Postural pattern was defined as frequency at which workers exceeded the postural threshold per hour. This would be the primary outcome measure considered for a future RCT. Differences in postural pattern between the baseline and follow-up measurements were used to assess the effectiveness of the Spineangel® as a postural feedback device. For the present study, it was measured prior to (at baseline), and one week after the intervention period (follow-up) (Figure 7-1).

7.2.12 Randomization

A blocked random allocation was used and participants were randomly assigned to the CG, IFG or CFG, according to a computer generated number list (Haahr, 2012). The researcher was responsible for enrolling and assigning participants to the intervention group. Participants were blinded to group allocation, but the researcher had access to that information.

7.2.13 Data processing and analysis

The Spineangel® records the day but not the time it was turned on and off. Therefore, postural pattern estimates are based on the assumption the device was turned on at the beginning of the shift and turned off at the end of it as instructed. The number of hours worked on each day was obtained from the managers of each health care services centre. To calculate for the ratio of lumbo-pelvic flexion events exceeding the postural threshold per hour, data gathered from the Spineangel® was divided by the number of hours worked, as indicated by the managers’ records.

Intention-to-treat analyses were performed to estimate the effect of feedback provision on postural pattern. Therefore, all participants randomly assigned to one of the intervention groups (CG, IFG, and CFG) were included at the final analyses, regardless of their adherence to the study.

7.2.14 Statistical analysis

All statistical analyses were performed using the R software (R_Core_Team, 2008). Scores for each of the work-related psychosocial constructs was calculated as recommended by the questionnaire developers (Pejtersen et al., 2010). Baseline
measurements including demographic variables, ODI scores and work-related psychosocial factors (13 constructs) were presented using simple descriptive statistics. For the purpose of this study, work-related psychosocial factors were also described by an overall score that represents the sum of all constructs (score ranging from 0 to 100%). Prior to summation, scales were recoded when necessary to accommodate for different score directions between constructs. Thus, the lower the overall score the poorer the work environment conditions.

There is a strong debate in the literature on the use of parametric tests for Likert type measurement scales (Jamieson, 2004, Norman, 2010, Pell, 2005). While each Likert question or item is an ordinal measure, the Likert scale (which consists of sums of numerous items) is accepted as an interval scale (Norman, 2010), warranting a parametric test (Pell, 2005). For the purpose of this study, parametric tests were used for analysing data from Likert scale, when data distribution indicated only small deviations from a Gaussian pattern (Norman, 2010).

7.2.14.1 Within and between group comparisons

Prior to within-group and between-group comparisons, data distributions were assessed for skewness, kurtosis and graphical analysis of Q-Q plots and histograms (Peat and Barton, 2008). Two-sided paired t-tests were used for within-group comparisons (baseline x follow-up). For between-group comparisons, the Analysis of Covariance (ANCOVA) was used with ODI scores, work-related psychosocial scores and postural pattern at baseline as covariates (Vickers and Altman, 2001). Prior to conducting the ANCOVA test, the homogeneity of regression slopes and the homogeneity of variance assumptions were tested. If differences between groups are identified, the Bonferroni test was used for adjustment of alpha and the Tukey test post hoc comparisons were conducted. The Kruskal-Wallis one-way analysis of variance by ranks was used to determine differences between groups (CG, IFG and CFG) on nominal variables (gender, smoking habits) or continuous variables with non-Gaussian distribution pattern. For all statistical tests, alpha was set at 0.05.

7.2.14.2 Post hoc power analysis

It was not the primary aim of this feasibility study to assess the effectiveness of feedback provision. However, to inform the analyses of within- and
between-group comparisons, and determine the likelihood of committing a Type II error, post hoc power analyses were conducted (Portney and Watkins, 2009). For each intervention group (i.e. CG, IFG and CFG), the within-group mean differences in postural pattern between baseline and follow-up, the correspondent effect size and sample size were used as input data for the post hoc power analysis.

The post hoc power analysis for between-group comparisons was calculated using the G*Power software (Buchner et al., 1997). The number of groups, number of participants per group, the square root of the mean square error, the mean differences in postural pattern between baseline and follow-up for each group, and the effect size were used as input data for these calculations.

7.3 Results

Sixty-nine workers from 4 work sites volunteered. Seven workers were excluded for working less than 20 hours/week. All 62 of the remaining eligible participants took part in this study. The flow of participants throughout each stage of data collection is represented in Figure 7-1. Demographic characteristics are described in Table 7-1. According to the 'Intention-to-treat' protocol missing values were replaced by the group mean (Armijo-Olivo et al., 2009), resulting in a final analysis of 18, 25 and 19 workers for the CG, IFG and CFG, respectively.
Figure 7.1. Flow of subjects throughout the trial.
7.3.1 Comparability at baseline

Baseline status of workers, including ODI and work-related psychosocial factors did not differ significantly between intervention groups (Table 7-1) for any of the monitored variables. Although not statistically significant, the CG tended to present a lower ODI score (Table 7-1). Participants in this study worked in different occupations within the health care organization, including: carers (n=23), administrative staff (n=3), cleaners (n=4), diversional therapists (n=2), kitchen staff (n=2), laundry staff (n=2), managers (n=14), nurses (n=11), and a physiotherapist (n=1).
Table 7-1. Baseline demographic and work psychosocial factors for all participants and the three intervention groups: control group (CG); intermittent feedback group (IFG) and constant feedback group (CFG). Values are presented as mean (standard deviation), unless otherwise denoted.

<table>
<thead>
<tr>
<th></th>
<th>All (n = 62)</th>
<th>CG (n = 18)</th>
<th>IFG (n = 25)</th>
<th>CFG (n = 19)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years) *</td>
<td>49.6 (12.4)</td>
<td>51.8 (9.9)</td>
<td>48.5 (11.3)</td>
<td>48.6 (15.7)</td>
<td>0.25</td>
</tr>
<tr>
<td>Height (cm) *</td>
<td>163.6 (7.4)</td>
<td>161.2 (6.9)</td>
<td>163.8 (12.3)</td>
<td>164.1 (5.5)</td>
<td>0.81</td>
</tr>
<tr>
<td>Body mass (kg) *</td>
<td>73.6 (14.7)</td>
<td>71.6 (11.3)</td>
<td>77.6 (23.4)</td>
<td>74.3 (13.3)</td>
<td>0.66</td>
</tr>
<tr>
<td>Gender: Male/Female (n)</td>
<td>5/57</td>
<td>1/17</td>
<td>3/22</td>
<td>1/18</td>
<td>0.64</td>
</tr>
<tr>
<td>Years at present job *</td>
<td>7.5 (7.3)</td>
<td>7.1 (4.6)</td>
<td>8.2 (9.6)</td>
<td>2.7 (1.6)</td>
<td>0.83</td>
</tr>
<tr>
<td>Smoking: Yes/No</td>
<td>18/44</td>
<td>4/14</td>
<td>9/16</td>
<td>5/14</td>
<td>0.59</td>
</tr>
<tr>
<td>Oswestry Disability Index (%) *</td>
<td>7.9 (9.4)</td>
<td>3.2 (5.6)</td>
<td>9.6 (11.0)</td>
<td>9.7 (8.9)</td>
<td>0.06</td>
</tr>
<tr>
<td>Postural pattern *</td>
<td>1.6 (1.8)</td>
<td>1.3 (1.2)</td>
<td>1.22 (1.6)</td>
<td>2.29 (2.5)</td>
<td>0.12</td>
</tr>
<tr>
<td>Occupation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.40</td>
</tr>
<tr>
<td>Carer</td>
<td>37%</td>
<td>55%</td>
<td>20%</td>
<td>42%</td>
<td></td>
</tr>
<tr>
<td>Administrative Staff</td>
<td>6%</td>
<td>6%</td>
<td>4%</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>Cleaner</td>
<td>6%</td>
<td>11%</td>
<td>8%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Diversional Therapist</td>
<td>3%</td>
<td>0%</td>
<td>8%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Kitchen staff</td>
<td>3%</td>
<td>0%</td>
<td>8%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Laundry staff</td>
<td>3%</td>
<td>0%</td>
<td>8%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Manager</td>
<td>22%</td>
<td>0%</td>
<td>32%</td>
<td>31%</td>
<td></td>
</tr>
<tr>
<td>Nurse</td>
<td>18%</td>
<td>22%</td>
<td>12%</td>
<td>21%</td>
<td></td>
</tr>
<tr>
<td>Physiotherapist</td>
<td>2%</td>
<td>6%</td>
<td>0%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Work psychosocial factors ( % of maximum score):</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall score *</td>
<td>62.9 (13.2)</td>
<td>67.7 (11.5)</td>
<td>62.0 (12.1)</td>
<td>59.5 (15.2)</td>
<td>0.25</td>
</tr>
<tr>
<td>Quantitative demands *</td>
<td>36.6 (23.5)</td>
<td>41.2 (28.2)</td>
<td>29.0 (19.0)</td>
<td>41.7 (22.3)</td>
<td>0.22</td>
</tr>
<tr>
<td>Work pace *</td>
<td>73.9 (20.1)</td>
<td>73.5 (26.5)</td>
<td>75.0 (18.9)</td>
<td>72.9 (15.0)</td>
<td>0.81</td>
</tr>
<tr>
<td>Emotional demands *</td>
<td>51.1 (25.7)</td>
<td>43.4 (31.0)</td>
<td>59.7 (20.4)</td>
<td>47.9 (24.3)</td>
<td>0.09</td>
</tr>
<tr>
<td>Influence at work *</td>
<td>46.3 (20.7)</td>
<td>50.7 (17.9)</td>
<td>48.9 (21.8)</td>
<td>38.9 (21.0)</td>
<td>0.25</td>
</tr>
<tr>
<td>Skill discretion *</td>
<td>66.1 (20.5)</td>
<td>72.8 (20.8)</td>
<td>66.1 (18.2)</td>
<td>59.7 (21.7)</td>
<td>0.20</td>
</tr>
<tr>
<td>Meaning of work *</td>
<td>82.4 (22.1)</td>
<td>89.0 (16.5)</td>
<td>85.1 (15.6)</td>
<td>72.9 (29.8)</td>
<td>0.17</td>
</tr>
<tr>
<td>Commitment to workplace *</td>
<td>67.4 (26.7)</td>
<td>77.2 (20.4)</td>
<td>66.5 (26.5)</td>
<td>60.4 (30.7)</td>
<td>0.19</td>
</tr>
<tr>
<td>Predictability *</td>
<td>57.6 (23.2)</td>
<td>66.2 (20.1)</td>
<td>52.4 (24.2)</td>
<td>55.6 (23.6)</td>
<td>0.30</td>
</tr>
<tr>
<td>Rewards *</td>
<td>64.5 (27.4)</td>
<td>70.6 (22.5)</td>
<td>64.2 (29.5)</td>
<td>59.0 (29.3)</td>
<td>0.58</td>
</tr>
<tr>
<td>Role clarity *</td>
<td>77.4 (19.5)</td>
<td>82.4 (25.0)</td>
<td>72.7 (16.7)</td>
<td>78.5 (16.5)</td>
<td>0.07</td>
</tr>
<tr>
<td>Quality of Leadership *</td>
<td>67.8 (27.2)</td>
<td>73.5 (23.3)</td>
<td>64.8 (28.3)</td>
<td>66.0 (30.0)</td>
<td>0.69</td>
</tr>
<tr>
<td></td>
<td>All (n = 62)</td>
<td>CG (n = 18)</td>
<td>IFG (n = 25)</td>
<td>CFG (n = 19)</td>
<td>p-value</td>
</tr>
<tr>
<td>------------------------</td>
<td>-------------</td>
<td>-------------</td>
<td>-------------</td>
<td>-------------</td>
<td>---------</td>
</tr>
<tr>
<td>Social support from supervisor</td>
<td>73.2 (28.6)</td>
<td>73.5 (26.5)</td>
<td>73.3 (29.2)</td>
<td>72.9 (31.3)</td>
<td>0.98</td>
</tr>
<tr>
<td>Job satisfaction</td>
<td>77.2 (27.6)</td>
<td>82.4 (20.8)</td>
<td>77.3 (28.0)</td>
<td>72.2 (32.8)</td>
<td>0.74</td>
</tr>
</tbody>
</table>

* = One-way ANOVA comparisons between intervention groups; Ψ = Kruskal-Wallis comparison by intervention groups.
7.3.2 Recruitment challenges

Managers from the four different centres of the health care organization were invited and agreed to have part of their workforce approached to participate in this study. Following voluntary recruitment, the number of participants per health care centre is presented in Table 7-2. The average recruitment rate was approximately one worker/week (SD=0.3). The lowest recruitment rate (0.6 workers/week) was associated with Health care centre 3. The other 3 centres had a similar recruitment rate, ranging from 1.1 to 1.4 workers/week. Qualitative data regarding challenges is reported in section 7.3.5.

Table 7-2. Number and percentage of participating workers per health care centre.

<table>
<thead>
<tr>
<th>Health care centre</th>
<th>Number of workers</th>
<th>Number of weeks</th>
<th>Recruitment rate (Workers/week)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health care centre 1</td>
<td>36 (58%)</td>
<td>26</td>
<td>1.4</td>
</tr>
<tr>
<td>Health care centre 2</td>
<td>8 (13%)</td>
<td>7</td>
<td>1.1</td>
</tr>
<tr>
<td>Health care centre 3</td>
<td>9 (14.5%)</td>
<td>16</td>
<td>0.6</td>
</tr>
<tr>
<td>Health care centre 4</td>
<td>9 (14.5%)</td>
<td>7</td>
<td>1.3</td>
</tr>
<tr>
<td>Total</td>
<td>62</td>
<td>56</td>
<td>--</td>
</tr>
<tr>
<td>Average (SD)</td>
<td>--</td>
<td>--</td>
<td>1.1 (0.3)</td>
</tr>
</tbody>
</table>

SD = standard deviation.

7.3.3 Adherence

On average, participants worked 5.1 days/week. The average (SD) of worked days per period (i.e. baseline, week 1-4 of intervention period and follow-up) is presented in Table 7-3. On average, the Spineangel® was not used for 1.2 day per week, corresponding to, approximately, 25% of worked days per week.
Table 7-3. Participants’ adherence to the use of the Spineangel®.

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Follow-up</th>
<th>Total period</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of worked days</strong></td>
<td>Mean (SD)</td>
<td>5.9 (1.9)</td>
<td>4.9 (1.3)</td>
<td>4.8 (1.0)</td>
<td>5.1 (1.5)</td>
<td>4.6 (1.0)</td>
<td>5.0 (1.3)</td>
</tr>
<tr>
<td><strong>Number of days Spineangel® was not used</strong></td>
<td>Mean (SD)</td>
<td>1.2 (1.5)</td>
<td>1.2 (1.2)</td>
<td>1.4 (1.6)</td>
<td>1.1 (1.3)</td>
<td>1.3 (1.4)</td>
<td>1.1 (1.5)</td>
</tr>
<tr>
<td><strong>Days Spineangel® was not used (%)</strong></td>
<td>Mean (SD)</td>
<td>20.8 (25.1)</td>
<td>23.9 (23.6)</td>
<td>28.5 (33.1)</td>
<td>22.3 (26.5)</td>
<td>29.1 (29.6)</td>
<td>23.1 (31.0)</td>
</tr>
</tbody>
</table>

SD = standard deviation.
7.3.4 Follow-up rates

Follow-up rates varied according to the health care centre. The lowest follow-up was 77.7%, while another centre had a follow-up of 100%. When follow-up is analysed according to the group intervention, CFG had the lowest follow-up (73.6%), while CG had a rate of 89% and IFG a rate of 92%. For the study as a whole, a total of 85.4% of enrolled participants completed the follow-up.

Table 7-4. Follow-up rates (per centre, group and for the study as a whole).

<table>
<thead>
<tr>
<th>Health care centre</th>
<th>Completed follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health care centre 1</td>
<td>77.7%</td>
</tr>
<tr>
<td>Health care centre 2</td>
<td>85.7%</td>
</tr>
<tr>
<td>Health care centre 3</td>
<td>88.8%</td>
</tr>
<tr>
<td>Health care centre 4</td>
<td>100%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intervention group</th>
<th>Completed follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>CG</td>
<td>88.8%</td>
</tr>
<tr>
<td>IFG</td>
<td>92.0%</td>
</tr>
<tr>
<td>CFG</td>
<td>73.6%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Study follow-up</th>
<th>Completed follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>85.4%</td>
</tr>
</tbody>
</table>

CG = Control group; IFG: Intermittent feedback group; CFG = constant feedback group.

7.3.5 Participating centres’ challenges with managing the study

One of the main challenges the participating centres had with regards to including the study within their daily routines was to collect the devices at the end of every week and return it to workers at the beginning of the following week. Workers were reminded by managers to either return or get the Spineangel® at the end or beginning of each week, respectively. Two centres used notices in the common room; another one used e-mail reminders while another used electronic reminders to staff members’ pagers. Data collection ran smoothly at the last two centres, where workers were reminded by electronic messages or e-mail.

7.3.6 Effectiveness of the Spineangel® as a postural and EF device

7.3.6.1 Within-group differences in postural pattern between baseline and follow-up

Within-group differences in postural pattern between baseline and follow-up are described in Table 7-5. No differences were found for postural pattern between baseline and follow-up periods for the CG and IFG. On the other hand,
postural pattern reduced significantly at the follow-up period, when compared to the baseline period, for the CFG.

Table 7-5. Within-group mean differences (and 95% confidence interval) for postural pattern (baseline – follow up).

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean difference between baseline and follow-up (frequency/hour)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CG</td>
<td>18</td>
<td>-0.1 (-0.6 to 0.6)</td>
<td>0.97</td>
</tr>
<tr>
<td>IFG</td>
<td>25</td>
<td>0.3 (-0.5 to 1.1)</td>
<td>0.44</td>
</tr>
<tr>
<td>CFG</td>
<td>19</td>
<td>-1.0 (-1.9 to -0.1)</td>
<td>0.03</td>
</tr>
</tbody>
</table>

CG = control group; IFG = intermittent feedback group; CFG = constant feedback group.

Post hoc power analysis revealed that based on the mean, the observed effect size (CG, d = 0.008; IFG, d = 0.15; CFG, d = 0.51), and the sample size, this study had a statistical power level of 0.05, 0.11, 0.56 for the CG, IFG and CFG comparisons, respectively.

### 7.3.6.2 Between-group differences in postural pattern between baseline and follow-up

![Figure 7-2. Mean differences (dot) and 95% confidence interval (bars) between baseline and follow-up measurements. CG: control group; IFG: intermittent feedback group; CFG: constant feedback group.](image)

An ANCOVA test was used to test for postural pattern differences among the three intervention groups (CG, IFG, CFG). Postural pattern at baseline, work-related psychosocial factors and ODI scores were considered as covariant variables. Postural pattern did not differ significantly across the three intervention groups, $F(4, 57) = 2.42, p = 0.058$.

Post hoc analysis also revealed that based on the number of groups, number of participants per group, the square root of the mean square error (square root
MSE = 1.74), the mean differences in postural pattern between baseline and follow-up for each group, and the effect size (f = 0.31), this study had a statistical power level of 0.57 for between-group comparisons.

### 7.3.7 Workers’ subjective perception

#### 7.3.7.1 Spineangel® usefulness

Workers’ subjective perception on the usefulness of the Spineangel® did not vary between groups (Table 7-6). Most workers (33/51) agreed the Spineangel® was useful to improve their posture at work and a total of 8/51 participants considered the Spineangel® not helpful to improve work posture.

*Table 7-6. Workers’ subjective perception on the usefulness of the Spineangel® device for all participants and the three intervention groups: control group (CG); intermittent feedback group (IFG) and constant feedback group (CFG). Values presented as frequency and proportions.*

<table>
<thead>
<tr>
<th>Score</th>
<th>All (n = 51)</th>
<th>CG (n = 14)</th>
<th>IFG (n= 22)</th>
<th>CFG (n= 15)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Strongly Agree</td>
<td>9 (17.6%)</td>
<td>2 (14.2%)</td>
<td>5 (22.7%)</td>
<td>2 (13.3%)</td>
<td>--</td>
</tr>
<tr>
<td>2 - Agree</td>
<td>24 (47.0%)</td>
<td>8 (57.1%)</td>
<td>9 (40.9%)</td>
<td>7 (46.6%)</td>
<td>--</td>
</tr>
<tr>
<td>3 - Undecided</td>
<td>10 (19.6%)</td>
<td>4 (28.6%)</td>
<td>4 (18.2%)</td>
<td>2 (13.3%)</td>
<td>--</td>
</tr>
<tr>
<td>4 - Disagree</td>
<td>6 (11.8%)</td>
<td>0 (0.0%)</td>
<td>3 (13.6%)</td>
<td>3 (20.0%)</td>
<td>--</td>
</tr>
<tr>
<td>5 - Strongly Disagree</td>
<td>2 (3.9%)</td>
<td>0 (0.0%)</td>
<td>1 (4.5%)</td>
<td>1 (6.6%)</td>
<td>--</td>
</tr>
<tr>
<td>Median (Interquartile)</td>
<td>2.0 (2.0 to 3.0)</td>
<td>2.0 (2.0 to 2.8)</td>
<td>2.0 (2.0 to 3.0)</td>
<td>2.0 (2.0 to 3.5)</td>
<td>0.67</td>
</tr>
</tbody>
</table>

#### 7.3.7.2 Additional comments provided by the participants

Six workers (two per group) provided comments regarding the usefulness of the Spineangel® device to improve their posture at work. A variety of perspectives were reported by workers, irrespectively of the group they were assigned to (Table 7-7). For example, the two workers assigned to the CG both stated that the Spineangel® never beeped, but one worker reported the device increased his postural awareness. One worker assigned to the IFG found the Spineangel® not useful for improving posture as, according to him, “there are jobs that have to be done” and there is “only one way to do it”. One worker assigned to the IFG agreed the device was useful to improve posture, especially when it beeped. Both workers of the CFG agreed the Spineangel® was useful to improve posture, and one worker highlighted that his pain would be the main factor for postural alignment while performing job tasks.
Table 7-7. Additional comments (and respective Likert Score) provided by workers with regards to the utility of the Spineangel®.

<table>
<thead>
<tr>
<th>Comments</th>
<th>CG</th>
<th>IFG</th>
<th>CFG</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>“Spineangel helped me be very aware of my position in lifting. It never beeped once.” (Likert Score: 2)</td>
<td>“There are jobs that have to be done and usually only one way to do it.” (Likert Score: 4)</td>
<td>“The Spineangel made me aware how often I bent over, it seemed more worried than me about it! I have a strong back but probably not the best posture so I made a conscious effort to straighten up more.” (Likert Score: 2)</td>
</tr>
<tr>
<td>2.</td>
<td>“It never went off.” (Likert Score: 4)</td>
<td>“More useful when it beeped to let me know I was not bending my knees as I should, but even having it on meant I was more aware of my posture.” (Likert Score: 2)</td>
<td>“I feel that the Spineangel has helped me when beeps to re-think my posture but due to pain, will find the posture that suits to alleviate the pain when doing my job.” (Likert Score: 2)</td>
</tr>
</tbody>
</table>

CG = control group; IFG = intermittent feedback group; CFG = constant feedback group; Likert Score 2 = "Agree"; Likert Score 4 = "Disagree".

7.3.8 Harm

No adverse events or side effects were reported by participants.

7.4 Discussion

The aim of this study was to evaluate the feasibility of a trial to investigate the effectiveness of the Spineangel® as an EF device for modifying daily activity postures for different job occupations in health care centres. No differences between groups were found for baseline measures. It was considered that having managers taking part in the study could facilitate the remaining staff to participate in the study, minimizing any negative attitudes and perceptions at the workplace by general staff members (Whysall et al., 2006). Recruitment challenges, adherence and follow-up rates, and challenges participating centres faced during data collection were identified.

7.4.1 Recruitment challenges

Four different centres of the health care organization were invited and agreed to participate in this study. Fifty-eight per cent of the 62 study participants were employed at one of the centres (Health Care centre 1). The larger number of participants from this centre is due to two streams of data collection taking place at this centre. The larger sample from this centre was probably also associated with the strong support from managers to run this study at their centre. This
centre also had volunteered to participate in the cross-sectional field study reported in Chapter 6. Therefore, a large number of workers knew about the study and were willing to participate. Data collection at the other three centres occurred simultaneously. Only one data collection stream took place at each of these centres (Health Care Centre 2, 3 and 4) resulting in a smaller number of participants (approximately 14%). The ‘Health Care Centre 3’ had an additional 9 week period of data collection, as some of the workers interested in taking part in the study were on annual leave when data collection started (Table 7-2).

The recruitment rate average was approximately one worker/week (SD=0.3). Three centres had approximately the same recruitment rate, ranging from 1.1 to 1.4 workers per week. A possible reason for Health care centre 3 to have the lowest recruitment rate (0.6 worker/week) is that at the time of data collection, this centre was undergoing administrative re-structuring. This could explain the low recruitment rate at this centre, compared to the other participating centres.

The meetings held prior to data collection helped to create a partnership between the researcher and the managers and workers. While recruiting participants, the information about the study was provided during workers’ morning or afternoon breaks or, in some cases, during staff meetings. The time for providing such information for potential participants was short, due to the busy work schedule. This is supported by the COPSOQII average score for the ‘Work pace’ item was 73.9 (SD = 20.1). The busy working schedule at these centres thus appeared to be a barrier for recruitment. On the other hand, the support provided by managers helped to recruit participants. The planning of future studies involving health care centres should consider establishing good and trustful partnerships with managers and workers.

7.4.2 Adherence

Numerous studies have focused on methods for assessing the effect of ergonomic interventions on postural exposure (Marras et al., 1993, van der Beek et al., 1995, Buchholz et al., 1996). There seems to be considerable variability within- and between-subjects (Mathiassen and Paquet, 2010). Therefore, it is recommended that postural samples are gathered across multiple days as this can
improve the statistical power for detecting the intervention effect (Mathiassen et al., 2002). The present study attempted to continuously record workers’ postural exposure during a period of 6 weeks.

The Spineangel® was not used, on average 1.2 days per week, thus approximately for 25% of the data collection time. This leads to an adherence of approximately 75%. Perry et al. (2010) assessed the adherence and data loss of a triaxial accelerometer for measuring physical activity in 21 healthy adults. According to their findings, only 6.7% (443.3 h) of activity over a 21 day period was not recorded, with non-adherence accounting for 169.5 h (approximately 38%) of data loss. These authors have used an activity diary for estimating physical activity hours. For the present study, it was decided not to request workers to fill a work-related postural log in order to minimize work disruption. As described at the end of Chapter 6, workers at this institution have a busy working schedule and requesting them to fill a log would possibly have impacted on the recruitment. Future studies using the Spineangel® or a similar device and sample need to consider strategies to improve adherence. One possible solution is the use of text messages to workers mobile phones or pagers.

7.4.3 Follow-up rates

Follow-up overall rates exceeded the a priori threshold of 80% with only one site less than that figure. This cut-off value is used in Evidence-Based Medicine for assessing the quality of RCTs (OCEBM, 2012). For example, a Cochrane protocol for assessing worksite intervention for neck and back disorders considered a rate of 20% as the maximum value for immediate and short-term follow-up (Aas et al., 2005). A previous study assessing the effectiveness of an intervention to improve work style behaviour had a short-term drop-out rate of approximately 20% (Bernaards et al., 2008). As previously stated, one criterion to consider this study as feasible was to have a minimum follow-up rate of 80%. Therefore, based on these follow-up rates, it seems feasible to conduct a larger study for assessing effectiveness of a postural monitor and feedback device to change postural behaviour in a group of care workers.
7.4.4 Challenges participating centres had with managing the study

Two of the participating centres had problems with collecting the devices at the end of every week and returning them to workers at the beginning of the following week. This was a problem especially in the first 3 weeks of data collection. After this time point, collecting and returning the device was perceived by workers as part of their routine. Not returning the Spineangel® at the end of the week was especially problematic for participants at the IFG, as the feedback mode (on/off) had to be changed every week during the intervention period.

7.4.5 Effectiveness of the Spineangel® as a postural and EF device

7.4.5.1 Within-group differences in postural pattern between baseline and follow-up

No differences were found between baseline and follow-up periods for the CG and IFG, while significantly differences were found for the CFG (Table 7-5). These findings suggest intermittent postural feedback may not be effective to change postural behaviour, while the provision of constant feedback during a period of 4 weeks may help workers to avoid hazardous posture. Future research is required to assess the effectiveness of different type of EF on postural behaviour.

A small effect size was found for CG and IFG intervention groups, while a moderate effect size was found for the CFG (Cohen, 1988). Post hoc power analysis indicates limited statistical power for the CG and IFG within-group comparisons due to modest sample size. On the other hand, the 95% CI were relatively narrow for both CG and IFG (Table 7-5). Therefore, based on the 95% CI analyses, it is likely that there were no significant differences between baseline and follow-up for the CG and the IFG.

7.4.5.2 Between-group differences in postural pattern between baseline and follow-up

The between-group differences observed did not reach statistical significance (p = 0.058) (Figure 7-2). There was a tendency for differences between CFG and the other two groups: CG and IFG (Figure 7-2). A relatively small effect size was found for between-group comparisons (Cohen, 1988). As post hoc analysis, also revealed a statistical power of 0.57, it is not possible to rule-out the
presence of a Type II error for non-significant findings found for the between-group comparisons.

It is possible that no between-group differences were identified due to variability on postural pattern and small sample size. Previous study suggests postural variability is more related to different work-tasks, rather than between-worker differences (Allread et al., 2000). One of the reasons for increased data variability may be that: this study recruited workers with different job occupations (e.g. care givers, nurses, administrative personal) which are associated with different postural demands. Further, the small sample size may have contributed towards the lack of significant between-group differences. The CFG appears to be a more promising intervention for modifying postural behaviour; therefore, a future RCT should have 2 arms: CG and a CFG. As a feasibility trial, the present study was not intended to have sufficient power to identify between-group differences.

These results seem to be in contrast to findings from the critical literature review (Chapter 3), which reported intermittent feedback to be more effective than constant feedback. However, it could be argued that EF definitions (i.e. intermittent and constant provision) were not correctly applied in this study. While the CFG received the audio-feedback whenever the postural threshold was exceeded during the whole intervention period (i.e. 4 weeks); no feedback was provided if flexed postures did not reach the ROM threshold, were not sustained for the minimum duration or were not performed at least twice per minute. Therefore, there were numerous situations in which workers adopted flexed postures but they did not receive any audio feedback. The audio-feedback could therefore be interpreted as being delivered in an intermittent mode. Furthermore, a constant postural EF could be defined as one in which workers receive a continuous auditory stimulus that becomes louder when they exceed the postural threshold. When designing the present study, it seemed appropriate to define the IFG by manipulating the timing characteristics of the EF (i.e. by alternating the weeks in which the audio-feedback was “on”). However, the preliminary findings from this study suggest those timing characteristics definitions may have been incorrectly applied, therefore those should be revised for future studies.
7.4.6 Sample size for future trials

The sample size estimation for future trials was based on the mean difference and standard deviation between baseline and follow-up periods for the CG and the CFG. Sample size cannot be estimated considering a clinically meaningful difference, as at this stage, such information is unknown. When comparing those groups (CG x CFG), the present study found an effect size of 0.62. Using such effect size, an alpha of 0.05 and a power of 80% as input data for sample size calculation; a 2 arm RCT, with allocation ratio of 1:1, and one-way alpha (based on preliminary data from the feasibility RCT), 33 subjects per group is the minimum required to achieve statistical significance level of 0.05 with power of 0.80. Assuming a 15% drop-out rate (Table 7-4), 39 participants are required per group.

7.4.7 Workers’ subjective perception

Most workers allocated to the CG, IFG and CFG agreed that the Spineangel® was a useful tool to improve posture: 57.1%, 40.9% and 46.6%, respectively (Table 7-6). Based on the usefulness scores (Table 7-6) and additional comments (Table 7-7), there seems to be a placebo effect influencing workers’ perception about the utility of the device. It is possible that workers performed their tasks with a ‘better posture’ as they were being monitored (Hawthorne effect), leading to an underestimation of postural exposure (Freitag et al., 2012). On the other hand, as reported by one worker (Table 7-7), work demands can be stressful and, according to this worker, adopting a hazardous posture may be the only way to complete the task. It is hard to determine whether this holds true for all participants.

In general, workers seem to value the use of Spineangel® to improve posture at work. In a previous study, feedback was provided to help workers to reduce upper trapezius muscle activity while performing computer tasks (Madeleine et al., 2006). That study provided two different feedback modes: audio or visual. The audio-feedback mode was perceived as slightly more useful than the visual feedback mode for improving posture. The average for the feedback usefulness score for the provision of audio-feedback, during different computer working conditions ranged from 77.8 to 88.9%; while average of feedback usefulness score for the provision of visual-feedback, ranged from 66.7 to 84.8% (Madeleine et al., 2006). Another study assessed the effect of vibration-feedback
using computer mouse on reduction of hovering movement behaviour while performing computer tasks. This study found the vibration-feedback from the mouse was perceived by participants as helpful to: remind them about unfavourable behaviour and to increase behaviour awareness (de Korte et al., 2008). On the other hand, a recent study also assessing the effect of vibration-feedback using a computer mouse on reduction of hovering movement behaviour found divergent results (de Korte et al., 2012). Those authors reported participants to prefer the non-feedback condition to execute computer tasks, when compared with four types of feedback provision (two tactile and two visual) (de Korte et al., 2012). There are different possibilities to explain EF acceptance rates by workers. Short-term EF exposure may have led to poorer acceptance rates when compared to prolonged exposure to EF, as participants needed time to familiarize with the EF (de Korte et al., 2012). Another reason relates to the interaction between EF and mental workload. Any work task will impose a further demand on human mental resources, and that mental resource is limited. An ideal work task will use less than the available mental resources, leaving a residual capacity to be used during unexpected situations (Wickens, 2008). If a working task imposes high levels of mental workload, the inclusion of EF may be perceived as disruptive, leading to increased mental workload (Oakley et al., 2000, Wickens, 2008).

For the present study, the postural threshold ROM was set at 45° of trunk forward flexion, while previous studies have used a threshold at 20° of trunk forward flexion (Freitag et al., 2012, Freitag et al., 2007, Mathiassen and Paquet, 2010). The option for 45° of trunk forward flexion was based on findings from the cross-sectional field study reported in Chapter 6 and outcome measures used by studies found included at the systematic review (Chapter 2). The aim was to identify a postural threshold that was frequently, but not constantly, reached by workers and that was considered to increase risk of NSLBP. The selection of a postural threshold that was constantly reached by workers (e.g. 20°) would lead to continuous audio-feedback provision. This could interfere with work performance, and workers’ adherence and acceptance of the device.

7.4.8 Limitations

The Spineangel® records and stores the number of times a posture exceeds the postural threshold as well as the day the device was used. However, it does not
record the time of the day it was turned on and turned off. Thus, the postural patterns described in this study are estimates based on postural data gathered from the Spineangel® and the number of hours worked per day for each participant, obtained from the records of each health care service centre. It is recommended the Movement Metrics Ltd to consider adding on/off time feature to the software.

It is possible that the use of different clothes between working days lead to changes in postural pattern estimates. The between-day ME for lumbo-pelvic postural measurements was found to be equivalent to 8° (Chapter 6). It could be argued that an error of 8° is significant, however, postural EF provided with the Spineangel® is defined as a program feedback (Chapter 3), i.e., it targets changes in the postural general movement pattern. Therefore, potential errors for postural pattern estimates are unlikely to distort the identification of postural changes between baseline and follow-up.

Another limitation of the present study is the inclusion of workers with different occupations, which may have contributed towards high variability on postural pattern measurements. However, including different staff members increased the external validity of this study.

For the present study, the impact of EF on task performance was not monitored. Therefore, it is unknown whether the provision of postural EF improved or worsened task performance. According to one worker who was allocated to the IFG, “there are jobs that have to be done and usually only one way to do it” (Table 7-6). This suggests workers may have disregarded the audio-feedback in order to complete work-related tasks in time. Future studies could assess the impact of the audio-feedback on task performance.

7.4.9 Interpretation

For this study, the follow-up rate was 85.4% and it is above the cut-off value of 80%. This result supports the feasibility of this study methodology. On the other hand, the adherence was approximately 75%, being below the cut-off value of 80%. Based on these findings, future researchers should include additional strategies to improve participants’ adherence. Future studies using the
Spineangel® as a feedback tool to change postural behaviour must consider additional strategies to improve participants’ adherence.

Workers seemed to value the use of the Spineangel® as a postural EF tool. The provision of constant postural EF reduced flexed postural exposure at the follow-up period when compared to the baseline period; however, intermittent EF did not. Although no significant between-group differences were found, this may be attributable to type 2 error in a feasibility study of this size and design. These are preliminary findings for how postural feedback should be provided. Future studies are warranted to compare the effectiveness of constant EF provision and a control group.

7.4.10 Generalizability

The inclusion of different centres of the same health care organization, and workers with different job occupations increased the external validity of the present study.

Since this is a feasibility study, it was expected that no statistically significant differences would be found (Thabane et al., 2010). These are preliminary findings and only inferences can be made. Based on the findings, for within-group and between-group differences, future studies assessing the effect of postural EF could focus on assessing the effectiveness of constant EF for modifying postural behaviour. These findings do not support exploring the effect of intermittent postural EF, as no difference was found between baseline and follow-up periods.

7.5 Final considerations

Based on follow-up and adherence rates, conducting a RCT with a similar method to the present study, with additional strategies to minimize the non-adherence to wear the Spineangel® at work are required for future a RCT to be succesful. The provision of constant postural EF seems promising for promoting changes in postural behaviour and future studies with an adequate sample size should be capable of identifying whether there are differences between constant EF and the control group.
8 General discussion

This thesis has explored the potential usefulness of the Spineangel® as a monitor and feedback postural EF device using one systematic and one critical review (Chapter 2 and 3, respectively), cross-sectional studies (Chapter 4, 5 and 6), and a feasibility RCT (Chapter 7). Based on the outcome of these individual studies:

(1) There is limited evidence for ROM or duration of flexed posture and no evidence regarding frequency of trunk flexion as risk factors for NSLBP (Chapter 2), even though laboratory studies have consistently reported deleterious neuromuscular effects for such sustained or frequent trunk flexion;

(2) According to the motor control and motor learning research field, there are optimal timing and content characteristics for EF provision (Chapter 3) and most of the literature on rehabilitation and NSLBP has not considered these optimal characteristics when providing EF;

(3) The Spineangel® did not affect the accuracy of the electromagnetic Fastrak™ motion analysis system (Chapter 4), therefore the latter was able to be used as the gold standard instrument for the assessing the validity of the former when clipped to the belt or waistband;

(4) The Spineangel® is a reliable and valid instrument for monitoring lumbo-pelvic gross movements during laboratory (Chapter 5) and field-based studies (Chapter 6), and;

(5) It is possible that constant postural EF can help to change postural pattern behaviour in health workers, and therefore minimize exposure to hazardous posture at the workplace (Chapter 7). Results from the feasibility RCT (Chapter 7) suggest when designing a study for assessing the effectiveness of the Spineangel®, strategies should be adopted in order to improve participants’ adherence (e.g. text reminders for workers).

While conducting each of those studies, a number of relevant issues on monitor and feedback devices were identified and are discussed in the next sections.
8.1 The use of postural monitor devices

Future research is required to determine whether gross lumbo-pelvic measurements obtained with the Spineangel® device are associated with increased risk of developing NSLBP. The systematic review on dose-response relationship between posture and NSLBP (Chapter 2) revealed no previous study using portable devices (such as the Spineangel®) for assessing posture as risk factor for NSLBP in prospective cohort study. Previous research with this device is limited to a case series report (Horton and Abbott, 2008) and a cross-sectional laboratory study (Intolo et al., 2010). The use of this instrument in prospective cohort studies may provide insightful information on this matter (Teschke et al., 2009, Trask et al., 2007). Studies assessing the relevance of this device as a rehabilitation tool for the management of NSLBP are warranted. Additionally, future research could assess the effectiveness of the Spineangel® as a postural feedback device to prevent occupational NSLBP.

8.2 The use of postural monitor and feedback devices in rehabilitation

The provision of EF on the management of NSLBP has been critically reviewed and discussed in Chapter 3. As described in that chapter, a variety of instruments have been used to provide EF during rehabilitation programmes (e.g. ultrasound imaging, pressure biofeedback units, and EMG). No study was found assessing the effectiveness of a postural monitor and feedback device to change postural behaviour during daily-life activities as leisure activities or work. Additionally, according to findings from the critical literature review (Chapter 3), only one study has assessed the impact of timing EF characteristics on clinical outcomes (Herbert et al., 2008). Considering the gap between recommended characteristics for provision of EF and rehabilitation research on that topic, implications for future research in rehabilitation and a rationale for EF provision towards management of NSLBP is presented in the next section.

8.3 Implications for future research in rehabilitation

Musculoskeletal movement syndromes, such as NSLBP, present with dysfunction of muscle systems (global and local) (Sahrmann, 2002), feedback (Brumagne et al., 2000) and feedforward postural control mechanisms (Hodges,
2001). While the local muscle system tends to have diminished activity thereby potentially exposing vertebral joints to increased instability, the global muscle system tends to present with increased muscular activity, increasing intervertebral compressive force (Granata and Marras, 2000). Furthermore, patients with NSLBP are likely to present with reduced lumbo-sacral position sense (disrupted feedback) (Brumagne et al., 1999) and delayed contraction of transversus abdominis (altered feedforward postural control) (Hodges and Richardson, 1996). These neuromuscular impairments might be related to the maintenance of symptoms (O’Sullivan et al., 2003) and therefore may be the target of physiotherapy interventions.

8.3.1 **Extrinsic feedback provision**

As described in Chapter 3, there are diverse forms of delivering EF and the different characteristics can be divided into two main domains: content and timing (Magill, 2003). Content characteristics refer to attributes of focus of intervention of the EF, e.g., how EF results are presented and the type of focus of attention associated with it. Timing characteristics refer to all attributes related to when feedback is provided during motor training (Magill, 2003) (as discussed in Chapter 3).

Feedback interventions can address generalized motor programs, or movement parameters characteristics (Lai et al., 2000). Generalized motor program can be defined as the basis for general movement pattern generation (Shea and Wulf, 2005). The generalized motor program is composed of parameter features such as limb and muscle recruitment, movement direction, movement amplitude, velocity and timing sequence (Shea and Wulf, 2005, Schmidt and Wrisberg, 2008). Different parameters of a generalized motor program are selected according to the aim of the task being executed, the external environment, and task and individual constraints (Shumway-Cook and Woollacott, 2007). Changes in parameter characteristics of the general movement pattern can be used to adapt these to the patient’s environmental and task requirements (Shea and Wulf, 2005).
8.3.2 Rationale for feedback provision for the management of low back pain

Due to altered feedback and feedforward postural control mechanisms, it is likely that patients with NSLBP will benefit from EF provision. However, since redundant feedback can retard motor learning (Park et al., 2000), physiotherapists should assess the real need to include this modality with rehabilitative exercises for each individual patient. Additionally, different motor control impairments might benefit from different types of EF (Dozza et al., 2005, Madeleine et al., 2006). For example, local muscle dysfunction can be targeted by means of parameter feedback to help patients enhance specific parameters of muscle recruitment such as multifidus or transversus abdominis (Herbert et al., 2008, Hides et al., 1996). On the other hand, global muscle dysfunctions and feedback mechanisms for postural control could be targeted with the use of postural feedback. Flexed posture is associated with increased spinal loads (Gregory et al., 2006) and spinal muscle co-contraction (Ferguson et al., 2004b). Avoiding flexed postures, the loads applied to the spine and recruitment of spinal extensor muscles should be reduced. Physiotherapists should consider the main clinical neuromuscular impairments when selecting the appropriate type of feedback for each patient.

8.3.2.1 Programme feedback and task-oriented motor training

With any treatment intervention, the selection of appropriate EF should be based on careful stages of decision-making (Figure 8-1). This section describes adapted decision-making stages for the provision of EF on the management of NSLBP, from literature related to motor learning and training (Schmidt and Wrisberg, 2008). It is important to highlight that both programme and parameter feedback should be provided under considered ideal content and timing characteristics (Schmidt and Wrisberg, 2008, van Vliet and Wulf, 2006, Magill, 2003). Such conditions were discussed in Chapter 3.

If the patient is not familiar with the exercise or incapable of performing it, program feedback should be provided. The general motor task concepts should be explained and, if needed, corrected. As the general motor task is mastered, improvement of specific characteristics of movement should be targeted with parameter feedback (Schmidt and Wrisberg, 2008). There is, theoretically, a further reason for this type of feedback provision. It is suggested that motor
training should be task oriented (van Vliet and Heneghan, 2006, Shumway-Cook and Woollacott, 2007). Under this perspective, isolated contraction of specific muscles is not the ideal motor training approach. There is evidence supporting the reorganization of motor cortex in response to task-specific motor training (van Vliet and Heneghan, 2006, Flor, 2003). Patients with chronic NSLBP were shown to have adaptive motor cortical reorganization which is associated with motor control changes (Flor et al., 1997). A task-oriented approach is considered to contribute to motor cortical neuroplasticity changes (Boudreau et al., 2010). As a result, the use of EF associated with a task-specific motor training approach seems promising (van Vliet and Heneghan, 2006). On the other hand, motor cortex reorganization was also found for patients with recurrent NSLBP after a period of specific transversus abdominis muscle training contraction (Tsao et al., 2010). Whether program or parameter feedback is more likely to improve clinical outcomes might depend on the patient’s main neuromuscular impairment.
Figure 8-1. Flowchart for provision of extrinsic feedback for the management of low back pain.

Task-oriented program feedback seems to be promising. In a recent study, Magnusson et al. (2008) have described the use of a postural feedback device during a rehabilitation program for chronic NSLBP patients. The device monitored trunk kinematics providing visual feedback during trunk exercises (Magnusson et al., 2008). The visual information increased patients’ postural awareness compared to control group. This study showed that adding feedback to the rehabilitation program was related to better clinical outcomes (Magnusson et al., 2008). Similarly, Wong and Wong (2008) found that the provision of audio feedback, by means of a spinal monitor device, reduced the amount of time spent...
in trunk flexion by healthy subjects during daily activities. These findings are encouraging results for programme feedback task-oriented provision.

The use of programme feedback could also target general sitting postural alignment. NSLBP patients have decreased proprioceptive awareness (Brumagne et al., 2000) and slouched posture has been found to expose the lower intervertebral joints to extreme flexion range of motion (Dunk et al., 2009). As a result, prolonged exposure to slouched posture can lead to creep deformation, stress relaxation of spinal soft tissues and reduced activity of low back muscles, due to flexion-relaxation phenomenon contributing to spinal instability (Mork and Westgaard, 2009, Shin and Mirka, 2007). In order to improve sitting posture, audio feedback could be used to help patients to improve spinal sense of position.

Since poor postural and movement habits are thought to be triggering factors for motor control impairments at the lumbar spine (Comerford and Mottram, 2001), targeting poor postural control might be clinically relevant. There are recent published studies related to devices developed to monitor lumbo-pelvic and spinal movements (O'Sullivan et al., 2010a, Intolo et al., 2010, Wong and Wong, 2008). Whether such novel instruments will have a positive impact over rehabilitation progress is unclear at present requiring further research to determine the value of these instruments for rehabilitation.

8.3.2.2 Parameter feedback and local system impairment

The literature has reported the use of feedback for the management of NSLBP, mainly focusing on the provision of parameter feedback (e.g. specific muscle contraction) (Hides et al., 1996). Pressure biofeedback units and rehabilitative ultrasound imaging feedback aim to enhance the contraction of specific muscles such as transversus abdominis (von Garnier et al., 2009, Herbert et al., 2008). By enhancing local system muscle motor control, local spinal stability is improved (Hides et al., 1996). Providing such parameter feedback has a strong spinal stabilization appeal (Richardson et al., 2004).

Considering rehabilitative ultrasound imaging for isolated contraction of transversus abdominis muscle as an example, feedback should only be provided after the patient is able to perform the general movement of abdominal hollowing exercise. Once this has been achieved rehabilitative ultrasound imaging could be
used for feedback provision focusing on specific parameters of the exercise such as the amount of muscle contraction and or duration of sustained contraction. By doing so, a sequence of programme and parameter feedback would be followed and, theoretically, leading to better motor performance. Clinicians should also consider the provision of summary or average feedback (Guadagnoli et al., 1996) whereby a number of trials should be conducted without feedback, followed by the patient receiving overall feedback comparatively related to previous performance(s). An example might include providing visual feedback of muscle contraction associated with increased muscle thickening (Whittaker et al., 2007).

A further important issue to consider is the feedback bandwidth. Feedback is provided to the patient when performance errors exceed this threshold. For example, while training isolated contraction of transversus abdominis, some NSLBP patients might present excessive contraction of rectus abdominis and external oblique (O’Sullivan et al., 1997). The amount of rectus abdominis or external oblique contraction that can be ignored should be larger at the beginning of treatment and progressively decreased, as the patient masters the task (Figure 8-1).

The focus of attention seems to have strong influence on motor learning (McNevin et al., 2000). When EF provision drives the patient’s attention to body movement characteristics, an internal focus of attention is being provided; on the other hand, external focus of attention drives patient’s attention to the effect of movement (Schmidt and Wrisberg, 2008). An example of internal focus of attention is to ask the patient to concentrate on the contraction of the abdominal muscles. For the same situation, an external focus of attention would be to ask the patient to concentrate on the changes of tissue thickness observable at the screen whilst the patient performs the task, or to ask the patient to feel the increased intra-abdominal pressure while performing the exercise. The literature suggests that the use of external focus of attention encourages better motor performance compared to internal focus of attention (Wulf et al., 2001).

With reference to timing feedback attributes, there is evidence that concurrent and constant feedback should be avoided (Schmidt and Wulf, 1997). It is suggested that concurrent feedback leads to increased dependency on EF inducing subjects to obliterate the use of somatosensory input (Anderson et al.,
Thus when using rehabilitative ultrasound imaging, feedback should not be provided immediately after the abdominal hallowing exercise was executed. By providing delayed feedback (e.g. verbal instruction or visual feedback after a few seconds of movement execution), patients are encouraged to better use and organize intrinsic feedback (somatosensory) information (Anderson et al., 2005). Clinicians should also consider the provision of EF when requested by the patient (self-controlled). It is suggested that by choosing when to receive feedback, subjects can better correlate the somatosensory input with EF information and motor performance (Chiviacowsky and Wulf, 2002).

8.3.2.3 Final considerations supporting the use of extrinsic feedback

There is considerable research potential regarding the optimal delivery of EF during the management of NSLBP. Clinicians should consider that the rationale for feedback provision presented here has been based on literature related to motor learning and performance, conducted mainly with healthy participants, and it is currently unclear whether this rationale holds true for people who present with motor or neuromuscular deficits in NSLBP. However the evidence suggests that patients with NSLBP will benefit from the above described extrinsic feedback characteristics. This presented rationale could be used by clinicians as a guide to provide feedback during the management of NSLBP, as well as by researchers to determine whether NSLBP patients respond differently to distinct EF characteristics while re-training motor skills.

8.4 The use of postural monitor and feedback devices in ergonomics

Work-related musculoskeletal disorders can be related to repetitive or sustained postures. Tasks requiring either high or low muscle force production can be associated with the onset of symptoms (McGill, 2009, Marras, 2005). Physically demanding jobs together with psychosocial factors have high risk (Marras et al., 2000), while jobs with low physical demands have moderate risk of developing NSLBP (Marras, 2008).

Research on the use of EF as an ergonomic intervention has mainly focused on reducing contraction magnitude of muscles at the neck-shoulder region.
Sustained muscle contraction is considered to be one of the causes for muscle pain at the neck-shoulder region (Madeleine et al., 2003); therefore, reducing muscle contraction in this area can potentially prevent musculoskeletal disorders (Vedsted et al., 2011, Madeleine et al., 2006). Interesting findings have been reported on the use of EMG or mechanomyography feedback for reducing trapezius muscle contraction during computer tasks. For example, a RCT found EMG-based EF to be an effective way of reducing trapezius muscle activity (Holtermann et al., 2008). Additionally, a cross-sectional study reported reductions of up to 50% on contraction of the trapezius muscle when providing EMG-based EF during computer tasks (Vedsted et al., 2011). The provision of EF during computer tasks seems to be more effective during stressful working conditions (Vedsted et al., 2011).

One study has assessed the effect of an EF training program on lumbar compressive forces during lifting simulated tasks (Agruss et al., 2004). That study compared two different types of EF (EMG-based and verbal feedback - based on acceleration index) to a control group. Verbal feedback was found to be the most effective intervention for reducing lumbar compressive forces. Together, findings from the above described studies on the use of feedback during work-related tasks and findings reported in Chapter 8 suggest the use of feedback for preventing musculoskeletal disorders is promising. Future research is required to assess whether the Spineangel® is an effective tool to prevent NSLBP in workers.

Based on findings from the feasibility RCT and the literature, a protocol is described in the next section for assessing the effectiveness of the Spineangel® to change work postural behaviour in health care workers.
8.5 Implications for future research in ergonomics

8.5.1 The effectiveness of the Spineangel® as a postural feedback device to change postural behaviour: the SAFE trial study protocol

A large sample and maybe a wide range of health care workers would be needed to assess the effectiveness of the Spineangel® as a postural feedback device to promote change in postural behaviour. Nursing students are, together with the health care work force (i.e. care givers and nurses), considered to be at increased risk of developing NSLBP (Yip, 2004). The prevalence of NSLBP within a cohort of training nurses was shown to sharply increase from 31% (at entry to nursing school) to 72% (at the end of the school), and to 82% after 5 years of working as a nurse (Videman et al., 2005). The presence of NSLBP at entry was found to be a predictor for NSLBP and related disability (Videman et al., 2005). Therefore, a future study using the Spineangel® as a monitor and feedback device for changing postural behaviour at work could include nursing students as participants. Considering the study will likely be carried-out in the Dunedin surroundings, including nurse students would facilitate achieving the sample size identified and described in Chapter 7 as being ideal. Based on findings from the feasibility RCT, the SAFE trial (SpineAngel® Feedback Experiment) was designed as a project to investigate the effectiveness of the Spineangel® as a postural EF to change postural behaviour in a group of health care workers. The specific aim of this trial will be to assess the effect of postural EF versus no feedback on exposure to flexed posture at work.

8.5.1.1 Methods

This project is a randomized controlled trial with blocked random allocation.

8.5.1.1.1 Ethical approval

This project will be submitted to the Ethical Committee of the University of Otago for consideration.

8.5.1.2 Participants

A total of 78 health care workers (carers and nurses) and health care trainees (e.g. nursing students) will be recruited from aged care institutions, the
Dunedin Public Hospital and from the School of Nursing at the Otago Polytechnic – Dunedin, New Zealand. The number of participants is based on the recommendations from the feasibility study (Chapter 7). The School of Nursing has approximately 100 students per year in the third year of the undergraduate course. Therefore, there are potentially, 100 students who could take part in this study (Figure 8-2).

![Diagram of participant flow](image)

Figure 8-2. Diagram of participant flow.
8.5.1.3 Eligibility criteria

Health care workers and nursing students, with or without low back symptoms, who have not stopped performing their regular work activities, will be included. Additionally, participants are required to work a minimum of 20 hours per week. Participants who are unable to undertake regular work-related activities due to NSLBP or work less than 20 hours per week will be excluded from this study.

8.5.1.4 Recruitment

Recruitment will last for a period of 18 months. Results from the feasibility study suggested a recruitment rate of 1.4 workers per week. In order to enhance the recruitment rate, a total of 60 Spineangel® devices will be used and the targeted recruitment rate was set as 2 participants per week. This will guarantee achieving a total of 60 participants for this study.

Managers from aged care institutions (e.g. Presbyterian Support Services, OTAGO) and hospital (Dunedin Public Hospital) as well as the Head of the Nursing School (Otago Polytechnic) will be approached and invited to have their workers or students participating in this study. Following approval from managers or the Head of the Nursing School, staff and students will be approached by posters, advertisements, mail and email. They will receive by mail an information sheet, letter of invitation to participate in this study, as well as a consent form. They will be provided with a post-paid return envelope, so they can return the signed consent form and their contact details. These will inform the nature of the study and give potential participants the contact details (email and telephone) of the research team. To improve participants’ adherence on the use of the Spineangel® during baseline, intervention and follow-up periods, all participants will receive a text to their mobile phones.

8.5.1.5 Baseline assessment

All participants will be requested to complete a self-administered questionnaire including demographic (age, gender, body mass, height, occupation, smoking habits), functional disability and psychosocial work characteristics. Functional disability will be measured by the ODI (Fairbank, 2000), while work-related psychosocial characteristics will be assessed by using the COPSOQ II
(Pejtersen et al., 2010). All participants will wear the Spineangel® for one week, so postural pattern is recorded at baseline.

**8.5.1.1.6 Randomization and allocation concealment**

After completing the baseline assessment, participants will be randomly allocated to one of the two intervention arms: “control group” or “feedback group”.

**8.5.1.1.7 Intervention**

The intervention period will consist of four weeks and participants will either receive or not receive postural audio-feedback according to their allocation into one of the following groups: control group and feedback group.

**8.5.1.1.7.1 Control group (CG)**

Participants allocated to the CG will not receive postural audio-feedback and the Spineangel® will be adjusted to monitor and record the postural pattern.

**8.5.1.1.7.2 Feedback group (FG)**

The FG will received postural audio-feedback, whenever the postural threshold is exceeded, during the four weeks of intervention. Following these four weeks, participants of all groups were monitored during their working days of the subsequent week, in order to assess the acute effect of EF provision on adopted postures during work.

**8.5.1.1.8 Follow-up**

The follow-up will occur at the sixth week of data collection. The Spineangel® was used as a postural monitor device and recorded workers’ postural pattern. At the end of the final week of data collection, participants will complete a questionnaire on functional status (assessed by means of the ODI). At the end of the questionnaire, there will be a section where workers may provide any comments with regards to the data collection procedures, the workplace, the Spineangel® device or any other additional comments they find relevant to report.

**8.5.1.1.9 Outcome measures**

The main focus of this trial is to assess the effectiveness of the Spineangel® as a feedback tool for changing postural behaviour. The primary outcome measure
is postural pattern and LBP-related disability is the secondary outcome measure. The time points for assessing those outcome measures are described in Table 8-1.

Table 8-1. Outcome measures.

<table>
<thead>
<tr>
<th>Primary outcome measure</th>
<th>Instrument</th>
<th>Time Point (weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Differences in postural pattern (baseline – follow-up)</td>
<td>Spineangel®</td>
<td>1 and 6</td>
</tr>
<tr>
<td>Secondary outcome measure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LBP-related disability</td>
<td>Oswestry Disability Index</td>
<td>0 and 6</td>
</tr>
<tr>
<td>(Fairbank, 2000)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8.5.1.2  **Statistical analysis**

All statistical analyses will be performed using R software (R_Core_Team, 2008).

8.5.1.2.1  **Descriptive analysis at baseline**

To assess comparability between groups, descriptive statistics for baseline measurements including demographic variables, ODI scores and work-related psychosocial factors (13 constructs) will be presented.

8.5.1.2.2  **Primary analysis**

Intention-to-treat analysis will be performed to estimate the effect of feedback provision on postural pattern. The ANCOVA will be conducted for between-group comparisons on the differences of postural pattern scores, using postural pattern baseline scores, work-related psychosocial factors and ODI scores as covariants.

8.5.1.3  **Timetable for the SAFE trial**

**October 2012:** Grant Application: Emerging Researcher First Grants – Health Research Council of New Zealand.

**January 2013:** Research ethics submission.

**June 2013:** Emerging Researcher First Grants awarded: NZ$ 150,000 – Health Research Council of New Zealand.

**July 2013:** Recruitment initiates.

**January 2015:** End of recruitment period.
February 2015: Data analysis and preliminary report.

April 2015: Submission of research report in an appropriate journal.

8.5.1.4 Discussion

The SAFE trial is designed to test the effectiveness of the Spineangel® to change postural behaviour at the workplace. The rationale and design of this trial is based on the research reported in previous chapters of this thesis. It is expected the SAFE trial will provide relevant information about the usefulness of the Spineangel® as a postural feedback device to decrease cumulative postural spinal load.

8.6 Final considerations

This thesis has presented evidence to add to the current body of knowledge on the use of a postural monitor and EF device as rehabilitation or ergonomic tool. The studies reported in this thesis are essential steps towards the evaluation phase and can be classified as development and feasibility studies, according to the MRC guidelines for researchers assessing complex interventions (MRC, 2008).

Findings from the systematic review (Chapter 2) clearly show there is a need for a consensus on outcome measures for assessing posture as risk factor for NSLBP as well as improving the way work-related posture is measured. The present thesis has indicated gaps of the literature on the use of EF as a rehabilitation tool. A rationale for EF provision is described and future research could use such rationale when assessing EF as part of the intervention programme to patients with NSLBP. The Spineangel® was tested under a variety of functional activities in a laboratory setting and in the field. Results suggest the device is reliable and valid for monitoring lumbo-pelvic gross movements. Findings from the feasibility RCT identified positive and negative aspects of the trial design. An improved protocol for a future RCT assessing the effectiveness of the Spineangel® as an EF tool to change posture at work was presented. Conducting this final RCT would allow advancing on the stages described at the MRC framework, leading to research being conducted at the ‘evaluation’ phase.
Appendices
Appendix A

An audit of recent injuries incurred by healthcare workers in Otago

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ABSTRACT

Aim: To identify musculoskeletal injuries incurred by a cohort of healthcare workers employed by Presbyterian Support Otago (PSO) from 2008 to 2010.

Methods: Health and safety incident report data of PSO were accessed and identifying features were removed from raw data. Injuries were classified according to worksites, anatomical location of injury, incident type and cause, and frequencies of these were established.

Results: Most of the 451 musculoskeletal injuries were reported in the hospital (37.9%), community (21.3%) and rest home care facilities (16%). An average of 12.5 injuries occurred per month. Manual handling (patient lifting, transfers and repositioning) was the most prevalent mechanism of injury in the hospital. Lumbar spine was the primary site of injury accounting for 22% of the total injuries. Sprains, strains and tears were the most common self-reported diagnosis (51%). Community-acquired injuries were more likely to be accidental. Over half the injuries in dementia care facilities were due to purposeful patient-caused incidents, a ten-fold increase since 2008.

Conclusions: The results of this study suggest future interventions to reduce injury risk to healthcare workers should be focused around preventing lumbar spine injuries, accidents in the community, and providing refresher courses on manual handling in hospitals and patient behaviour in dementia care.
INTRODUCTION

The physical nature and unpredictability of job tasks in healthcare predisposes workers in this field to an increased risk of injury. Among the most risky jobs in the United States of America (USA) is that of a Nurse Aide (Castle et al. 2009). The US Bureau of Labour Statistics (BLS) supports this finding, citing the injury rate for Nurse Aides as second among all industries (Trinkoff et al. 2005). Within New Zealand (NZ) provisional statistics showed 213,000 claims were made for all work-related injuries in 2009 (Statistics New Zealand 2010). This correlates to 112 claims per 1,000 full time equivalent employees (FTEs), and as an industry, Health and Community services recorded 55 claims per 1,000 FTEs in 2007 (NZ Department of Labour 2007).

New Zealand has an escalating shortage of healthcare workers, with the demand for labour expected to outstrip supply within the next year according to the Ministry of Health (MoH) projections (NZIER 2004). MoH predicts that the population aged 65 and over will grow by 215,000 between 2011 and 2021, and by 250,000 between 2021 and 2031. By the year 2051, a predicted 1.18 million people in NZ will be 65 or over. This corresponds to an increase of 165% since 1999, and such a trend presents further burdens for the country (NZIER 2004). Due to the ageing population it is predicted that the demand for healthcare labour will grow from 40% to 69% by 2021 (NZIER 2004). The MOH has thus highlighted the importance of providing sufficient healthcare services to meet this increasing demand, compounded by those within the healthcare sector workforce age and retire also (NZIER 2004). In order to recruit and retain workers in these physically and mentally demanding occupations, trends for work-related injuries incurred and strategies to reduce these need to be established.

The work-related injuries in this study were recorded by Presbyterian Support Otago (PSO), one of the largest employers in the Otago region of the South Island. PSO is a non-profit organisation that provides rest home care for the elderly in Otago at community, hospital, rest home, dementia and psychogeriatric levels. It has over 1,250 full- and part-time employees and around 600 volunteers. The aim of this research is to identify the musculoskeletal injuries reported by a cohort of healthcare workers in this organisation. The findings will add towards the
understanding of how and why these workers are injured, and provide information towards future interventions to reduce the risk of such injuries.

**METHODS**

Employers in NZ are legally required to record all work-related accidents or incidents that harmed or might have harmed any person at work in an accident register. PSO requires its employees to file Health and Safety Incident reports for such incidents. The subjects of this audit were the healthcare workers employed by PSO who filed a report for sustaining musculoskeletal injuries between 2008 and 2010. The research was approved by the Lower South Regional Ethics Committee (Ref. no. LRS/11/EXP/006).

Retrospective data of self-reported incidences were provided by the PSO. To be included in this study, the incident had to provide the date, type and mechanism of injury or causative factor. The anatomical location of the injury had to relate to the reported mechanism of injury. Non-musculoskeletal injuries such as stress and needle stick injuries were excluded. Duplicate data reporting the same incident were removed. Five reviewers applied the above criteria, reducing the initial cohort of 482 incidents to 451 incidents (Figure 1).

**Data Collection and Analysis**

Identifying features of age, occupation and ethnicity were removed from raw Health and Safety Incident report data and classified into injury frequencies according to worksites, anatomical location of injury, incident type (diagnosis) and cause (mechanism of injury). No identifying participant characteristics were known for this cohort other than for sex. As the ‘diagnosis’ was self-reported according to the information in the Health and Safety Incident reports, these were cross-referenced with Accident Compensation Corporation (ACC) Read Codes to ensure consistency. Remaining categories were classified by consensus of five reviewers.

Data was analysed using IBM Statistical Package for the Social Sciences (SPSS) Version 18. Musculoskeletal injury frequencies were calculated for each year from 2008 to 2010, according to site of injury, diagnosis and mechanism of injury for each worksite.
RESULTS

Characteristics of Participants

At the time of the audit, 95% of the PSO employees were females, with an average age of 47. New Zealand European staff account for 409 of PSO’s workforce, the remainder comprise of 24 Māori, 19 Indian, 5 Samoan, 5 Tongan and 2 Cook Island Māori (133 employees listed ethnicity as ‘Other’ and 266 did not wish to provide this information). A total of 451 incident reports resulting in musculoskeletal injuries were filed during 2008 and 2010.

Frequency of injuries according to worksite

Overall, the hospital was the most frequent worksite for employees to acquire an injury, accounting for 37.9% of all injuries (n = 171) (Figure 2). There were 96 injuries to healthcare workers in the community (21.3%), increasing from 23 incidents in 2008, 31 in 2009 to 42 in 2010. Reports from rest home and dementia care facilities accounted for 16.4% (n = 74) and 11.1% (n = 50) of total injuries respectively.

Mechanism of injury according to worksite

Patient handling, including repositioning, lifting and transfers, was the most prevalent mechanism causing injury in the hospital contributing to 26.3% of the reported incidents (n = 45) from this site (Table 1). In community care, 19 injuries (19.8%) occurred independently of others, followed by slips, trips and falls (STF, n = 17, 17.7%). STF increased 6-fold since 2008, from 4 to 24 (n = 45 total). 24% of all STF’s resulted in injuries to multiple injury sites.

While injuries in the rest home care sector occurred via widespread mechanisms of injury, over half of the injuries occurring in dementia care facilities were reported to be due to purposeful patient-caused injury (n = 26, 52%, Table 1). There was a 10-fold increase in purposeful patient-caused injuries from 2 in 2008 to 20 in 2010. In the kitchen, nearly two-thirds (60%) of incidents were reported as accidents incurred independently of others (n = 10, 34%) or STF (n = 7, 24%).
**Self-reported diagnosis of injury according to worksite**

An average of 12.5 injuries were reported per month, with sprains, strains and tears (SST) the most common self-reported diagnosis (51.1%, Table 2). SST was the most common diagnosis for all top five worksites, except for those reported from the dementia care facilities where it was second only to ‘not specified’. Contusions and abrasions contributed to 9.5% of diagnoses. A further 4.9% of diagnoses were classified as open wounds, lacerations and cuts, frequently reported in the kitchen (n = 8/22). ‘Not specified’ was listed as a diagnosis in 132 incident reports.

**Body location of reported injuries according to worksite**

Lumbar spine injuries were the most frequently reported injuries (Table 3), accounted for 98 of the total 451 injuries (21.7%), or an average of 2.7 per month. However, injuries to multiple areas of the lower limb were also commonly observed (overall n = 66, 14.6%). In dementia care facilities purposeful patient-caused injuries usually occurred to the head/face, multiple lower limb or multiple injury sites, which were most likely to be ‘not specified’ or the cause of sprain, strains and tears. Multiple lower limb injury sites were the most reported injury site to workers in the kitchen (n = 13, 44.8%).

**Key trends – lumbar spine**

The lumbar spine was the primary site of injury for three worksites; hospital (n = 44, 44.9% of the lumbar spine injuries), rest home (n = 17, 17.3%), and in community care (n = 23, 23.5%). Aside from 35 cases of lack of documentation, the top mechanisms of injury in the lumbar spine were patient lifting (12%), lifting objects (8%), accidental patient-caused injury (7%), bending (6%) and twisting (5%). The most common diagnosis of the lumbar spine injury was sprains, strains and tears (n = 79, 80.6%), but 18 reports did not specify a diagnosis. Lumbar spine injuries decreased over time from 37 in 2008, 35 in 2009, to 26 in 2010. Correspondingly, the main cause of lumbar spine injury (bar lack of documentation), patient lifting also decreased from 15 in 2009 to two in 2010.
**Key trends – sprains, strains and tears**

SST was reported as the diagnosis for over half of all 451 incidents (51%, Table 2) and most common in the lumbar spine (34%). Other injury sites for SST were multiple sites of the lower limb (13%) and upper limb (8%), shoulder (7%) and thoracic spine (5%). The main mechanisms of injury were patient lifting and repositioning at 17%, the most common mechanism accounting for one fifth of all causes of injury in the hospital. Self-reported SST as a diagnosis decreased by 46% between 2008 and 2010 (n = 95, 92, 44 respectively). As previously mentioned, the main cause of SST (patient lifting) also decreased - particularly over the last two years, from 15 in 2009 to two in 2010.

**Key trend – lack of documentation/not specified**

Mechanism of injury was not correctly documented in 120 incident reports, this correlated to 26.6% of the total incident reports. The hospital accounted for 50% of reports lacking sufficient information, followed by the community (22%), and rest home care facilities (14%).

Diagnosis of injury was ‘not specified’ in 29.3% (n = 132) of the total incident reports. 34.1% (n = 45) of these occurred in the hospital, 20.5% (n = 27) in dementia care facilities, 13.6% (n = 18) in the community, and 13.6% (n = 18) in rest home care facilities. There was an increasing trend towards not specifying diagnosis, with only 19 in 2008, 24 in 2009 and 89 in 2010. In addition 25 reports did not specify the site of the injury. Dementia care facilities and the hospital each accounted for eight of these reports, with four lacking information in the community.
DISCUSSION

This study aimed to specify how and why healthcare workers in Otago reported to be injured, and furthermore provide specific information as to the areas that may need to be targeted for reducing injuries in this population.

_Lumbar spine injury_

One of the main findings of this study revealed the lumbar spine as the most commonly reported injured body location for the healthcare workers. A literature review on work-related back pain in nurses reported research has confirmed the risk of lumbar spine injury with nursing for over 20 twenty years, finding a yearly prevalence of lumbar spine injury of 40-50% and a lifetime prevalence of 35-80% (Hignett 1996). Another study reported the prevalence of low back pain among nurses increased from entry to end of nurse school. At entry level, prevalence was found to be equivalent to 31% and it increased to 72% by the end of nurse school. After 5 years of professional practice, the prevalence reached 82% (Videman et al 2005).

Injuries to the lumbar spine have been commonly found to be associated with patient contact (Molumphy et al 1985) and flexed postures (Van Nieuwenhuyse et al 2006). 83% of physical therapists reported lumbar spine injury while treating or handling a patient (Molumphy et al 1985). One study found that physical therapists that transferred patients were 2.4 times more likely to develop lower back pain than those who did not (Campo et al 2008). In addition, Collins et al (2004) reported lifting patients in the healthcare setting as a leading cause of injury. In another study, 20.9% of workers were injured whilst carrying out manual therapy techniques and 13.8% whilst transferring patients (West and Gardner 2001). In this current study 12% of lumbar spine injuries were due to patient lifting. It is suggested in the literature that nurses and other health care workers seem to be exposed to stressful postures during the work shift (Freitag et al 2007, Kumar 1990, Ribeiro et al 2011). Nieuwenhuyse et al (Van Nieuwenhuyse et al 2006) reported an increased risk (RR = 2.2, 95% confidence interval: 1.2 to 4.1) of low back pain for healthcare or distribution workers who spent more than 2 hours in bent or twisted postures. Similarly, Videman et al (Videman et al 2005) found nurse workers had an increased risk (odds ratio: 6.2, 95% confidence
interval: 1.7 to 23) of developing low back pain if they were exposed to twisted or bent postures at work. It is encouraging that the number of reported low back injuries decreased over the three years. However, a recommendation for reducing this injury risk further is to review manual handling and address risk factors for lumbar spine injury.

Injury according to worksite

In the current study, hospitals were the most common worksite for injuries to occur, contributing towards 37.9% of the reported injuries. It is well-established that work stresses can lead to increased risks of mental and physical health problems (Hägglund et al 2010, Salminen et al 2003). Predictors of injury in the hospital setting include interpersonal relationships and independence of work (Salminen et al 2003). Nonetheless, financial and personal life events have also been shown to influence stress levels (Hägglund et al 2010, Salminen et al 2003). It is accepted that there is an interaction between psychological and physical risk factors, even though, the way these factors interact is unclear (Vandergrift et al 2011). Work-related psychosocial factors seem to be associated with low back pain only when workers were also exposed to high physical demands (Vandergrift et al 2011). In terms of work stresses, it was found that ergonomic and physical demands were two factors greatly responsible for an increased risk of occupational injuries (Salminen et al 2003). The same study also identified hospital workers over the age of 50 as 31% more likely to be involved in work-related injuries, compared to those 31-50 years of age (Salminen et al 2003). Further, repetitive jobs (Salminen et al 2003) and long working hours (Dembe et al 2009) have been identified as risk factors for work-related injuries in hospital workers. This can be attributed to increased fatigue and stress levels due to the accumulation of working hours over the week, rather than the pattern of hours worked (Dembe et al 2009).

The community care setting had the second highest reported incidence of injuries, with an increase of reports from 23 in 2008 to 42 in 2010. Community workers visit various centres and private homes, completing various tasks that include helping clients getting washed and dressed, wound care, and ensuring the general well-being. In Otago, they travel mainly by car or by walking. Risk assessments for all workplaces are undertaken regularly by PSO. The importance
of these is highlighted by the finding that 36 (37.5%) of the reported injuries from these workers were indicated as being due to slips, tripping, or accidents occurring independently of others. The reason for the increased number of injuries is unclear, and future studies could consider various factors, such as increased confidence to report injuries, possible change or increase in community carers or an actual increase in injuries per worker. A multi-factorial approach, considering various personal and work-related factors, may thus be needed to determine cause of injuries across the work sites. In particular, further research into the contributing factors to overall injuries in the hospital setting and accidental injuries incurred in the community, as in this study, may yield useful information as to whether these can be minimised.

**Purposeful patient-caused injury**

This audit found a ten-fold increase in patient-caused injury over the three year period. It is well known that violence is experienced by a range of health care workers, including nurses, doctors and physiotherapists (Ferns 2007, Stubbs and Dickens 2009, Winstanley and Whittington 2004). The risk of violence for those working in the healthcare sector has been reported as being approximately 17 times higher than at any other workplace (Payne and Appel 2007). This includes verbal and physical abuse, such as being hit, kicked or beaten by patients (Payne and Appel 2007). Workplace factors that have been suggested as influencing violence include working alone or in a small group, working late at night or early in the morning, working in community-based setting and working with unstable patients (Payne and Appel 2007). Winstanley and Whittington (2004) indicated that reported incidence of violence by patients is most likely to be underreported. Further, there has been an association shown between staff burnout and reported resident aggression (Payne and Appel 2007). It needs to be kept in mind that the apparent increase in incidences may be based on an increased willingness of health care workers to report these, rather than an increase in the actual frequency of such incidences. However, based on the increased reported number of these incidences found in this study, it may be important to consider strategies to decrease the number and to support the staff with coping mechanisms. Therefore courses on patient behaviour and violence in dementia care facilities may be beneficial in reducing the injury rates in NZ healthcare workers.
**Limitations**

A major limitation of this study is the tendency of healthcare workers to under-report work-related injuries (Menzel 2008). A study in Canada estimated that 40-50% of work-related injuries went unreported to workers compensation boards (Alamgir et al 2009). Failing to document work-related injuries has been a reoccurring practice (Alamgir et al 2009). The reason for nurses in an emergency department not reporting assaults stemmed from the consensus that assaults were part of the job, and reporting them would not change the occurrence rate (Azaroff et al 2002). Other reasons proposed for under-reporting incidents were inadequate systems to collect records, lack of communication regarding the incident, and perceived lack of time due to increased workload and demands (Azaroff et al 2002). Reasons for not reporting work-related injuries include fear of missing out on overtime or promotional opportunities, risking disciplinary action, stigmatisation or job loss (Azaroff et al 2002). It was also suggested in the same study reporting such injuries may mean missing out on future temporary or bureau employment, as injuries may imply that a worker is incompetent or unreliable (Azaroff et al 2002).

A further limitation is the lack of documentation on incident reports. Over one quarter of forms did not specify mechanism of injury, or provide adequate information on diagnosis. There was a five-fold increase in lack of documentation relating to diagnosis, highlighting hospital workers as more likely to file incomplete forms. Lack of documentation was the main mechanism and diagnosis of injury across worksites, therefore trends concluded from this study could possibly be confounded by lack of information.
CONCLUSION

The results of this study suggest future interventions to reduce injury risk to healthcare workers should be focused around preventing lumbar spine injuries, accidents in the community, and providing refresher courses on manual handling in hospitals and patient behaviour in dementia care.

Acknowledgements

We would like to acknowledge the support and assistance of Presbyterian Support Otago and its employees, in particular Mary Phillips.

References – Appendix G)


All health and safety incidents reported by PSO employees (2008-2010), n = 482

Preliminary exclusion:
Date not specified, n = 2

Injury not specified, n = 2

Incident with no reported injury, n = 2

Repeats identified, n = 14

Employees who suffered an injury (2008-2010), n = 462

Further exclusion criteria:
Needlestick injury, n = 8

Mechanism of injury did not match injury, n = 3

Final study cohort, n = 451

Figure 1. Flowchart of procedure of including and excluding data
Figure 2. Distribution of work-related injuries across PSO worksites between 2008 and 2010
Table 1. Reported mechanism of injury of 451 incidences in the different work sites.

<table>
<thead>
<tr>
<th>Mechanism of Injury</th>
<th>Hospital</th>
<th>Rest Home</th>
<th>Dementia Ward</th>
<th>Community Care</th>
<th>Laundry</th>
<th>Kitchen</th>
<th>Housekeeping, administration</th>
<th>Total</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient handling*</td>
<td>45</td>
<td>15</td>
<td>6</td>
<td>5</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>72</td>
<td>16.0</td>
</tr>
<tr>
<td>Preventing or attempting to prevent patient falls</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>2.4</td>
</tr>
<tr>
<td>Lifting objects</td>
<td>4</td>
<td>2</td>
<td>0</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>19</td>
<td>4.2</td>
</tr>
<tr>
<td>Moving or pushing objects</td>
<td>8</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>2.4</td>
</tr>
<tr>
<td>Bending</td>
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<td>4</td>
<td>0</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>10</td>
<td>2.2</td>
</tr>
<tr>
<td>Reaching</td>
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<td>0</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>9</td>
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<tr>
<td>Twisting</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>6</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>13</td>
<td>2.9</td>
</tr>
<tr>
<td>Slips, trips, falls</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>17</td>
<td>0</td>
<td>7</td>
<td>3</td>
<td>45</td>
<td>10.0</td>
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<tr>
<td>Accidents occurred independently of others</td>
<td>13</td>
<td>3</td>
<td>1</td>
<td>19</td>
<td>0</td>
<td>10</td>
<td>3</td>
<td>49</td>
<td>10.9</td>
</tr>
<tr>
<td>Jammed appendages</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>8</td>
<td>1.8</td>
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<td>Dropping something causing injury</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>0.7</td>
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<tr>
<td>Faulty equipment</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>11</td>
<td>2.4</td>
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<tr>
<td>Burns</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
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<tr>
<td>Insidious onset</td>
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<td>2</td>
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<td>0</td>
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<td>7</td>
<td>1.6</td>
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<tr>
<td>Purposeful patient-caused injury</td>
<td>8</td>
<td>3</td>
<td>26</td>
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<td>0</td>
<td>0</td>
<td>37</td>
<td>8.2</td>
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<tr>
<td>Accidental patient-caused injury</td>
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<td>9</td>
<td>1</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>23</td>
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<tr>
<td>Vehicle accident</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0.4</td>
</tr>
<tr>
<td>Lack of documentation</td>
<td>60</td>
<td>17</td>
<td>4</td>
<td>26</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>120</td>
<td>26.6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>171</strong></td>
<td><strong>74</strong></td>
<td><strong>50</strong></td>
<td><strong>96</strong></td>
<td><strong>12</strong></td>
<td><strong>29</strong></td>
<td><strong>10</strong></td>
<td><strong>451</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

* Patient handling includes repositioning, lifting and transfers
### Table 2. Reported diagnosis of injuries in the different work sites

<table>
<thead>
<tr>
<th>Condition</th>
<th>Hospital</th>
<th>Rest Home</th>
<th>Dementia Ward</th>
<th>Community Care</th>
<th>Laundry</th>
<th>Kitchen</th>
<th>Housekeeping, Administration</th>
<th>Total</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sprain, strain, tear</td>
<td>102</td>
<td>44</td>
<td>15</td>
<td>50</td>
<td>7</td>
<td>9</td>
<td>4</td>
<td>231</td>
<td>51.2</td>
</tr>
<tr>
<td>Contusion and abrasions</td>
<td>9</td>
<td>9</td>
<td>6</td>
<td>10</td>
<td>1</td>
<td>5</td>
<td>3</td>
<td>43</td>
<td>9.5</td>
</tr>
<tr>
<td>Open wound, laceration, cut</td>
<td>6</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>8</td>
<td>2</td>
<td>22</td>
<td>4.9</td>
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<td>Gradual onset</td>
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<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>0.7</td>
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<td>Burn</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
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<td>Fracture</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td>Concussion, head injury</td>
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<td>0</td>
<td>1</td>
<td>0</td>
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<td>0</td>
<td>4</td>
<td>0.9</td>
</tr>
<tr>
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<td>18</td>
<td>27</td>
<td>26</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td>132</td>
<td>29.3</td>
</tr>
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<td>Multiple injuries</td>
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<td>0</td>
<td>7</td>
<td>0</td>
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<td>0</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>171</strong></td>
<td><strong>74</strong></td>
<td><strong>50</strong></td>
<td><strong>96</strong></td>
<td><strong>12</strong></td>
<td><strong>29</strong></td>
<td><strong>19</strong></td>
<td><strong>451</strong></td>
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</table>
Table 3. Frequency of reported injuries to different body locations per work site

<table>
<thead>
<tr>
<th>Work site</th>
<th>Hospital Care</th>
<th>Rest Home</th>
<th>Dementia Ward</th>
<th>Community Care</th>
<th>Laundry</th>
<th>Kitchen</th>
<th>Housekeeping, Administration</th>
<th>Total</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Head, face</td>
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<td>4</td>
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<td>3</td>
<td>22</td>
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<tr>
<td>Neck, cervical spine</td>
<td>5</td>
<td>4</td>
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<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
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<td>Lumbar spine</td>
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<td>17</td>
<td>6</td>
<td>23</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>98</td>
<td>21.7</td>
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<tr>
<td>Sternum, ribs, abdomen</td>
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<td>0</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>1.3</td>
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<td>Shoulder</td>
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<td>4</td>
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<td>0</td>
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<td>Upper arm, elbow, forearm, wrist</td>
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<td>1</td>
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<td>2</td>
<td>16</td>
<td>3.5</td>
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<td>Hand, fingers, thumb</td>
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<td>3</td>
<td>2</td>
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<td>1</td>
<td>2</td>
<td>1</td>
<td>16</td>
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<td>Lower leg, Achilles tendon</td>
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<td>2</td>
<td>0</td>
<td>0</td>
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<td>0</td>
<td>3</td>
<td>0.7</td>
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<td>Ankle</td>
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<td>4</td>
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<td>0</td>
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<td>0</td>
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<td>0</td>
<td>0</td>
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<td>Multiple injuries to upper limb</td>
<td>8</td>
<td>7</td>
<td>3</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>25</td>
<td>5.5</td>
</tr>
<tr>
<td>Multiple injuries to lower limb</td>
<td>20</td>
<td>12</td>
<td>5</td>
<td>9</td>
<td>3</td>
<td>13</td>
<td>4</td>
<td>66</td>
<td>14.6</td>
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<tr>
<td>Multiple injuries to trunk</td>
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<td>6</td>
<td>0</td>
<td>9</td>
<td>1</td>
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<td>Multiple injury sites</td>
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</tbody>
</table>
Appendix B

Ethics approval

Dr S Milosavljevic
School of Physiotherapy

30 March 2010

Dear Dr Milosavljevic,

I am again writing to you concerning your proposal entitled ‘The effectiveness of the Spineangel® as a real-time biofeedback device for modifying trunk posture during daily activity’, Ethics Committee reference number 10/035.

Thank you for sending me an amended application indicating that there was no funding from Spineangel, recruitment would be done via All Departments email and an Information Sheet amended to include more information regarding Study 2, that there will be a follow up and a self-administered questionnaire.

On the basis of this response, I am pleased to confirm that the proposal now has full ethical approval to proceed.

Approval is for up to three years. If this project has not been completed within three years from the date of this letter, re-approval must be requested. If the nature, consent, location, procedures or personnel of your approved application change, please advise me in writing.

Yours sincerely,

[Signature]

Mr Gary Witte
Manager, Academic Committees
Tel: 479 0235
Email: gary.witte@otago.ac.nz

o.c. Professor G D Baxter  Dean School of Physiotherapy
Research Consultation with Māori

Ngāi Tahu Research Consultation Committee
Te Komiti Rakahau ki Kāi Tahu

17/11/2009 - 24
Tuesday, 17 November 2009

Dr Milosavljevic
School of Physiotherapy
Dunedin

Tēnā koe Dr Milosavljevic

Title: The effectiveness of the Spineangel as a real-time biofeedback device for modifying trunk posture during daily activity.

The Ngāi Tahu Research Consultation Committee (The Committee) met on Tuesday, 17 November 2009 to discuss your research proposal.

By way of introduction, this response from the Committee is provided as part of the Memorandum of Understanding between Te Rūnanga o Ngāi Tahu and the University. In the statement of principles of the memorandum, it states “Ngāi Tahu acknowledges that the consultation process outlined in this policy provides no power of veto by Ngāi Tahu to research undertaken at the University of Otago”. As such, this response is not “approval” or “mandate” for the research, rather it is a mandated response from a Ngāi Tahu appointed committee. This process is part of a number of requirements for researchers to undertake and does not cover other issues relating to ethics, including methodology; they are separate requirements with other committees, for example the Human Ethics Committee, etc.

The Committee considers the research to be of importance to Māori health.

As this study involves human participants, the Committee strongly encourages that ethnicity data be collected as part of the research project. That is the questions on self-identified ethnicity and descent, these questions are contained in the 2006 census.

The Committee notes the researchers have identified that an important number of Māori are engaged in work that may effect lower back pain, and the Committee suggests dissemination of the research findings to relevant Māori health organisations regarding this study, including Tāora Tinana, Māori Physiotherapists within the New Zealand Society of Physiotherapists.

We wish you every success in your research and the Committee also requests a copy of the research findings.

The recommendations and suggestions above are provided on your proposal submitted through the consultation website process. These recommendations and suggestions do not necessarily relate to ethical issues with the research, including methodology. Other committees may also provide feedback in these areas.

The Ngāi Tahu Research Consultation Committee has membership from:

Te Rūnanga o Ōhau Incorporated
Kāti Huirapa Runanga ki Pokotakawa
Te Rūnanga o Moeraki
The effectiveness of the Spineangel® as a real-time biofeedback device for modifying trunk posture during daily activity

INFORMATION SHEET FOR PARTICIPANTS – Study 1

Thank you for showing an interest in this project. Please read this information sheet carefully before deciding whether or not to participate. If you decide to participate we thank you. If you decide not to take part there will be no disadvantage to you of any kind and we thank you for considering our request.

What is the Aim of the Project?

This project is being undertaken as part of the requirements for PhD study at the University of Otago. As work posture is related to the development of low back pain, investigating posture will help us to understand how this occurs. A postural monitoring device will be fixed to your belt and will monitor spinal movement and posture during your work day. This information will help us to devise strategies to improve working posture.

What Type of Participants are being sought?

We are searching for students and/or workers, in good health, either male or female, aged 18 to 65 years, with or without a history of back pain, who are undertaking regular daily activities (such as study, sports activities and work related tasks). However, students and/or workers, who are unable to undertake regular daily activities due to back pain, will not be able to participate in the project because, in the opinion of the researchers and the University of Otago Human Ethics Committee, it may involve an unacceptable risk to them.

What will Participants be Asked to Do?

Should you agree to take part in this project, you will be asked to perform five repetitions of six different trunk movements: forward bending with fingers to the knees, forward bending with fingers to the middle leg, full trunk flexion, anterior and posterior pelvic rotation while sitting, squatting as well as lifting an empty cardboard box from the floor.

In order to record spinal movements, you will be asked to wear trousers/pants/jeans that allow you to wear a belt. The Spineangel® postural monitoring device will then be attached to your belt, in a manner recommended by the manufacturer.

The protocol will expose you to neither potential harm nor discomfort. Please be aware that you may decide not to take part in the project without any disadvantage to yourself of any kind.

Can Participants Change their Mind and Withdraw from the Project?

You may withdraw from participation in the project at any time and without any disadvantage to yourself of any kind.
What Data or Information will be Collected and What Use will be Made of it?

The only people who will have access to the raw data are the researchers involved in this project. The results of the project may be published and will be available in the University of Otago Library (Dunedin, New Zealand) but every attempt will be made to preserve your anonymity. You are most welcome to request a copy of the results of the project should you wish.

The data collected will be securely stored in such a way that only those mentioned below will be able to gain access to it. At the end of the project any personal information will be destroyed immediately except that, as required by the University's research policy, any raw data on which the results of the project depend will be retained in secure storage for five years, after which it will be destroyed.

What if Participants have any Questions?

If you have any questions about our project, either now or in the future, please feel free to contact either:

Mr Daniel Ribeiro  
School of Physiotherapy  
Phone: 03 479 5422  

or  

Dr Stephan Milosavljevic  
School of Physiotherapy  
Phone: 03 479 7193  

This study has been approved by the University of Otago Human Ethics Committee. If you have any concerns about the ethical conduct of the research you may contact the Committee through the Human Ethics Committee Administrator (ph 03 479 8256). Any issues you raise will be treated in confidence and investigated and you will be informed of the outcome.
The effectiveness of the Spineangel® as a real-time biofeedback device for modifying trunk posture during daily activity

Thank you for showing an interest in this project. Please read this information sheet carefully before deciding whether or not to participate. If you decide to participate we thank you. If you decide not to take part there will be no disadvantage to you of any kind and we thank you for considering our request.

What is the Aim of the Project?

This project is being undertaken as part of the requirements for PhD study at the University of Otago. As work posture is related to the development of low back pain, investigating posture will help us to understand how this occurs. A postural monitoring device will be fixed to your belt and will monitor spinal movement and posture during your work day. This information will help us to devise strategies to improve working posture.

What Type of Participants are being sought?

We are searching for health care workers, in good health, either male or female, aged 18 to 65 years, with or without a history of back pain, who are undertaking regular daily activities (such as study, sports activities and work related tasks). However workers, who are unable to undertake regular daily activities due to back pain, will not be able to participate in the project because, in the opinion of the researchers and the University of Otago Human Ethics Committee, it may involve an unacceptable risk to them:

What will Participants be Asked to Do?

Should you agree to take part in this project, you will be asked to complete a self administered questionnaire and use the Spineangel® which is small device (size similar to a mobile phone), fixed on your belt for one week, to allow baseline postural data collection. The intervention period will last for 4 weeks and at this stage you will be allocated to one of three groups who will each receive a different form of postural advice as well as continued monitoring from the Spineangel®. On the subsequent week, there will be one follow-up measurement week and after three months from the intervention period, another follow-up measurement week. During the follow-up period, you will be asked to use the Spineangel® attached to your belt. In total, you will be involved in this study for 7 weeks.

There is no potential harm or discomfort in taking part of this study. We only request for you to use a belt and trousers, to allow attachment of the Spineangel®.

Please be aware that you may decide not to take part in the project without any disadvantage to yourself of any kind.
Can Participants Change their Mind and Withdraw from the Project?

You may withdraw from participation in the project at any time and without any disadvantage to yourself of any kind.

What Data or Information will be Collected and What Use will be Made of it?

The only people who will have access to the raw data are the researchers involved in this project. The results of the project may be published and will be available in the University of Otago Library (Dunedin, New Zealand) but every attempt will be made to preserve your anonymity. You are most welcome to request a copy of the results of the project should you wish.

The data collected will be securely stored in such a way that only those mentioned below will be able to gain access to it. At the end of the project any personal information will be destroyed immediately except that, as required by the University’s research policy, any raw data on which the results of the project depend will be retained in secure storage for five years, after which it will be destroyed.

What if Participants have any Questions?

If you have any questions about our project, either now or in the future, please feel free to contact either:

Mr Daniel Ribeiro  
School of Physiotherapy  
Phone: 03 479 5422

Dr Stephan Milosavljevic  
School of Physiotherapy  
Phone: 03 479 7193

This study has been approved by the University of Otago Human Ethics Committee. If you have any concerns about the ethical conduct of the research you may contact the Committee through the Human Ethics Committee Administrator (ph 03 479 8256). Any issues you raise will be treated in confidence and investigated and you will be informed of the outcome.
Consent form for participants

The effectiveness of the Spineangel® as a real-time biofeedback device for modifying trunk posture during daily activity

I have read the Information Sheet concerning this project and understand what it is about. All my questions have been answered to my satisfaction. I understand that I am free to request further information at any stage.

I know that:

1. My participation in the project is entirely voluntary;
2. I am free to withdraw from the project at any time without any disadvantage;
3. Personal identifying information will be anonymised or destroyed at the conclusion of the project but any raw data on which the results of the project depend will be retained in secure storage for five years, after which they will be destroyed;
4. I understand that my participation is voluntary and no payment or reward is offered;
5. The results of the project may be published and will be available in the University of Otago Library (Dunedin, New Zealand) but every attempt will be made to preserve my anonymity.

I agree to take part in this project.

.............................................................
(Signature of participant) ........................................
.............................................................
(Date)

This study has been approved by the University of Otago Human Ethics Committee. If you have any concerns about the ethical conduct of the research you may contact the Committee through the Human Ethics Committee Administrator (ph 03 479 8256). Any issues you raise will be treated in confidence and investigated and you will be informed of the outcome.
Appendix C

First Questionnaire (used at the beginning of data collection)

SECTION 1 – Personal and general information

First name: _________________________ Surname: ____________________________

Job Address: ______________________________________________________________

Occupation _________________ Height: _______ Weight:________

Date of birth: ______/_____/19______ Sex:       M _______ F ______

Which of the following ethnic groups do you belong to or identify with?

| NZ Maori | NZ European | Other European | Samoan | Tongan | Niuean | Asian | Other? (describe) ................

1. How many years have you spent working in the present job?

   Years | 

2. How many days a week do you work on this job? Days | 

3. Do you have more than one job?

   YES | NO | 

4. How many hours per-week are spent at this other job?

5. Do you spend most of your time working in a sitting posture?

   YES | NO | 

6. Does your work involve frequent trunk bending postures?

   YES | NO | 

7. Do you smoke? YES | NO |
SECTION 2 – Oswestry low back pain disability questionnaire

This questionnaire has been designed to give us information as to how your back or leg pain is affecting your ability to manage in everyday life. Please answer by checking one box in each section for the statement which best applies to you. We realise you may consider that two or more statements in any one section apply but please just shade out the spot that indicates the statement which most clearly describes your problem.

Part 1 - Pain intensity

☐ I have no pain at the moment.

☐ The pain is very mild at the moment.

☐ The pain is moderate at the moment.

☐ The pain is fairly severe at the moment.

☐ The pain is very severe at the moment.

☐ The pain is the worst imaginable at the moment.

Part 2 - Personal care (washing, dressing, etc.)

☐ I can look after myself normally without causing extra pain.

☐ I can look after myself normally but it is very painful.

☐ It is painful to look after myself and I am slow and careful.

☐ I need some help but manage most of my personal care.

☐ I need help every day in most aspects of self-care.

☐ I do not get dressed, wash with difficulty and stay in bed.

Part 3 - Lifting

☐ I can lift heavy weights without extra pain.

☐ I can lift heavy weights but it gives extra pain.
Pain prevents me from lifting heavy weights off the floor but I can manage if they are conveniently positioned, e.g. on a table.

Pain prevents me from lifting heavy weights but I can manage light to medium weights if they are conveniently positioned.

I can lift only very light weights.

I cannot lift or carry anything at all.

Part 4 - Walking

Pain does not prevent me walking any distance.

Pain prevents me walking more than 2 kilometers.

Pain prevents me walking more than 1 kilometer.

Pain prevents me walking more than 500 metres.

I can only walk using a stick or crutches.

I am in bed most of the time and have to crawl to the toilet.

Part 5 - Sitting

I can sit in any chair as long as I like.

I can sit in my favourite chair as long as I like.

Pain prevents me from sitting for more than 1 hour.

Pain prevents me from sitting for more than 30 minutes.

Pain prevents me from sitting for more than 10 minutes.

Pain prevents me from sitting at all.

Part 6 - Standing

I can stand as long as I want without extra pain.

I can stand as long as I want but it gives me extra pain.
□ Pain prevents me from standing for more than 1 hour.

□ Pain prevents me from standing for more than 30 minutes.

□ Pain prevents me from standing for more than 10 minutes.

□ Pain prevents me from standing at all.

**Part 7 - Sleeping**

□ My sleep is never disturbed by pain.

□ My sleep is occasionally disturbed by pain.

□ Because of pain I have less than 6 hours sleep.

□ Because of pain I have less than 4 hours sleep.

□ Because of pain I have less than 2 hours sleep.

□ Pain prevents me from sleeping at all.

**Part 8 - Sex life (if applicable)**

□ My sex life is normal and causes no extra pain.

□ My sex life is normal but causes some extra pain.

□ My sex life is nearly normal but is very painful.

□ My sex life is severely restricted by pain.

□ My sex life is nearly absent because of pain.

□ Pain prevents any sex life at all.

**Part 9 - Social life**

□ My social life is normal and causes me no extra pain.

□ My social life is normal but increases the degree of pain.
Pain has no significant effect on my social life apart from limiting my more energetic interests, e.g. sport, etc.

- Pain has restricted my social life and I do not go out as often.

- Pain has restricted social life to my home.

- I have no social life because of pain.

**Part 10 - Travelling**

- I can travel anywhere without pain.

- I can travel anywhere but it gives extra pain.

- Pain is bad but I manage journeys over two hours.

- Pain restricts me to journeys of less than one hour.

- Pain restricts me to short necessary journeys under 30 minutes.

- Pain prevents me from travelling except to receive treatment.
SECTION 3 – Second short version of the Copenhagen Psychosocial Questionnaire (COPSOQ II):

The following questions are about your psychosocial work environment. Please choose the answer that fits best to each of the questions.

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<tr>
<th></th>
<th>Always</th>
<th>Oftenn</th>
<th>Sometimes</th>
<th>Seldom</th>
<th>Never/hardly ever</th>
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<tr>
<td>1A. Do you get behind with your work?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1B. Do you have enough time for your work tasks?</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
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<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>2A. Is it necessary to keep working at a high pace?</td>
<td></td>
<td></td>
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<td></td>
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<tr>
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<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2B. Do you work at a high pace throughout the day?</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td>4</td>
<td>3</td>
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<td>1</td>
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<tr>
<td>3A. Does your work put you in emotionally disturbing situations?</td>
<td></td>
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<td></td>
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<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3B. Do you have to relate to other people’s personal problems as part of your work?</td>
<td></td>
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<td></td>
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<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
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</tbody>
</table>
4A. Do you have a large degree of influence concerning your work?  
☐ ☐ ☐ ☐ ☐

4B. Can you influence the amount of work assigned to you?  
☐ ☐ ☐ ☐ ☐

5A. Do you have the possibility of learning new things through your work?  
☐ ☐ ☐ ☐ ☐

5B. Does your work require you to take the initiative?  
☐ ☐ ☐ ☐ ☐

6A. Is your work meaningful?  
☐ ☐ ☐ ☐ ☐

6B. Do you feel that the work you do is important?  
☐ ☐ ☐ ☐ ☐

7A. Do you feel that your place of work is of great importance to you?  
☐ ☐ ☐ ☐ ☐

7B. Would you recommend a good friend to apply for a position at your workplace?  
☐ ☐ ☐ ☐ ☐

8A. At your place of work, are you informed well in advance concerning for example important decisions, changes, or plans for the future?  
☐ ☐ ☐ ☐ ☐
8B. Do you receive all the information you need in order to do your work well?

<table>
<thead>
<tr>
<th></th>
<th>To a very large extent</th>
<th>To a large extent</th>
<th>Somewhat</th>
<th>To a small extent</th>
<th>To a very small extent</th>
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9A. Is your work recognised and appreciated by the management?

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<th>To a large extent</th>
<th>Somewhat</th>
<th>To a small extent</th>
<th>To a very small extent</th>
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9B. Are you treated fairly at your workplace?

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<th>To a very large extent</th>
<th>To a large extent</th>
<th>Somewhat</th>
<th>To a small extent</th>
<th>To a very small extent</th>
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10A. Does your work have clear objectives?

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<th>To a large extent</th>
<th>Somewhat</th>
<th>To a small extent</th>
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</tbody>
</table>

10B. Do you know exactly what is expected of you at work?

<table>
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<tr>
<th></th>
<th>To a very large extent</th>
<th>To a large extent</th>
<th>Somewhat</th>
<th>To a small extent</th>
<th>To a very small extent</th>
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</table>

11A. To what extent would you say that your immediate superior gives high priority to job satisfaction?

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<th></th>
<th>To a very large extent</th>
<th>To a large extent</th>
<th>Somewhat</th>
<th>To a small extent</th>
<th>To a very small extent</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
<td></td>
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</tbody>
</table>

11B. To what extent would you say that your immediate superior is good at work planning?

<table>
<thead>
<tr>
<th></th>
<th>To a very large extent</th>
<th>To a large extent</th>
<th>Somewhat</th>
<th>To a small extent</th>
<th>To a very small extent</th>
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</table>

12A. How often is your nearest superior willing to listen to your problems at work?

<table>
<thead>
<tr>
<th></th>
<th>Always</th>
<th>Often</th>
<th>Sometimes</th>
<th>Seldom</th>
<th>Never/hardly ever</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tbody>
</table>

12B. How often do you get help and support from your nearest superior?

<table>
<thead>
<tr>
<th></th>
<th>Always</th>
<th>Often</th>
<th>Sometimes</th>
<th>Seldom</th>
<th>Never/hardly ever</th>
</tr>
</thead>
<tbody>
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<td></td>
<td></td>
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</tbody>
</table>
13. Regarding your work in general. How pleased are you with your job as a whole, everything taken into consideration?

<table>
<thead>
<tr>
<th>Very satisfied</th>
<th>Satisfied</th>
<th>Unsatisfied</th>
<th>Very unsatisfied</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

There are no more questions.

At this page you may write more about your working conditions, stress, health, etc.
Second Questionnaire (used at the end of data collection)

SECTION 1 – Personal and general information

First name: _________________________ Surname: ____________________________

This question aims to gather your opinion regarding the Spineangel ® device. Please choose the most appropriate option, considering the following statement:

“The Spineangel ® device was useful to help me to improve my posture at work.”

Strongly agree ( ) Agree ( ) Undecided ( ) Disagree ( ) Strongly disagree ( )

SECTION 2 – Oswestry low back pain disability questionnaire

This questionnaire has been designed to give us information as to how your back or leg pain is affecting your ability to manage in everyday life. Please answer by checking one box in each section for the statement which best applies to you. We realise you may consider that two or more statements in any one section apply but please just shade out the spot that indicates the statement which most clearly describes your problem.

Part 1 - Pain intensity

☐ I have no pain at the moment.

☐ The pain is very mild at the moment.

☐ The pain is moderate at the moment.

☐ The pain is fairly severe at the moment.

☐ The pain is very severe at the moment.

☐ The pain is the worst imaginable at the moment.

Part 2 - Personal care (washing, dressing, etc.)

☐ I can look after myself normally without causing extra pain.

☐ I can look after myself normally but it is very painful.
☐ It is painful to look after myself and I am slow and careful.

☐ I need some help but manage most of my personal care.

☐ I need help every day in most aspects of self-care.

☐ I do not get dressed, wash with difficulty and stay in bed.

**Part 3 - Lifting**

☐ I can lift heavy weights without extra pain.

☐ I can lift heavy weights but it gives extra pain.

☐ Pain prevents me from lifting heavy weights off the floor but I can manage if they are conveniently positioned, e.g. on a table.

☐ Pain prevents me from lifting heavy weights but I can manage light to medium weights if they are conveniently positioned.

☐ I can lift only very light weights.

☐ I cannot lift or carry anything at all.

**Part 4 - Walking**

☐ Pain does not prevent me walking any distance.

☐ Pain prevents me walking more than 2 kilometers.

☐ Pain prevents me walking more than 1 kilometer.

☐ Pain prevents me walking more than 500 metres.

☐ I can only walk using a stick or crutches.

☐ I am in bed most of the time and have to crawl to the toilet.

**Part 5 - Sitting**

☐ I can sit in any chair as long as I like.

☐ I can sit in my favourite chair as long as I like.
□ Pain prevents me from sitting for more than 1 hour.

□ Pain prevents me from sitting for more than 30 minutes.

□ Pain prevents me from sitting for more than 10 minutes.

□ Pain prevents me from sitting at all.

Part 6 - Standing

□ I can stand as long as I want without extra pain.

□ I can stand as long as I want but it gives me extra pain.

□ Pain prevents me from standing for more than 1 hour.

□ Pain prevents me from standing for more than 30 minutes.

□ Pain prevents me from standing for more than 10 minutes.

□ Pain prevents me from standing at all.

Part 7 - Sleeping

□ My sleep is never disturbed by pain.

□ My sleep is occasionally disturbed by pain.

□ Because of pain I have less than 6 hours sleep.

□ Because of pain I have less than 4 hours sleep.

□ Because of pain I have less than 2 hours sleep.

□ Pain prevents me from sleeping at all.

Part 8 - Sex life (if applicable)

□ My sex life is normal and causes no extra pain.

□ My sex life is normal but causes some extra pain.

□ My sex life is nearly normal but is very painful.
☐ My sex life is severely restricted by pain.

☐ My sex life is nearly absent because of pain.

☐ Pain prevents any sex life at all.

Part 9 - Social life

☐ My social life is normal and causes me no extra pain.

☐ My social life is normal but increases the degree of pain.

☐ Pain has no significant effect on my social life apart from limiting my more energetic interests, e.g. sport, etc.

☐ Pain has restricted my social life and I do not go out as often.

☐ Pain has restricted social life to my home.

☐ I have no social life because of pain.

Part 10 - Travelling

☐ I can travel anywhere without pain.

☐ I can travel anywhere but it gives extra pain.

☐ Pain is bad but I manage journeys over two hours.

☐ Pain restricts me to journeys of less than one hour.

☐ Pain restricts me to short necessary journeys under 30 minutes.

☐ Pain prevents me from travelling except to receive treatment
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