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***LOWER LIMB PAIN, MUSCLE FATIGUE AND PROLONGED STANDING AT WORK:  
SCIENTIFIC INSIGHTS FOR OCCUPATIONAL ERGONOMICS AND HEALTH***

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## **Abstract**

Prolonged standing work is very common among different occupations including retail staff, machine operators, assembly line workers, health care personnel, and service workers. Standing for the majority of the workday is associated with fatigue, discomfort, and health symptoms such as musculoskeletal disorders and varicose veins in the lower limbs. Unfortunately, studies in this area are very limited leading to recommendations and guidelines for standing work that lack the support from scientific studies. The objectives of this dissertation are to first clarify the relations between working conditions and lower limb pain, then evaluate the contribution of prolonged standing to muscle fatigue, and finally to test possible prevention methods of prolonged standing effects. Three studies were conducted to address these questions with the overall aim of contributing to the scientific efforts in the prevention of the work-related health effects of prolonged standing.

The first study, Lower Limb Pain among the European Workforce, developed and validated a logistic regression model to understand lower limb pain in the working environment. This study was based on epidemiology data of 35'372 workers from the 27 countries of the European Union. The model revealed ten physical and psychosocial exposure variables relevant for the evaluation of work-related lower limb pain. It further estimated that around 22 million cases of lower limb pain in the EU could be explained by tiring or painful positions, carrying or moving heavy loads, lifting or moving people, and standing.

The second study, Long-Term Muscle Fatigue after Standing Work, was a laboratory study to determine the effects of prolonged standing on lower limbs muscle fatigue and to estimate possible age and gender effects. Muscle twitch force (MTF), postural stability, and subjective evaluations of discomfort were used to quantify muscle fatigue in 26 participants during and after five hours of simulated standing work and a seated control day. A reduction

in MTF and the subjective evaluations showed evidence of fatigue immediately after completion of the standing work regardless of age or gender. However, only MTF – and not the subjective evaluations - showed evidence of fatigue after a 30-minute period of seated recovery. This result indicates that the component of fatigue contributing to the persistent reduction in MTF may be not be subjectively perceived after post-work rest.

The third study, Long-Lasting Changes in Muscle Twitch Force during Simulated Work while Standing or Walking, was again a laboratory study that aimed to compare the effects of prolonged standing on the lower leg muscles during and after standing work on a hard floor, on an antifatigue mat, and walking on a treadmill. Eighteen participants simulated standing work for more than 5 hours in the three conditions on non-consecutive days in a laboratory setting. MTF measurements revealed evidence of long-lasting fatigue after both standing conditions - regardless of the flooring type - but less during walking. It was then concluded that antifatigue mats may not contribute to the alleviation of the long-lasting component of muscle fatigue during prolonged standing work, however slow-paced walking may contribute on the attenuation of long-lasting fatigue.

Work-related lower limb pain is a relevant disorder that could be predicted by specific working conditions related to physical and psychosocial factors including standing at work. The persistence of muscle fatigue observed in the laboratory studies suggests that prolonged standing is likely to contribute to lower limb disorders. Furthermore, these effects may not be relieved by the use of antifatigue mats. Further prevention methods like walking work or disruption of prolonged static standing postures need to be explored.

## **Zusammenfassung**

Langandauerndes Stehen ist in vielen Berufsfeldern, wie im Verkauf, an Industriearbeitsplätzen, im Gesundheitswesen oder im Dienstleistungssektor, weit verbreitet. Stehen während eines grossen Teils des Arbeitstages wird in Verbindung gebracht mit Ermüdung, Diskomfort und Symptomen wie muskuloskeletalen Problemen und Krampfadern in den Unterschenkeln.

Leider gibt es in diesem Bereich nur sehr wenige Studien und den allgemeinen Empfehlungen zu Steharbeit fehlt die wissenschaftliche Begründung. Das Ziel dieser Studie war es, den Zusammenhang zwischen Arbeitsplatzfaktoren und Beschwerden in den Unterschenkeln zu klären, den Einfluss von langandauerndem Stehen auf die Muskelermüdung zu untersuchen und schliesslich potentielle Präventionsmassnahmen zu testen. Das allgemeine Ziel dieses Projektes war es, einen Beitrag zu den wissenschaftlichen Bemühungen in der Prävention der Gesundheitseffekte von langandauerndem Stehen zu leisten.

Die erste Studie, Schmerzen in den Unterschenkeln bei Europäischen Arbeitnehmenden, entwickelt und validiert ein Regressionsmodell um Schmerzen in den Unterschenkeln im Arbeitsumfeld zu verstehen. Die Studie basierte auf Daten von 35372 Arbeitnehmern aus 27 Ländern der Europäischen Union. Die Analyse konnte zehn physische und psychosoziale Faktoren identifizieren, die für die Evaluation von arbeitsbezogenen Schmerzen in den Unterschenkeln wichtig sind. Es wird geschätzt, dass etwa 22 Millionen Fälle von Schmerzen in den Unterschenkeln in der Europäischen Union durch ermüdende oder schmerzhaft Positionen, Heben und Tragen von schweren Gewichten, Bewegen oder Heben von Personen und Stehen erklärt werden können.

Die zweite Studie, Langzeit-Muskelermüdung nach Steharbeit, war eine Laborstudie, um die Effekte von langandauerndem Stehen auf die Ermüdung der Unterschenkel und mögliche Effekte des Alters und des Geschlechtes zu untersuchen. Die Stärke der Muskelzuckung (Twitch Force), Stabilität der Haltung und die subjektive Evaluation des Diskomforts wurden gebraucht, um die Muskelermüdung in 26 Probanden, während und nach einer fünfstündigen, simulierten Steharbeit und eines Kontrolltages, welcher sitzend verbracht wurde, zu bestimmen. Die Twitch Force und die subjektive Evaluation zeigen unabhängig vom Alter und Geschlecht Evidenz für Ermüdung direkt nach der Steharbeit. Nach einer 30-minütigen Erholphase, zeigt jedoch nur noch die Twitch Force Ermüdung. Dieses Ergebnis zeigte, dass die Komponenten der Ermüdung, die dazu beitragen, dass die Ermüdung über längere Zeit erhalten bleibt, nach der sitzenden Pause nicht mehr wahrgenommen werden.

Die dritte Studie, langanhaltende Veränderungen in der Twitch Force während simulierter Arbeit im Stehen oder Gehen, verglich die Effekte von langandauerndem Stehen auf den Unterschenkel während und nach Steharbeit auf dem Boden, auf einer Anti-Ermüdungsmatte und Gehen auf dem Laufband. Achtzehn Probanden simulierten im Labor Steharbeit während mehr als fünf Stunden und in den drei Bedingungen. Die Tests fanden an nicht-aufeinanderfolgenden Tagen statt. Es zeigten sich ähnliche Effekte der langandauernden Ermüdung im Stehen, unabhängig von der Bodenbeschaffenheit. Im Gehen wurde jedoch weniger Ermüdung gefunden. Die Schlussfolgerung war somit, dass Anti-Ermüdungsmatten nicht zur Reduktion der langandauernden Komponenten der Muskelermüdung beitragen konnten, langsames Gehen jedoch schon.

Schmerzen in den Unterschenkeln ist ein wichtiges, arbeitsbezogenes Problem, das durch spezifische Arbeitsbedingungen vorausgesagt werden kann, welche in Verbindung zu physischen und psychosozialen Faktoren stehen (u.a. Stehen bei der Arbeit). Das Fortbestehen

der Muskelermüdung nach Beenden der Arbeit, welches durch objektive Parameter in der Laborstudie gezeigt werden konnte, legt nahe, dass Steharbeit in Zusammenhang mit Beschwerden in den Unterschenkeln stehen könnte und dass diese Effekte durch Anti-Ermüdungsmatten nicht abgeschwächt werden können. Weitere Präventionsmassnahmen wie Gehen bei der Arbeit oder eine Unterbrechung der statischen Position im Stehen, müssen untersucht werden.

## Preface

This dissertation was performed at the Sensory-Motor Systems Lab, Department of Health, Sciences and Technology, ETH Zurich, Switzerland. The structure of this thesis is cumulative. It incorporates two manuscripts published in one of the most important journals in the field of ergonomics (Chapter 3 and 4) and one manuscript in press (Chapter 2) to another prominent peer reviewed journal. Chapter 4 contains part of the results from the study performed in collaboration with the University Hospital of Tübingen, Institute of Occupational Medicine, Social Medicine and Health Services Research in Germany. The manuscript referenced and their corresponding chapters are described below:

Chapter 2: Embodies the peer-reviewed version of the in press manuscript Garcia, M.G., Graf, M., & Läubli, T. (in press). Lower Limb Pain among Workers: A Cross-Sectional analysis of the Fifth European Working Conditions Survey. *International Archives of Occupational and Environmental Health*.

Chapter 3: Includes the peer-reviewed version of the accepted manuscript Garcia, M. G., Läubli, T., & Martin, B. J. (2015). Long-Term muscle fatigue after standing work. *Human Factors*, 57(7), 1162 – 1173. doi: 10.1177/0018720815590293, in agreement with the Copyright Clearance Center of SAGE Publications and Human Factors journal. The study was approved by the ethics committee of ETH Zürich.

Chapter 4: Contains the peer-reviewed version of the accepted manuscript Garcia, M. G., Wall, R., Steinhilber, B., Läubli, T., & Martin, B. J. (2016). Long-Lasting Changes in Muscle Twitch Force during Simulated Work While Standing or Walking. *Human Factors*, 58(8),



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## 1. Introduction

Work-related musculoskeletal disorders (MSDs) and health problems not only affect the quality of life of the worker, but are also associated with high costs to employers and the society. Musculoskeletal disorders have been generally defined as injuries that affect the muscles, joints, tendons, ligaments, bones and nerves. The economic burden of musculoskeletal disorders in the United States reached \$1.5 billion in 2007 (Bhattacharya 2014). In the European Union, the total cost of lost productivity was estimated at more than 2% of gross domestic product (Bevan, 2015). As a result, national institutes for occupational health of many countries have developed research programs for the prevention of work-related health problems. This has led to many studies that have investigated the causes and developed methods to prevent work-related musculoskeletal symptoms and health issues. However, a large majority of these studies has focused on the upper body and only a few on the lower body. The prevalence of work-related musculoskeletal symptoms varies widely across occupational groups. Several studies have identified risk factors in work environments that include exposures such as heavy lifting, vibration, repetitive tasks, prolonged sitting and recently prolonged standing. However, less attention has been paid to prolonged standing work and its effects on the lower body. The current dissertation addressed these gaps.

Ergonomics guidelines for prolonged standing are scarce and/or often lack scientific support. Some guidelines suggest providing seating alternatives to standing jobs; however, the characteristics of some standing tasks render working in a sitting posture unfeasible. Adequate ergonomic strategies to avoid the negative health effects of prolonged standing are needed. The aim of this thesis is to contribute to the development of such strategies by first filling the gaps in the literature regarding the health consequences of prolonged standing, then investigating - through physiological measures - the effects of standing work to determine

which measures are the most practical and sensitive, and finally, evaluating these measures with the existing intervention strategies to prevent prolonged standing health effects. Creating this scientific background is of practical importance for the development of better ergonomic solutions in the prevention of prolonged standing work-related health problems.

The research performed for this dissertation thus focused on 1) evaluating epidemiological evidences of work-related lower limb pain, 2) investigating the effects of prolonged standing work through objective and subjective measures of fatigue, and 3) comparing interventions proposed for prolonged standing through fatigue-related measures applied to lower leg muscles.

### ***1.1 Prolonged standing work***

Prolonged standing work is very common in a variety of manufacturing and service industries such as restaurants, hospitals, retail stores, assembly companies, hairdressers, security companies, among others. In many of these workplaces employees are confined to a limited work area and cannot sit at will. In the European Union more than 45% of employees reported that they perform standing work for more than three quarters of their working time (Graf, 2015). The same amount was found in North America (Messing, Stock, Côté, & Tissot, 2015) where it was additionally reported that 41% of female workers and 32% of male workers are not allowed to sit at will. Furthermore, in the last few years there has been a trend to increase standing time at office jobs to avoid the negative health effects of prolonged sitting. Although research that focuses on prolonged standing at work is limited. It is important to acknowledge that this posture has been associated with various health repercussions and physical symptoms by relevant epidemiology and laboratory studies.

The next two sections present a brief summary of the epidemiology, laboratory, and field evidence of the potential health consequences of prolonged standing at work. For more

detailed information, Halim and Omar (2011) and McCulloch (2002) summarized health effects related to standing while Waters and Dick (2014) provided an in depth review of the health risks and prevention methods related to prolonged standing. Only the most recent and relevant peer review literature available in English was chosen from electronic databases (PubMed and Elsevier Science Direct) to summarize the health issues of prolonged standing presented below.

### **1.1.1 Health risks: Epidemiology evidence**

Several studies have analyzed prolonged standing at work and the relations to symptoms and disorders in the musculoskeletal and cardiovascular systems. One of the most widely investigated work-related musculoskeletal disorders is low back pain. A review by Waters and Dick (2014) presented three studies that reported an increased risk of low back pain in workers exposed to prolonged standing when compared to a control population. In addition, a recent cross-sectional study by Sorensen, Norton, Callaghan, Hwang, and Van Dillen (2015) concluded that lumbar lordosis may be a risk factor for low back pain developed during prolonged standing. Finally, a longitudinal study with individuals without prior history of low back pain concluded that transient low back pain developed during prolonged standing is a good predictor of future clinical low back pain (Nelson-Wong & Callaghan, 2014). Overall there is scientific evidence that links low back pain to prolonged standing.

Several epidemiology studies have presented important links between prolonged standing and problems in the cardiovascular system. The review by Waters and Dick (2014) presented five studies indicating a higher risk of venous diseases for people exposed to prolonged periods of standing. The review also presented a study indicating a significant relationship between prolonged standing at the workplace and carotid atherosclerotic progression. A recent longitudinal study by Tabatabaeifar et al. (2015) suggests that the risk

of needing surgery for varicose veins in the lower extremities increases with prolonged standing at work.

Although an increased risk for the development of musculoskeletal symptoms in the lower limbs (hips, upper and lower leg, knees and feet) has been related to standing at work, there is currently limited research in this area. Some studies have shown evidence of hip pain and an increased risk of hip osteoarthritis with exposure to prolonged standing at work (Pope, Hunt, Birrell, Silman, & Macfarlane, 2003; Sulsky et al., 2012). Other studies have linked ankle, foot, and leg pain (Messing, Tissot, & Stock, 2008), and knee problems - such as arthrosis - with prolonged standing (Elsner, Nienhaus, & Beck, 1996). Furthermore, epidemiological studies present evidence of an association between lower limb pain and standing at work in diverse occupational groups such as nurses (Reed, Battistutta, Young, & Newman, 2014), craft workers, machine operators, and elementary occupation personnel (Montano, 2014). A qualitative review on lower limb MSDs conducted by Okunribido and Lewis (2010) concluded that standing may be one of the causal risk factors for lower limb disorders. However, the research regarding the prevalence of lower limb pain and its association with standing at work is limited. This dissertation thus contributes with a model to predict the prevalence of lower limb pain based on working-conditions indicators (Chapter 1). Understanding the importance of lower limb pain and its association with working exposures, such as prolonged standing, is the first step in providing evidence that supports the need for investigating prolonged standing effects in laboratory and field studies.

### **1.1.2 Physical symptoms: Laboratory and field evidence**

Moving beyond epidemiology studies related to prolonged standing, a number of laboratory and field studies have presented evidence of potential health problems linked to

physiological alterations measured using objective and subjective methods during prolonged standing.

Some studies have presented evidence of the effects of prolonged standing on physical symptoms and fatigue indicators. Two laboratory studies showed a higher co-activation of the gluteus medius muscles during prolonged standing, which influenced the frequency of low back pain complaints (Marshall, Patel, & Callaghan, 2011; Nelson-Wong, Gregory, Winter, & Callaghan, 2008). A recent laboratory study by Miller, Brent Edwards, and Deluzio (2015) observed that the total knee joint load, accumulated when standing, was as high as when walking. However, during standing, a continuous compression of cartilage areas was observed – something that could potential lead to knee joint problems - as described in Chaffin, Andersson, and Martin (2006).

Other evidence involves postural changes during prolonged standing, which have also been identified as indicators of fatigue (Wiggermann & Keyserling, 2013). These changes in posture could increase the risk of falls (Freitas, Wieczorek, Marchetti, & Duarte, 2005) or the persistence of musculoskeletal problems in the lower back (Lafond et al., 2009).

An additional issue with standing work may be cardiovascular effects, such as leg edema, which has been observed in both laboratory and field studies after long periods of standing (da Luz, Proenca, de Salazar, & Galego, 2013; Zander, King, & Ezenwa, 2004). This phenomenon could be related to potential vascular problems and overall body fatigue. In addition, Ngomo, Messing, Perrault, and Comtois (2008) reported a decrease in blood pressure during standing work and concluded that this posture is associated with orthostatic intolerance in workers.

An increase in self-reported fatigue and discomfort in the lower limbs was observed after standing work in various studies (Antle & Côté, 2013; Chester, Rys, & Konz, 2002; Waters &

Dick, 2014). In addition, the review from Waters and Dick (2014) presented two field studies where significant low back discomfort was reported due to standing work.

Most of the laboratory and field studies explored the effects of prolonged standing through fatigue indicators. A long accepted model suggests that fatigue is a precursor of musculoskeletal disorders (Armstrong et al., 1993; Edwards, 1988). Moreover, fatigue could increase the risk of injuries such as slips and falls and in general be detrimental to the individuals' health (Côté, Raymond, Mathieu, Feldman, & Levin, 2005). Further information about fatigue and its importance to the present study is described in the following section.

### **1.1.3 Fatigue**

As noted in several studies, there is a lack of consensus in the literature regarding a canonical definition of fatigue (Aaronson et al., 1999; Enoka & Duchateau, 2015; Friedman et al., 2007; Noakes, 2012; Weir, Beck, Cramer, & Housh, 2006). Some definitions of fatigue - particularly in clinical settings - refer to the sensation of weakness, tiredness, lack of energy, decrease in physical or mental capacity, an unpleasant symptom, and/or exhaustion (Aaronson et al., 1999; Friedman et al., 2007; Ream & Richardson, 1996). However, these definitions often involve only subjective components. Fatigue is a very complex phenomenon that can be caused by many different mechanisms (Bigland-Ritchie, Cafarelli, & Vollestad, 1986; Enoka & Duchateau, 2008; Enoka & Stuart, 1992; Gandevia, Enoka, McComas, Stuart, & K., 1995) related to both objective and subjective components (Gandevia, 2001; Noakes, 2012; Phillips, 2015; Volker, Kirchner, & Bock, 2015). Several investigators, especially those in neuromuscular research, have defined fatigue, particularly fatigue in the muscles, as “a failure to maintain the required or expected force” (Edwards, 1981), as “any reduction in the force generating capacity of the total neuromuscular system regardless of the force required” (Bigland-Ritchie & Woods, 1984), as “the loss in the ability to produce muscle force or power

output” (Gandevia, 2001; Vollestad, 1997), or as “a transient decrease in the capacity to perform physical actions” (Enoka & Duchateau, 2008). The present dissertation is guided by these definitions and considers the scientific evidence suggesting that during fatiguing tasks the decrease in muscle performance can be attributed in part to components of the central nervous system and to mechanisms within the muscle (Enoka & Stuart, 1992; Weir et al., 2006). Fatigue mechanisms correspond to the central nervous system’s drive to motor neurons, neural strategy, neuromuscular propagation, excitation-contraction coupling, the availability of metabolic substrates, the intracellular milieu, the contractile apparatus, and muscle blood flow (Enoka & Stuart, 1992; Gandevia et al., 1995; Jones, Round, & de Haan, 2004b). Whether some mechanisms contribute or not to fatigue depends on the task and their effect could change as the task is being performed (Enoka, 2012; Enoka & Stuart, 1992; Gandevia et al., 1995).

It is easy to see how fatigue can occur in tasks involving high force exertions; however, it is also present in those tasks demanding low force exertions which frequently lead to a fatigue condition of slow recovery (Adamo, Khodaei, Barringer, Johnson, & Martin, 2009; Adamo, Martin, & Johnson, 2002; Johnson, Ciriello, Kerin, & Dennerlein, 2013; Kim & Johnson, 2014; Sogaard, Blangsted, Jorgensen, Madeleine, & Sjogaard, 2003). This feature of fatigue has been commonly named long-lasting, long-term, or low-frequency fatigue (Edwards, Hill, Jones, & Merton, 1977; Jones, 1996) and it may be a consequence of a failure in the excitation contraction coupling mechanisms of the muscle - in particular a reduction in calcium released during an action potential (Enoka & Stuart, 1992; Jones, Round, & de Haan, 2004a; Jones, 1996). Previous literature suggests that long-lasting fatigue may persist more than 30 minutes post work (Adamo et al., 2009; Enoka & Stuart, 1992; Jones, 1996) and its recovery may last up to 24 hours (Edwards et al., 1977).



Numerous studies have focused on the quantification of fatigue in order to evaluate occupational tasks and ergonomic solutions. Methods to evaluate fatigue include subjective rating scales (Waters & Dick, 2014), shifts in the center of pressure sway (Antle & Côté, 2013), electrically induced muscle twitches at low frequencies (Adamo et al., 2009; Adamo et al., 2002; Johnson et al., 2013), and changes in the median or mean frequency of surface electromyography (EMG) (Blangsted, Sjogaard, Madeleine, Olsen, & Sogaard, 2005; Madeleine, Jorgensen, Sogaard, Arendt-Nielsen, & Sjogaard, 2002). However, only the last two methods have been shown to be sensitive to the long-lasting component of fatigue in studies involving the upper limbs (Adamo et al., 2009; Kim & Johnson, 2014; Sogaard et al., 2003). Since fatigue is considered a precursor of MSDs (e.g. Côté (2014) for review), its long-lasting effects are important to explore. Furthermore, standing tasks do not involve high force exertions but rather low ones, thus investigating the long-lasting component of fatigue is of particular interest for the present studies. Further details of the methods used to quantify fatigue are presented below and in Chapters 3 and 4.

#### **1.1.4 Interventions strategies for the prevention of work-related health problems**

The use of antifatigue mats or shoe insoles has been proposed to alleviate fatigue and reduce discomfort during standing. Reviews by Redfern and Cham (2000) and by Waters and Dick (2014) refer to various studies indicating a significant relief of discomfort when using antifatigue mats. These results were based on subjective perceptions reported in questionnaires referring to overall fatigue or discomfort in various body parts. Some of these studies used also objective measures during the standing experiments. These measures included center of pressure, EMG activity of various leg and/or back muscles, leg volume, skin temperature, heart rate, blood pressure, and oxygen uptake. However, the results from subjective and objective measurements were not in agreement and presented contradictions.

Although some studies show that perceived discomfort is significantly reduced by these foot-floor interfaces, localized muscle fatigue may not be relieved (Kim, Stuart-Buttle, & Marras, 1994).

Other studies have suggested that standing work should be limited and alternate with other positions (Van Dieen & Oude Vrielink, 1998). Controlling the work rhythm (work-rest cycle) may be a better approach to prevent MSDs and injuries associated with jobs that require standing work and mobility. Some studies have sought to define work-rest cycles that prevent work related health problems (Tiwari and Gite (2006); Van Dieen & Oude Vrielink, 1998; Dababneh et al., 2001); however, none of these studies evaluated the fatigue induced by standing work. One promising approach to alleviate fatigue is to integrate a more dynamic posture in the stationary standing posture at work, but this scheme has received little attention (Balasubramanian, Adalarasu, & Regulapati, 2009).

## ***1.2 Main methods used to evaluate prolonged standing effects***

Methods to evaluate the effects of prolonged standing include both subjective and objective measures such as questionnaires, visual analog scales, postural stability, water-displacement plethysmography, and EMG. As mentioned above, many of these methods have led to contradicting results when evaluating different interventions. These discrepancies may be due to differences in standing duration exposure in each study. In the review by Redfern and Cham (2000), only two out of the eleven studies concerning flooring conditions and standing work exposed the participants to more than 2 hours. The authors concluded that significant effects are not observed until after 3 hours of standing; hence, studies with longer duration of exposure are needed.

Other methods have been used to evaluate fatigue in ergonomics studies; however, most concerned the upper body. Several studies have investigated muscle function alterations

using electrical stimulation (Adamo et al., 2009; Kim & Johnson, 2014), electro- and mechanomyography (Sogaard et al., 2003), and near infrared spectroscopy (Boushel & Piantadosi, 2000; Crenshaw, Komandur, & Johnson, 2010). These methods have the potential to evaluate fatigue in the lower limbs after prolonged standing work.

For the laboratory studies in this dissertation, three methods were chosen to evaluate the effect of standing work after five hours: subjective evaluation, electrical stimulation, and postural stability. These methods were chosen because of their potential sensitivity to detect muscle fatigue and discomfort, the feasibility and easiness of implementation in future field studies, and their practicability in terms of cost and time. The background and further justification of these methods is described below. Note that two additional methods (water-displacement plethysmography and EMG) were included in the research project described in Chapter 4; however, the results are not part of this dissertation and will be presented in upcoming publications from our research partners of the University of Tübingen.

### **1.2.1 Subjective evaluation**

Self-reports of overall fatigue and discomfort in specific body segments have been used broadly to evaluate fatigue induced by a work task. A common self-report is the updated version of Nordic Questionnaire originally designed by Kuorinka et al. (1987). This questionnaire evaluates discomfort using visual analog scales and anatomical areas represented on a body diagram.

Subjective evaluations have been considered the gold standard measure of fatigue (Shen, Barbera, & Shapiro, 2006). In ergonomics it is generally accepted that when individuals perceive discomfort or pain due to working conditions, risk assessments should be performed; however, the absence of discomfort or pain does not necessarily equate to the absence of risk. In fact, some studies have shown that the long-lasting component of fatigue that may not be

perceived after low-level exertion tasks (Adamo et al., 2009; Adamo et al., 2002). Thus, subjective evaluations may have important limitations in the evaluation of fatigue in standing work, but this relationship has not been investigated yet. The first laboratory study, presented in Chapter 3, aims to address this issue.

### **1.2.2 Electrical stimulation – Muscle twitch force**

In this method, involuntary muscle contractions - known as muscle twitches - are generated in response to low frequency electrical impulses. Localized muscle fatigue is then indicated as the change in the twitch force of the muscle under stimulation (Edwards et al., 1977; Enoka & Stuart, 1992). Many studies have reported evidence of a decrease in muscle twitch force after a fatiguing task in various human muscles including the flexor digitorum (Adamo et al., 2002; Johnson et al., 2013; Kim & Johnson, 2014), forearm extensor (Bystrom & Kilbom, 1991), ankle dorsiflexor (Garner, Hicks, & McComas, 1989), and the quadriceps (Ratkevicius, Skurvydas, & Lexell, 1995). In addition, a laboratory study also showed evidence of muscle fatigue in a rat medial longissimus muscle after applying electrical stimulation (Wawrow, Jakobi, & Cavanaugh, 2011).

Since the electrical stimulation is directly applied to a muscle - or muscle group, this method measures fatigue related to the mechanisms at the muscle level and not those at the central nervous system. This method is particularly well-suited to evaluate long-lasting fatigue after sustained or repetitive low-level muscle exertions (Adamo et al., 2009; Adamo et al., 2002; Kim & Johnson, 2014). To the best of our knowledge, the laboratory studies in this dissertation are the first to investigate long-lasting fatigue of the legs associated with standing work. So far, the long-lasting component of muscle fatigue has been ignored in standing work, mainly because the studies have focused only on the short term evidence of muscle fatigue (immediately after the end of the task) and short exposure durations (< 2 hours).

Thus, not reflecting real-world work durations encountered in the majority of jobs involving standing work. Specific details of the electrical stimulation method, as well as the findings associated with its use, are described in the experimental studies in Chapters 3 and 4. An additional picture of an experimental setup for electrical stimulation of the lower leg is presented in appendix A.

### **1.2.3 Postural stability**

This method involves measuring the changes in the body's center of pressure while standing in an erect posture during or after a motor task. Monjo, Terrier, and Forestier (2015) reviewed various studies that suggest that changes in postural and movement strategies are related to the neuromuscular response to compensate for fatigue during a task. The review by Enoka and Duchateau (2008) presented several studies showing the significant influence of postural muscle activity in the performance of physical tasks. Other researches have also argued that changes in postural control due to muscle fatigue may contribute to an increase in the risk of falling (Papa, Foreman, & Dibble, 2015) and body discomfort. A recent study on standing work suggests that postural stability tests could provide relevant information about the mechanisms of postural control associated with discomfort in the lower back (Antle & Côté, 2013). Several center of pressure parameters are affected by fatigue in the lower limb while standing for as little as thirty minutes (Freitas et al., 2005). However, very limited studies have evaluated postural stability after standing for more than two hours. The experimental study presented in Chapter 3 provides further information regarding this method and the results following a five-hour exposure to simulated standing at work. A picture of the experimental setup for the postural stability test is presented in appendix B.

### ***1.3 Objectives***

The overall goal of this dissertation was to investigate the prevalence of work-related lower limb pain and determine the influence of prolonged standing work on lower leg muscle fatigue. Findings from this work aim to contribute to the prevention and potential reduction of work-related health symptoms and musculoskeletal disorders. This goal was accomplished by fulfilling the following specific objectives:

1. Identify the most important indicators among various exposure variables at work that could predict the prevalence of lower limb pain and determine whether standing exposure could be considered as a significant indicator.
2. Quantify the amount of lower limb pain cases due to work exposures in the European Union member states and evaluate its impact on work absenteeism and worker's expectations.
3. Investigate the effects of prolonged standing work on lower leg muscle fatigue and body part discomfort, and estimate possible age and gender influences.
4. Evaluate and compare the effects of prolonged standing on the long-lasting muscle fatigue indicators in three conditions: standing on a hard floor, standing on an antifatigue mat, and walking at slow-pace on a treadmill. Use these findings to determine the effectiveness of possible prevention strategies.

The first and second specific objectives are addressed by the study presented in Chapter 2. The third objectives guided the study presented in Chapter 3. The fourth objective corresponds to the study in Chapter 4.

## 2. Lower limb pain among the European workforce

*(Maria-Gabriela Garcia, Margaret Graf, Thomas Läubli)*

### Abstract

**Objective:** Develop a model to predict the prevalence of lower limb pain using indicators of high workplace exposures based on the fifth European Working Conditions Survey (EWCS), evaluate its impact and explore its significance for work-related health problems.

**Method:** Cross-sectional interview data of 35'372 workers from 27 countries of the European Union in 2010 (EU27) were used to develop (20% sample) and validate (80% sample) a logistic regression model for lower limb pain. Independent variables included descriptions of working-conditions, assessments of physical and psychosocial exposures at work, and demographic factors. The impact of the model was explored through the amount of lower limb pain cases attributable to work and estimating work absences correlated with lower limb pain.

**Results:** The resulting logistic model included ten risks indicators and one preventive factor. The highest odds ratios (OR) corresponded to “tiring or painful positions” OR 2.0, 99% confidence interval (99% CI) 1.9 - 2.2, and “not satisfied with level of working-conditions in the job” (OR 1.6, 99% CI 1.5 - 1.7). The prevalence of work-related lower limb pain was 16.5% for men and 15.8% for women for the 27 countries of the European Union. Estimates based on the developed model revealed more than 34 million cases of work-related lower limb pain, where four physical risks explained about 22 million cases. In addition, more than 3 million days of absence from work in 2010 could be attributed to lower limb pain.

**Conclusion:** Lower limb pain is highly prevalent among the European workforce and work exposures are a major contributing factor. Effective workplace interventions should aim at improving working-conditions at workplaces with multiple risks.

## ***2.1 Introduction***

In Europe, work-related musculoskeletal disorders represent a substantial economic burden to society and are one of the major causes of health-related productivity loss (Bevan, 2015). Besides having obvious consequences for the individual, work-related health problems have substantial costs for their employers (Oh, Yoon, Seo, Kim, & Kim, 2011). Many studies have investigated the prevalence of and risk factors for work-related disorders of the upper limbs, neck and low back. However, work-related lower limb symptoms have received less attention when compared to other work-related musculoskeletal symptoms in the upper body or low back pain.

A small number of studies present evidence that working populations such as nurses, assembly line workers, industrial workers and service and sales workers report work-related lower limb symptoms (Andersen, Haahr, & Frost, 2007; Chee & Rampal, 2004; Montano, 2014; Roelen, Schreuder, Koopmans, & Groothoff, 2008; Stolt, Suhonen, Virolainen, & Leino-Kilpi, 2016). The prevalence of lower limb pain in these studies varied from 16% to 50%. Several physical risk factors such as heavy pushing or pulling, standing and regular lifting have been associated with lower limb pain as well as psychosocial factors (Andersen et al., 2007; Dawson et al., 2002; Roelen et al., 2008; Yue, Xu, Li, & Wang, 2014). In general, most epidemiology studies of the lower limbs focus on the analysis of risk indicators in specific work tasks. However, to our knowledge, a broader evaluation of working-conditions associated with lower limb pain has not been performed. Thus, clear risk indicators are missing to evaluate the impact of lower limb symptoms in a large population.



The purpose of this study is to develop a model based on the very large fifth European Working Conditions Survey (EWCS) in order to predict the prevalence of lower limb pain as a function of indicators of high exposures at work. The research questions were:

- Which are the most important working-conditions indicators correlated with a high prevalence of lower limb pain?
- How many cases including lower limb pain can be attributed to exposures at work in the EU?
- What is the association of work-related lower limb pain with other health problems, absenteeism and expectations regarding ability to continue to do the same job in the future?

## ***2.2 Method***

### **2.2.1 Population and setting**

The present study analyzed data from the fifth EWCS carried out in 2010. The survey was undertaken in 27 European Union Member States (EU) and seven further European countries not included in this study. The target population was EU residents aged 15 and over who worked for payment for at least one hour in the week prior to the survey. A multi-stage random stratified sample was performed to identify participants. A random sample of households was drawn from a random section of each country that was divided according to degree of urbanization. In each household, the person with current employment and with the most recent birthday was interviewed face to face, for about 44 minutes and using a questionnaire in the national language of the country. The survey consisted of 325 questions on the quality of employment, working-conditions and health status of the interviewee. In total 35'372 interviews were completed. The overall response rate was 44% (Parent-Thirion

et al., 2012). A detailed description of the standardized questionnaire and the methods has been published by Eurofound (2010).

### **2.2.2 Working-condition variables**

The survey covered multiple aspects of work such as physical factors, psychosocial factors, work organization, financial security, among others, classified into different topics by Eurofound (2010). In addition, questions regarding household characteristics and demographics were included. A detailed list of the classification of the variables into topics has been published elsewhere (Eurofound, 2010). This study uses the working-condition variables and that topic classification. These variables are not considered to be risk factors that directly predict a higher prevalence of symptoms; however, this study assumes that they identify work situations associated with health risks.

### **2.2.3 Case definition**

Several EWCS questions are related to health problems over the last 12 months before the interview (health outcome variables). In this study the variable of interest was the presence of muscular pains in the lower limbs, hereafter referred to as lower limb pain. This variable corresponds to the survey question: “Over the last 12 months, did you suffer from muscular pain in lower limbs (hips, legs, knees, feet, etc.)?” The answers were: Yes/No.

### **2.2.4 Analysis**

The analytical procedure of this study has three steps: 1) development of a logistic regression model; 2) validation of the model; 3) exploring the impact of the derived model. In summary, 20% of the interviews were randomly selected and stratified by country to form a subsample data set of 7083 interviews. The subsample was used to develop a statistical model that was subsequently validated using the rest of the data. From the subsample, questions with missing responses of over 5% were excluded. In addition, questions

concerning information about the respondent household members and those not related to working-conditions were not included. The variables related to health outcomes were used only in the third step of the analytical procedure; impact evaluation. The responses for each of the remaining 161 questions were dichotomized with 1 representing high exposure and 0 none, low or moderate exposure. Dichotomization for all questions that involve Likert scales was done through grouping the side of the scale with 20-25% of the responses representing the negative aspect or high exposures into the “exposed group” (1) and all other responses into the “controls” (0). Variables that presented a skewed distribution with less than 10% of responses on either side were discarded.

A chi-square goodness of fit test was performed to test for correlation of the 133 remaining variables with the lower limb pain outcome variable. Sixty-four variables with a phi coefficient equal or lower than 0.05 were discarded from further analysis. The remaining variables were grouped according to the topics specified by Eurofound, with the exception of the variables related to health outcomes. Thus, 46 variables grouped into 21 topics were used for a bivariate analysis and per group multivariate modelling in relation to lower limb pain. Odds ratios (OR) and confidence limits (CL) were estimated using logistic regression techniques with backward elimination for each group at  $p = .05$ . The variables that were not eliminated in the group logistic regression procedure were entered into a new model and tested again using logistic regression with backward elimination to determine the final model at  $p = .01$ . This model was correlated with three demographic variables; age, gender and level of education. Age was classified into two categories,  $< 50$  and  $\geq 50$  years of age, with higher age considered as “exposed group”. For the level of education, high exposure was defined as having no or only primary education (ISCED 1).

For the second step of the analytical procedure, the developed model was tested on the rest of the data set (80%). The sample size for this step was 28,289. The OR and CL of both subsamples were compared to check the stability of the model.

For the third and last step, exploring the impact of the derived model, the complete EWCS 2010 data set ( $n = 35,372$ ) was used. By means of frequency analysis, the number of lower limb pain cases attributable to work was calculated for each gender depending on the number of risks indicators present in each case. For this analysis, the variables of the model with positive associations with lower limb pain were used and the single subjects were weighted according to the cross-national selection probability weighting performed by Eurofound (2010). The frequency analysis considered the presence of risk indicators from 1 to 5 and  $\geq 6$ : Only a few respondents were exposed to more than six predictors included in the model. The frequency of lower limb pain cases without any risk indicator was used as the reference for calculating those cases attributable to work. In addition, a similar procedure was performed for those risk indicators related to physical load; defined as the involvement of mechanical forces generated by the human body. An estimate of the work-related lower limb pain cases and those cases due to physical load were calculated using the employment statistics of the 27 countries of the EU in 2010 (Eurostat, 2010). Furthermore, risk ratios were calculated by the ratio of the probability of an event when exposed to the probability of the event when not exposed.

The complete EWCS 2010 dataset was used to explore the association of lower limb pain with other health outcome variables through bivariate correlations and ascertain the number of cases with both symptoms. Factors like country of residence, socioeconomic characteristics, occupational groups, etc., were not considered; however, the analysis was adjusted by age and gender. The expectation of the respondents toward being able to do the same job when

reaching 60 years of age was compared between those that reported lower limb pain and those who did not. Furthermore, absenteeism from work due to health problems and due to an accident at work was investigated among respondents with and without lower limb pain. The amount of days of absence from work over the year was estimated by the difference between the mean of absenteeism of respondents with lower limb pain and those without.

All statistical analyses were performed with SAS 9.3 (SAS Institute, North Carolina, USA). The variable names present in this study were shortened for presentation purposes. The complete variable question and its number according to the EWCS 2010 survey can be found at Eurofound website.

## ***2.3 Results***

### **2.3.1 Model development**

#### **Bivariate results**

Table 2.1 presents the bivariate analysis of lower limb pain with the 46 variables and 21 topics. The topics were sorted in descending order according to the variable with the highest OR. Within each topic, data is also presented from the highest to lowest OR. Thirteen topics included only one variable. The topics with the highest OR for lower limb pain were ergonomic issues, work satisfaction and job hazards. The three highest OR among all variables were: tiring and painful positions, carrying or moving heavy loads and dissatisfaction with working-conditions.

#### **Analysis within topics**

The results for logistic regressions analysis performed within each topic are also present in Table 2.1. In this analysis, seven variables from six groups were eliminated by the logistic regression procedure. The OR were lower for the following topics: ergonomic issues, job hazards, job security, work-life balance, working time and cognitive topics when compared to

the bivariate analysis respectively. The OR was higher for pace of work and remained the same for repetitive tasks when compared with their correspondent bivariate analysis. The variables analyzed showed mostly positive associations with lower limb pain, with the exception of two: 1) working with computers: PCs, network, mainframe, and 2) using internet / email for professional purposes.

Table 2.1. Correlations between lower limb pain and working-conditions from the Fifth European Working Conditions Survey 2010 on 27 EU countries.

Variable	Bivariate Analysis			Analysis per topic			Topics
	OR	95%LCL	95%UCL	OR	95%LCL	95%UCL	
Tiring or painful positions	3.0	2.7	3.4	2.2	1.9	2.5	Ergonomic issues
Carrying or moving heavy loads	2.7	2.4	3.1	1.7	1.5	1.9	Ergonomic issues
Standing	2.2	2.0	2.4	1.4	1.3	1.6	Ergonomic issues
Repetitive hand or arm movements	1.8	1.6	2.0	.	.	.	Ergonomic issues
Lifting or moving people	1.3	1.2	1.5	1.2	1.0	1.3	Ergonomic issues
Working with computers	0.5	0.4	0.6	0.8	0.6	1.0	Ergonomic issues
Using internet / email for professional purposes	0.5	0.4	0.6	0.7	0.6	0.8	Ergonomic issues
Dissatisfaction with working conditions	2.5	2.2	2.8	2.5	2.2	2.8	Work satisfaction
High temperatures	2.4	2.2	2.7	1.6	1.4	1.9	Job hazards
Breathing in smoke, fumes, powder or dust	2.3	2.0	2.6	1.2	1.0	1.4	Job hazards
Low temperatures	2.2	1.9	2.4	1.3	1.2	1.5	Job hazards
Vibrations from hand tools, machinery, etc.	2.2	1.9	2.4	1.2	1.0	1.4	Job hazards
Loud noise	2.1	1.9	2.4	1.2	1.1	1.4	Job hazards
Breathing in vapours	1.9	1.7	2.2	1.2	1.0	1.4	Job hazards
Contact with chemical products	1.9	1.7	2.2	1.3	1.1	1.5	Job hazards
Tobacco smoke from others	1.6	1.4	1.7	.	.	.	Job hazards
Contact with materials which can be infectious	1.6	1.4	1.7	.	.	.	Job hazards
Disagree: "I am well paid for the work I do"	2.0	1.8	2.2	1.7	1.5	1.9	Job security
Disagree: "My job offers good prospects for career advancement"	1.9	1.7	2.2	1.5	1.3	1.7	Job security
Disagree: I feel 'at home' in this organisation	1.6	1.4	1.9	.	.	.	Job security
Disagree: It would be easy for me to find a job of similar salary	1.6	1.4	1.8	1.4	1.2	1.6	Job security
Disagree: The organisation I work for motivates me to give my best job performance	1.6	1.4	1.8	1.2	1.0	1.4	Job security
Agree: I might lose my job in the next 6 months	1.5	1.3	1.7	1.3	1.1	1.4	Job security
Required to wear personal protective equipment	1.7	1.6	1.9	1.7	1.6	1.9	Protective equipment <sup>§</sup>

Working at very high speed	1.7	1.5	1.9	1.7	1.5	2.0	Pace of work
Working to tight deadlines	1.3	1.2	1.5	.	.	.	Pace of work
Working hours do not fit well with family or social commitments	1.7	1.5	1.9	1.6	1.4	1.8	Work-life balance
Very difficult to take an hour or two off during working hours	1.5	1.3	1.7	1.4	1.2	1.6	Work-life balance
Subjected to verbal abuse at work	1.6	1.3	1.8	1.6	1.3	1.8	Verbal abuse <sup>§</sup>
Mostly experience stress in the work	1.5	1.4	1.7	1.5	1.4	1.7	Work pressure <sup>§</sup>
Work 6 or 7 days per week in main job	1.5	1.4	1.7	1.5	1.4	1.7	Working days per week <sup>§</sup>
Short repetitive tasks of less than 10 minutes	1.5	1.4	1.7	1.5	1.4	1.7	Repetitive tasks
Short repetitive tasks of less than 1 minute	1.3	1.2	1.5	.	.	.	Repetitive tasks
Main place of work isn't employers' or own business' premises	1.5	1.4	1.7	1.5	1.4	1.7	Place of work <sup>§</sup>
Work on Saturdays more than 2 times a month	1.5	1.3	1.6	1.4	1.2	1.6	Working time
Work in the evening more than 5 times a month	1.3	1.2	1.5	1.2	1.1	1.3	Working time
Work on Sundays more than 1 time a month	1.3	1.1	1.5	.	.	.	Working time
Own mistakes could cause physical injury to others	1.4	1.3	1.6	1.4	1.3	1.6	Consequences of mistakes <sup>§</sup>
Pace of work dependent on speed of a machine or movement of a product	1.4	1.2	1.6	1.4	1.2	1.6	Factors of pace
No change of salary or income from January 2009	1.4	1.2	1.5	1.4	1.2	1.5	Changes in work situation <sup>§</sup>
No training paid for or provided	1.3	1.2	1.5	1.3	1.2	1.5	Training <sup>§</sup>
Monotonous tasks	1.3	1.2	1.5	1.3	1.2	1.4	Cognitive dimensions
Main job doesn't involve learning new things	1.3	1.2	1.5	1.3	1.1	1.4	Cognitive dimensions
More than 15 years in company or organization	1.3	1.2	1.5	1.3	1.2	1.5	Seniority <sup>§</sup>
Rarely consulted before targets for work are set	1.3	1.1	1.4	1.3	1.1	1.4	Decision latitude <sup>§</sup>
Not able to choose or change order of tasks	1.3	1.1	1.4	1.3	1.1	1.4	Control <sup>§</sup>

Note. OR = Odds Ratio, 95%LCL = 95% lower confidence limit, 95%UCL = 95% upper

confidence limit. <sup>§</sup> indicates not adjusted analysis per topic due to the availability of only a single indicator, bivariate analysis shown twice to improve the readability of the table.



### **Logistic model**

The logistic regression procedure performed in one single equation of lower limb pain with all 39 variables eliminated 28. Thus, the remaining 11 variables defined our logistic model. The variables correspond to the following topics: ergonomic issues, work satisfaction, job hazards, job security, working time and repetitive tasks. The OR and CL of this model including the three demographic variables are presented in Table 2.2. The highest positive associations of lower limb pain were with: 1) tiring or painful positions, 2) carrying or moving heavy loads and 3) dissatisfaction with working-conditions. Only one variable presented a negative OR with lower limb pain: working with computers.

Table 2.2. Associations between lower limb pain, working-conditions and demographics from the Fifth European Working Conditions Survey 2010 (27 EU countries).

Variable	Analysis Model 20% Sample			Analysis Model 80% Sample			Topics
	OR	99%LCL	99%UCL	OR	99%LCL	99%UCL	
Tiring or painful positions	1.7	1.5	2.0	2.0	1.9	2.2	Ergonomic issues
Carrying or moving heavy loads	1.6	1.4	1.9	1.5	1.4	1.6	Ergonomic issues
Standing	1.4	1.2	1.6	1.5	1.4	1.6	Ergonomic issues
Working with computers	0.7	0.6	0.8	0.7	0.7	0.8	Ergonomic issues
Dissatisfaction with working conditions	1.6	1.3	1.8	1.6	1.5	1.7	Work satisfaction
High temperatures	1.6	1.3	1.8	1.3	1.2	1.4	Job hazards
Breathing in vapours	1.4	1.2	1.6	1.3	1.2	1.4	Job hazards
Disagree: "I am well paid for the work I do"	1.4	1.2	1.6	1.4	1.3	1.4	Job security
Disagree: It would be easy for me to find a job of similar salary	1.3	1.1	1.5	1.1	1.0	1.2	Job security
Work in the evening more than 5 times a month	1.3	1.1	1.4	1.2	1.1	1.3	Working time
Short repetitive tasks of less than 10 minutes	1.3	1.1	1.4	1.2	1.1	1.3	Repetitive tasks
Gender	1.3	1.1	1.4	1.3	1.2	1.4	Demographics
No or only primary education	1.2	1.0	1.4	1.2	1.1	1.3	Demographics
Age	1.9	1.6	2.1	1.8	1.7	1.9	Demographics

Note. OR = Odds Ratio, 99%LCL = 99% lower confidence limit, 99%UCL = 99% upper

confidence limit.

### 2.3.2 Model validation

The results of the model validation using the remaining 80% of the data are presented in Table 2.2. The strongest associations with lower limb pain in this case were with: 1) tiring and painful positions, 2) dissatisfaction with working-conditions and 3) standing. Similar OR and CL were observed for both data samples among the variables. However, for the following variables: a) tiring or painful positions, b) carrying or moving heavy loads, c) high temperatures, d) breathing in vapours e) standing and f) it would be easy for me to find a job

of similar salary (disagree), the 80% subsample OR values were outside the 20% subsample confidence limits and vice versa. Among the demographic variables, the highest associations were with age in both data sets.

Although the developed model (here tested with the full data set) was highly significant (Likelihood Ratio  $\chi^2=3969.2$ ; degrees of freedom, 14;  $p<.0001$  the maximized  $R^2$  only reached 0.173. Checking the model for each of the 27EU countries revealed that the model was highly significant but ranges of single ORs were large. For example, for tiring and painful position ORs lay between 1.34 – 2.72, for standing between 1.05 - 2.34, and for gender between 0.74 – 2.09.

### **2.3.3 Impact of the model**

#### **Work-related cases and exposures**

From the complete (N males = 17,466; N females = 17,906) EWCS 2010 data set, 31.7% male and 33.9% female respondents reported suffering from lower limb pain within the last 12 months. The percentage of lower limb pain cases attributable to working-conditions when the respondents are exposed to different numbers of risk indicators (1 to  $\geq 6$ ) from the present model are displayed in Figure 2.1 for each gender along with the non-work-related lower limb pain cases. For this analysis only the model variables with positive associations with lower limb pain were considered, thus “working with computers” was excluded. In addition, the EWCS cross-national selection probability weighting was considered. The prevalence of work-related lower limb pain was 16.5% for males and 15.9% for females. The results showed that the number of work-related lower limb pain cases increases with an exposure to more than six risk indicators for male respondents and four risk indicators for female respondents. There were 5,040 lower limb pain cases for males and 4,072 for females; 2,759 of the male cases were work-related and 2,215 of the female cases. In addition, the relative

ratio for male respondents ranged from 1.25 to 4.68 as the number of risk indicators increased (from 1 to 5). For female respondents the range was from 1.39 to 5.09. Overall, the risk ratios were higher for females than males.

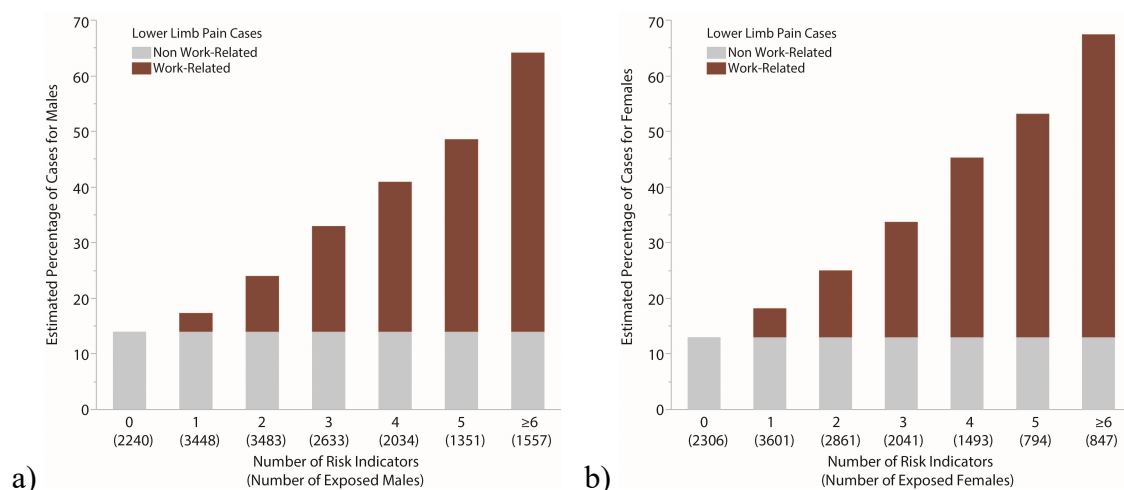


Figure 2.1. Number of work related lower limb pain cases when exposed to different numbers of risk indicators, for males (a) and females (b). Note. Males:  $n = 16,746$ , frequency missing = 2,629, Females:  $n = 13,942$ , frequency missing = 2,055. Weighted according to the EWCS cross-national selection probability weighting.

### Lower limb pain and physical load

The variables related to physical loads (ergonomic issues topic) were used in a further frequency analysis. These variables are: 1) tiring or painful positions, 2) carrying and moving heavy loads, 3) standing, and 4) lifting or moving people. In addition, the EWCS cross-national selection probability weighting was considered. The prevalence of work-related lower limb pain due to physical loads was 10% for males and 10.5% for females. The number of work-related lower limb pain cases increases when more than three physical risk indicators are present in males and two physical risk indicators in females. From the respondents that answered the questions related to physical loads, 5,818 males and 4,729 females reported lower limb pain. The total number of work-related lower limb pain cases was 1,926 males

and 1,661 females. Table 2.3 presents the amount of lower limb pain cases associated with working-conditions when exposed to 1 to  $\geq 3$  physical load risk indicators for both genders. In addition, it shows the risk ratio when exposed to the different number of risk indicators for both men and women. Overall, the risk ratios were higher for females than for male respondents.

Table 2.3. Total lower limb pain cases and work-related cases from the Fifth European Working Conditions Survey 2010 (27 EU countries) according to the number of physical risk indicators present.

Number of physical risk indicators present	Males				Females			
	n	Total lower limb pain cases	Work-related lower limb pain cases	Relative Ratio	n	Total lower limb pain cases	Work-related lower limb pain cases	Relative Ratio
0	9564	1936	0	1	8042	1554	0	1
1	5201	1613	560	1.53	4746	1512	595	1.65
2	2724	1256	705	2.28	2022	998	607	2.55
$\geq 3$	1738	1013	661	2.88	1067	665	459	3.23

Note. Males: n= 19228, frequency missing = 147. Females: n = 15878, frequency missing =

120. Weighted according to the EWCS cross-national selection probability weighting

### **Work-related lower limb pain in the EU**

In the 27 countries of the EU, 114,597,000 men and 95,145,000 women were employed during the study period according to Eurostat (2010). Based on this study, 30.1% of males and 29.2% of females suffered from lower limb pain; considering the EWCS cross-national selection probability weighting. Approximately half of the cases could be attributed to working-conditions, for both genders. Thus, we estimate that in the 27 EU countries more than 18 million men and more than 15 million women suffered from work-related lower limb pain in 2010. Considering only the physical load, 33% of the lower limb pain cases for males and 35% for female respondents were work-related based on our model. Therefore, we

estimate that more than 11 million men and more than 9 million women suffered from work-related lower limb pain due to physical loads at work in the 27 EU countries.

### Associations with other health problems

The association of lower limb pain with other health related variables showed the highest OR with muscular pains in shoulders, neck and/or upper limbs, and backache for both men and women (Table 2.4). Lower limb pain was also highly correlated with cardiovascular diseases and fatigue. Table 2.4 presents the percentage of respondents with other health problems according to the presence or absence of lower limb pain.

Table 2.4. Associations of lower limb pain with other health problems for males and females.

Variable	Males					Females				
	Lower limb pain (%)		OR	95%LCL	95%UCL	Lower limb pain (%)		OR	95%LCL	95%UCL
	Yes	No				Yes	No			
Muscular pains in shoulders, neck and/or upper limbs	77.6	24.4	10.7	9.9	11.6	78.0	31.8	7.6	7.1	8.2
Backache	75.8	31.3	6.9	6.4	7.4	76.5	34.1	6.3	5.9	6.8
Respiratory difficulties	12.3	3.6	3.7	3.3	4.2	12.3	4.5	3.0	2.7	3.4
Overall fatigue	58.3	28.0	3.6	3.4	3.9	65.9	34.4	3.7	3.5	3.9
Injury	21.9	7.3	3.5	3.2	3.9	10.5	3.8	3.0	2.6	3.4
Cardiovascular diseases	11.1	3.8	3.2	2.8	3.6	12.9	3.9	3.7	3.3	4.2
Depression or anxiety	16.3	6.1	3.0	2.7	3.4	21.4	9.1	2.7	2.5	3.0
Skin problems	12.4	4.8	2.8	2.5	3.2	15.1	7.2	2.3	2.1	2.5
Insomnia or general sleep difficulties	28.1	12.6	2.7	2.5	2.9	35.3	17.1	2.7	2.5	2.9
Headaches, eyestrain	47.3	26.0	2.5	2.4	2.7	62.1	38.9	2.6	2.4	2.7
Hearing problems	13.5	5.9	2.5	2.2	2.8	8.5	3.4	2.6	2.3	3.0
Stomach ache	19.7	9.0	2.5	2.3	2.7	23.8	11.2	2.5	2.3	2.7

Note. N = 35,372 (males = 17466 and females = 17,906).

### Work expectations and absenteeism

For the male respondents with lower limb pain 56.25% believe they won't be able to do the same job at 60 years of age, while 37.76% of the respondents without lower limb pain expected the same. The results were similar for the female respondents; 57.25% with lower limb pain believe they won't be able to do the same job at 60 years, while 39.92% without lower limb pain believe the same. The associations between lower limb pain and the expectation not to be able to do the same job at 60 years were 2.1 (95% CI 2.0-2.3) for males and 2.0 (95% CI 1.9-2.2) for females.

Among the respondents that reported lower limb pain, 23.6% males and 25.1% females were absent from work for more than 10 days in the last 12 months due to health problems as opposed to 12.9% of the males and 15.7% of the females without lower limb pain. However, 53.8% of the males and 51.8% of the females that reported lower limb pain did not miss any work days due to health problems. In addition, 11.4% of the males and 5.9% of the females that reported lower limb pain were absent from work more than 10 days in the last year due to an accident at work as opposed to 4.1% of the males and 2.1% of the females without lower limb pain. 79.5% of the males and 89.3% of the females that reported lower limb pain did not miss any work days due to an accident at work. This study estimates that over 146 million working days of male employees and 126 million working days of female employees were lost over the survey year due to lower limb pain in the EU.

## ***2.4 Discussion***

By means of logistic regression analysis with backward elimination and using the EWCS 2010 data, this study identified ten indicators of working-conditions that are combined with increased risk of lower limb pain. 30% of the EU27 workers experience lower limb pain which gives an estimate of 62 million (males: 34 million cases; females: 28 million cases) within a year. Based on this model 16% of the EU27 workers, 18 million male and 15 million

female cases can be linked to exposures at work. The more risk indicators reported, the higher the prevalence of lower limb pain. It increases from 17% at work situations without indicators of risk to 70% when six or more risk indicators are present. A substantial portion of the lower limb pain cases could be statistically linked to physical exposures at work such as standing, lifting, repetitive movements and awkward postures.

#### **2.4.1 Methodological considerations**

The present study investigates risk indicators for lower limb pain from a wide range of topics related to working-conditions using a large high quality random sample drawn from the EU workforce. The EWCS has been carried out every five years since 1990 and its scope has increased substantially since its first launch. The large representative sample size and the numerous countries included in the EWCS offer a clear opportunity for this type of study and provide a good estimation of the impact of lower limb pain on the EU workforce, although the national languages translations may introduce some variance to the study. The EWCS data is cross-sectional and all limitations related to such studies apply, in particular the inability to determine casual relationships. It should also be noted that the data is based on self-reports: Exposures were not validated with independent measurements and health disorders were not diagnosed by clinical assessments. In addition, although the EWCS psychosocial questions have affinities with the well-established Karasek-Model and the Copenhagen Psychosocial Questionnaire (COPSOQ), they have not been validated through psychometric methods.

The EWCS questions use either Likert type scales or yes/no answers, thus it was possible to calculate odds ratios based on dichotomized variables. We chose to set the limit between exposed and not exposed in such a way that about one fifth to one quarter was considered exposed and all the others were considered as controls. This has the advantage of focusing on the highest existing exposures at EU workplaces and of simplifying the analysis, because



modelling of the dose-response relationship is avoided. However, it is acknowledged that this method biases toward conservative numerical risk evaluation, lacks evaluation of dose effects and provides no estimation of safe levels.

Finally, it should be noted that the present analysis focuses on the relationship between the reported work situation and lower limb pain. The analysis does not consider factors such as socioeconomic status, nationality, ethnicity, language, or occupational group. The present findings are relevant for the population of the total sample (EU27), it should be considered as a general model. Considerable deviations may occur when analyzing single countries or economic sectors, as noted by the high variability of the size of the ORs of single risk indicators among the EU27 countries. Last, with EWCS data we are not able to distinguish the specific region of the pain (hips, legs, knees, feet, etc.) as all are grouped in one category lower limb pain.

#### **2.4.2 Model validation**

Due to the sheer number of potential predictors developed by logistic regressions, the resulting model may be biased. In an effort to better control this potential bias, a subsample of 20% was used for the development of the model and the remaining 80% was used for its validation. The magnitude of the calculated OR from both 20% and 80% subsamples were similar, but discrepancies were observed on six variables in that the corresponding OR values of the 80% subsample were outside the confidence limits obtained from the 20% subsample. These deviations show that the present model is not perfect; however, the included predictors were highly significant in the replication with the 80% subsample. To our knowledge, this is the first study that aims to develop a model of risk indicators for lower limb pain.

### **2.4.3 Prevalence and risk indicators for lower limb pain**

A high prevalence of lower limb pain was observed among the EWCS 2010 respondents and it strongly differed, depending on the number of risk indicators, rising from 17% when all ten risk indicators were negative to more than 70% when six or more were positive. Lower limb pain was associated with working-condition variables from the topics: ergonomic issues, job hazards and job security. Previous studies have found that poor ergonomic design, working in hazardous exposures and/or psychological factors may contribute to an increase of sickness absences, physical symptoms and/or musculoskeletal disorders (García-Herrero, Mariscal, García-Rodríguez, & Ritzel, 2012; Laaksonen, Pitkaniemi, Rahkonen, & Lahelma, 2010; Yue et al., 2014). However, the evaluation of such factors with lower limb pain has received little attention.

The present study produced a model for lower limb pain that includes ten working-condition variables with positive associations and one (working with computers) with negative. It is reasonable to suppose that working with computers may be related to office work, where lower limb pain may be less prevalent than in other types of jobs. In the model, the topic “ergonomic issues” included the variables with the highest positive associations with lower limb pain. These correspond to work that requires physical loading. These findings corroborate a similar epidemiology study where exposures to tiring postures, carrying heavy loads and standing were also associated with lower limb symptoms in major occupational groups of the EWCS (Montano, 2014). In addition, the present study revealed that when exposed to three physical risks indicators, lower limb pain is almost four times more probable in women and more than three times in men than without these exposures. Previous studies have shown an association between physical loading, such as tiring postures, standing and/or carrying heavy loads, with musculoskeletal symptoms in the ankle/foot, lower leg, knee and

hips (Elsner et al., 1996; Messing et al., 2008; Riddle, Pulisic, Pidcoe, & Johnson, 2003; Sandmark, Hogstedt, & Vingard, 2000; Sulsky et al., 2012; Werner, Gell, Hartigan, Wiggerman, & Keyserling, 2010). These results support the view that ergonomic issues at work are a priority for the prevention of work-related lower limb health problems.

Work satisfaction and job insecurity, as presented in our model, have been previously associated with musculoskeletal symptoms and health issues. Low job satisfaction was related to symptoms in the low back and lower limbs in studies with teachers and manufacturing workers (Gell, Werner, Hartigan, Wiggermann, & Keyserling, 2011; Yue et al., 2014). Review papers have emphasized the strong associations between job insecurity with both mental health and physical symptoms (Kim & von dem Knesebeck, 2015; Sverke, Hellgren, & Naswall, 2002). However, the specific association of job insecurity and lower limb pain has not been investigated before. Our findings suggest that satisfaction with the perceived working-conditions and a lack of job security may also be important in the prevention of lower limb pain.

Many studies have shown an association between working-conditions that involve exposures to hazardous chemicals, extreme temperatures, working at night and/or performing repetitive tasks with health problems (Ramin et al., 2015; Ross, Shipp, Trueblood, & Bhattacharya, 2016). However, very few studies have investigated the impact of these risks indicators on lower limb pain. A recent study found a significant association of lower limb pain with extreme-temperatures and night shifts among workers of a processing plant (Barro et al., 2015). Performing repetitive tasks may increase the prevalence of MSDs such as upper extremity pain and low back pain (Andersen et al., 2007; Latza, Pfahlberg, & Gefeller, 2002; Roelen et al., 2008; Tissot, Messing, & Stock, 2005). However, there is little research that investigates the direct association of repetitive tasks with lower limb pain. One study found

association of repetitive movements and extreme temperatures with lower limb pain in major occupational groups (Montano, 2014). The present study suggests that repetitive tasks, job hazards and night shifts may be risk indicators for work related lower limb pain and should be considered in its prevention.

#### **2.4.4 Work-related lower limb pain**

The findings of this study show that more than 50% of the lower limb pain cases could be attributed to work. Work-related lower limb pain cases increase when individuals are exposed multiple risk indicators. The corresponding risks ratio triples if the individual is exposed to more than six risk indicators compared to only one. However, the number of respondents exposed to more than 3 risk indicators in males and 2 risk indicators in females was relatively small, and jobs where workers are simultaneously exposed to all ten risk indicators are rare. Prevention should therefore focus on working situations where several risk indicators concur. The findings showed that the risk ratios for males and females were similar. However, lower limb pain was slightly more often reported by females than males, which corroborates with Montano (2014) study.

#### **2.4.5 Lower limb pain, health problems and absenteeism**

The high association of lower limb pain with upper limb symptoms and back pain is not surprising, as work with exposures to physical risk factors may impact on diverse areas of the musculoskeletal system. A study found that both upper and lower limb symptoms are more common among craft workers, machine operators and workers in elementary occupations (Montano, 2014). Another cross-sectional study revealed that end-of-line assembly workers have higher levels of complaints of pain in upper limbs, lower limbs and the back when compared to other workers (Chee & Rampal, 2004). Improving the working-conditions of lower limb pain sufferers may have a positive impact on other musculoskeletal symptoms.

Although studies focus more on the upper body, lower limb pain also needs attention. The present shows a substantial impact of such symptoms on absenteeism and the workers' expectations as to their future ability to perform their job. Absenteeism is a relevant measure to evaluate employee health status in the job environment and is an indication of the economic and social costs of work-related MSDs (Bevan, 2015; Laaksonen et al., 2010).

## **2.5 Conclusions**

This study is one of the few that have focused on lower limb pain and developed a model, based on working-condition indicators that include both physical and psychosocial aspects. The present model was validated and is capable of predicting the prevalence of lower limb pain in working populations, although it may contain a moderate level of conservative bias. The analysis estimated a prevalence of 30.1% for males and 29.2% of lower limb pain. Half of those cases are attributable to working-conditions, where most cases are attributed to physical risks. More than 270 million days of absence from work can be explained by lower limb pain. Finally, the correlation of lower limb pain with other health problems may be explained by similar exposures at the same hazardous work places. Prevention strategies for work-related health problems should acknowledge the relevancy of lower-limb pain and may focus on improving workplaces with multiple risks.

### **Key points**

- Previous studies on risk indicators for work-related musculoskeletal disorders have mainly focused in the upper body and lower back, whereas this study focuses on the lower limbs.
- Using a very large survey this study identifies ten risk indicators and it has produced and validated model to predict lower limb pain related to working-conditions.

- The results show a high prevalence of lower limb pain in the European Union that is attributable to working-conditions and a substantial number of work absences due to lower limb pain.
- The present study indicates that lower limb pain should be considered in occupational health intervention strategies.

### **Acknowledgments of the study**

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### 3. Long-term muscle fatigue after standing work

*(Maria-Gabriela Garcia, Thomas Läubli, Bernard J. Martin)*

#### **Abstract**

**Objective:** To determine long-term fatigue effects in the lower limbs associated with standing work, and estimate possible age and gender influences.

**Background:** The progressive accumulation of muscle fatigue effects is assumed to lead to musculoskeletal disorders, as fatigue generated by sustained low-level exertions exhibits long lasting effects. However, these effects have received little attention in the lower limbs.

**Method:** 14 men and 12 women from two different age groups simulated standing work for five hours including 5-minute seated rest breaks and a 30-minute lunch. The younger group was also tested in a control day. Muscle fatigue was quantified by electrically induced muscle twitches (MTF), postural stability and subjective evaluation of discomfort.

**Results:** MTF showed a significant fatigue effect after standing work that persisted beyond 30 minutes after the end of the workday. MTF was not affected on the control day. The center of pressure displacement speed increased significantly over time after standing work, but was also affected on the control day. Subjective evaluations of discomfort indicated a significant increase in perception of fatigue immediately after the end of standing work; however, this perception did not persist 30 minutes after. Age and gender did not influence fatigue.

**Conclusion:** Objective measures show the long-term effects of muscle fatigue after five hours of standing work; however, this fatigue is no longer perceived after 30 minutes of rest post work.

**Application:** The present results suggest that occupational activities requiring prolonged standing are likely to contribute to lower extremity and/or back disorders.

### ***3.1 Introduction***

Many workplaces require the workers to perform their tasks standing. Workers spending most of their time on their feet include retail staff, assembly line workers, health care personnel, among others (Hazards, 2005). The analysis of the European Survey of Working Conditions (Parent-Thirion et al., 2012) reveals that 47 % of employees stand for more than 75% of their work time. In addition, prolonged standing at work was associated with reports of fatigue, leg muscle pain and backache (Graf, Krieger, Läubli, & Martin, 2015). These results parallel studies investigating the association of prolonged standing at work with musculoskeletal disorders. In a recent review of health risks associated with prolonged standing Waters and Dick (2014) presented ten studies reporting evidence of low back problems after standing over 50 % of the work shift. Moreover, Gregory and Callaghan (2008) confirmed that individuals who stand for more than two hours are vulnerable to low back pain. In a case-control study, Elsner et al. (1996) showed that prolonged standing at work was associated with knee arthrosis in women. A review by D'Souza, Franzblau, and Werner (2005) revealed that ankle/feet musculoskeletal disorders may be associated with standing work. Ryan (1989) suggested that the prevalence of ankle, foot, and lower leg complaints in supermarket workers was higher for cashiers standing more than 90% of the work shift when compared to other employees. Standing the majority of the workday is also associated with ankle/feet musculoskeletal symptoms and plantar fasciitis (Riddle et al., 2003).

Antifatigue mats or antifatigue shoe in-soles (Cham & Redfern, 2001; Orlando & King, 2004) have been proposed as prevention methods to alleviate the consequences of prolonged standing; however, the effectiveness of both are unconfirmed as they do not seem to reduce the physiological effects of muscle fatigue (Brownie & Martin, 2015; Zander et al., 2004).



From a review, Redfern and Cham (2000) concluded that although discomfort may be relieved by softer flooring condition objective measures of fatigue presented conflicting results. This was also emphasized by later studies (King, 2002; Lin, Chen, & Cho, 2012). Hence, localized muscle fatigue, which is considered as a precursor of musculoskeletal disorders (Armstrong et al., 1993; Côté, 2014; Edwards, 1988), may not be relieved by these methods (Kim et al., 1994).

Muscle fatigue, defined as the reduction in the ability to produce force in response to a desired effort (Edwards, 1981; Enoka & Stuart, 1992; Gandevia, 2001), results from high-force and/or prolonged muscle contractions as well as low-force and/or intermittent contractions (Adamo et al., 2009; Blangsted et al., 2005). The type of fatigue associated with low levels of muscle exertion, commonly named long-term fatigue, may be objectively measured by specific methods quantifying the magnitude of electrically induced muscle twitches at low frequencies (Adamo et al., 2009; Adamo et al., 2002; Edwards et al., 1977) or the shift in the median or mean frequency of surface EMG power spectra obtained from low level static contractions (Blangsted et al., 2005; Sogaard et al., 2003). This type of fatigue may persist up to 24 hours after exposure (Edwards et al., 1977).

Long-term fatigue after low force exertions activities has been investigated in the upper limbs (Adamo et al., 2009; Adamo et al., 2002; Sogaard et al., 2003). However, the extent to which long-term fatigue develops and persists in the lower limbs after prolonged standing work has received little attention. Although postural stability (Freitas et al., 2005; Madeleine, Voigt, & Arendt-Nielsen, 1998), EMG (Cham & Redfern, 2001; Hansen, Winkel, & Jørgensen, 1998) and subjective discomfort (Antle & Côté, 2013; Drury et al., 2008) have been used to quantify standing fatigue, most studies considered  $\leq 2$  hours exposures and all considered only immediate post work effects. Furthermore, subjective evaluations do not

appear to correlate with long-term muscle fatigue in upper body muscles (Adamo et al., 2009; Nakata, Hagner, & Jonsson, 1992). Thus, there is a need to investigate the development of fatigue in the lower limbs during prolonged standing work and to consider possible age and gender effects, which are factors that may influence fatigue (Hunter, Critchlow, & Enoka, 2004).

Hence, we attempted to address the issue of long-term fatigue in the lower limbs during prolonged standing work by testing the following hypotheses:

1. Long-term fatigue develops in the lower limb muscles as a consequence of prolonged standing work.
2. Age and gender influence muscle fatigue induced by standing work.
3. Muscle twitch force and postural stability are sensitive methods to assess the long-lasting effects of fatigue, while subjective evaluation of discomfort is not.

## **3.2 Method**

### **3.2.1 Participants**

Twenty-six healthy individuals (14 men and 12 women) participated in this study as paid volunteers. The participants were recruited from two different age groups, 13 young adults (7 males and 6 females; 18-30 years old) and 13 older workers (7 males and 6 females; 50-65 years old). Participants were part of the working age population but having a standing job was not required. Their average height and weight  $\pm$  SD were  $172.9 \pm 12.5$  cm and  $67.9 \pm 10.2$  kg, respectively. The exclusion criteria included current pregnancy, and any neurological or musculoskeletal conditions that could interfere with the study. All participants signed an informed consent form approved by the ethics committee of ETH Zürich.

### 3.2.2 Apparatus

#### Muscle twitch force (MTF).

**Experimental setup.** The participants were seated in a comfortable armchair with their right foot resting on a reclined adjustable plate equipped with a strain gauge force transducer. The plate was adjusted to obtain a right leg posture corresponding to a knee included angle of about  $120^\circ$  and ankle included angle of  $90^\circ$  (Figure 3.1a). The right leg was stabilized with a strap passing over the knee and attached to the floor. A second plate placed over the dorsal side of the foot, also equipped with a force transducer, was attached to a fixed frame through adjustable supports. This plate contacted the foot at the midpoint between the metatarsals joints (Figure 3.1b). The initial contact force was set to the same value for all participants and verified for each replacement of the foot during the experiment. Both force transducers were connected to amplifiers. No voluntary effort was necessary to maintain the foot-leg posture and required relaxation was verified using both force signals. Each transducer measured the twitch force elicited by electrical stimulation of the gastrocnemius-soleus (GS) and tibialis anterior (TA) muscles, respectively.

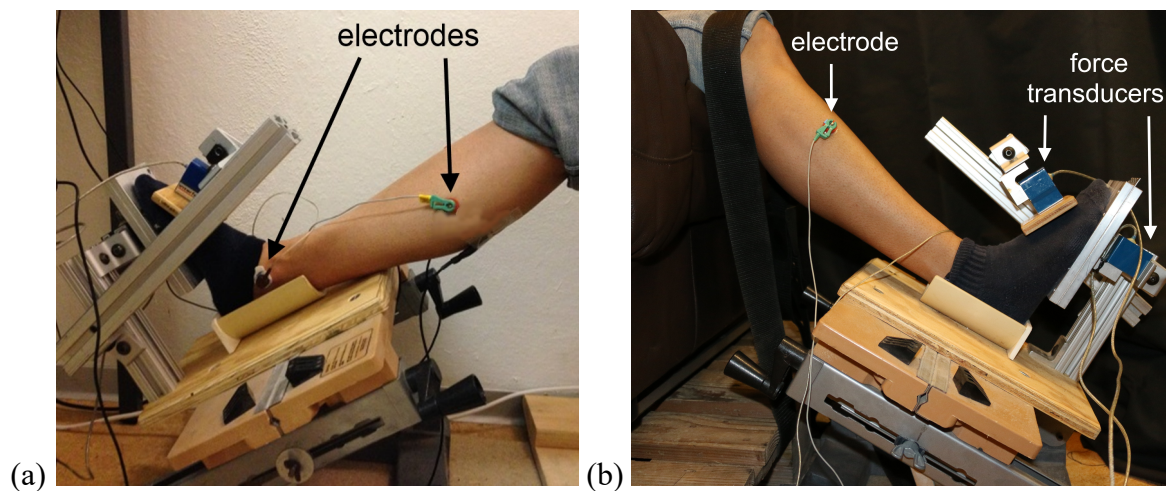


Figure 3.1. Experimental set up for measuring muscle twitch force elicited in the (a) gastrocnemius-soleus and (b) tibialis anterior muscles.

**Electrical stimulation.** Muscle stimulation and procedure were adapted from previous studies using muscle twitch force (MTF) to quantify the long-term effects of fatigue (Adamo et al., 2009; Adamo et al., 2002). Circular stimulation electrodes (Ag/AgCL, ø8 mm) filled with gel, were placed on the skin over the GS and TA muscles. A disposable pre-gelled surface electrode (57 x 34 mm, Kendall) was placed on the lower area of the medial malleolus. The optimal location was determined by the area of the muscles for which a maximum twitch force was obtained in accordance to the maximum sustainable discomfort elicited by the stimulation. Electrical pulses of 1 ms duration were delivered at a frequency of 2 Hz, with a current in the 10 – 30 mA range. Each participant indicated when the stimulation level became unpleasant and then the intensity was adjusted to the highest level that could be tolerated for the entire stimulation period. This procedure was used to recruit the largest number of muscle fibers without inducing pain beyond a level of tolerable discomfort. The locations of the stimulation electrodes were clearly marked and measured, relative to the tibia bone and lower edge of the patella for exact replacement on succeeding measurement days. The electrical stimulation was delivered through a stimulator (GS880) connected to an isolation unit (SIU5) and a constant current unit (CCU1A), all from Grass™ Instruments.

For each MTF measure, stimulations were applied for 3 - 4 minutes to reach the steady state twitch force level following potentiation (Desmedt & Hainaut, 1968; Rankin, Enoka, Volz, & Stuart, 1988). Three series of 30 twitches with a coefficient of variation of less than 5% were then recorded (Adamo et al., 2009; Adamo et al., 2002). The MTF was determined as the average of the three series.

**Postural stability.** The participants were asked to stand still on a force plate (Kistler, Winterthur), without shoes, in an upright posture with arms at the sides for 30 seconds and

with their eyes closed. Foot prints, corresponding to shoulder width with 15° ankle abduction were marked on the plate to obtain the same foot placement for every test. The force plate system provided the X and Y coordinates of the center of pressure (COP). The COP displacement speed (Geurts, Nienhuis, & Mulder, 1993) was calculated using Matlab™.

**Subjective evaluation of discomfort-fatigue.** Participants assessed localized discomfort on identical 10 cm visual analogue scales (0 – 10) for 11 body areas (lower back, and right-left hip/upper leg, knee, lower leg, ankle, foot) indicated on a body diagram (adapted Nordic questionnaire, Kuorinka et al. (1987)). The participants rated each discomfort level by placing a vertical mark through the line of the corresponding scale. In addition, a question about overall fatigue was also rated on a similar scale.

### **3.2.3 Work task**

Participants simulated standing work that consisted of performing various light manual tasks on a workbench adjusted to elbow height to prevent torso flexion. The tasks included computer work, reading, playing games, among others freely selected by the participants and alternated to prevent boredom. Forceful exertions were excluded. To maintain consistency across conditions and over time, supporting the arms on the workbench was not allowed and the same type of new sport shoe was provided to all participants. The participants were allowed to move freely within an area of 1.5 m<sup>2</sup> in front of the workbench on the linoleum over concrete laboratory floor. The standing tasks were performed over five 55-minute periods. Five minutes of rest was provided at the end of the first, third and fourth standing work period, and a 30-minute lunch break at the end of the second standing work period. The participants sat in a comfortable armchair during the rest periods.

### 3.2.4 Procedure

All participants were instructed to minimize physical exertions 24 hours prior to the experiment. Activities requiring a high level of physical exertion were not allowed. The total duration of the experimental day was about 7 hours. All participants were informed about the experimental procedure and signed a consent form, prior to the experiment. MTF and subjective evaluation of discomfort-fatigue were performed according to the schedule illustrated in Figure 3.2; in the morning before the first standing work period (baseline-M), at the beginning of the lunch break (L), immediately after the last work period (E1), and 30 minutes after that period (E2). Postural stability was tested in M, E1, and E2. The participants remained seated during the last 30 minutes after the end of the work task. Lunch and drinks were brought to the participants. In addition, to contrast standing work with a seated “office” day, the younger participants were also tested on a control day during which they remained mostly seated without performing any specific task besides usual computer work. The measurement protocol was the same for both days, only skipping E2 on the control day. The order of the experimental and control day was randomized and each were performed in two non-consecutive days.

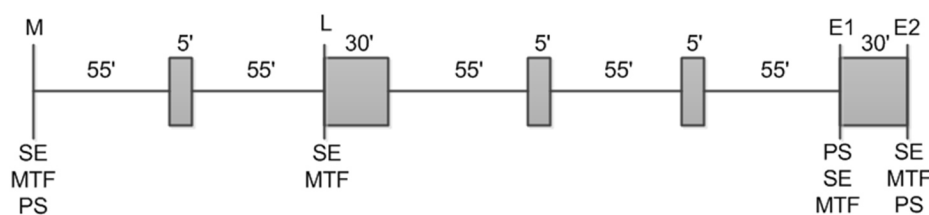


Figure 3.2. Experimental day time-line. Boxes represent the sitting time and horizontal segments the standing time. Subjective evaluation of discomfort-fatigue (SE), muscle twitch force (MTF), and postural stability (PS) were measured at different times (M, L, E1, E2).

### **3.2.5 Data analysis**

Repeated measures analysis of variance (ANOVA) was applied to each dependent variable (MTF and COP Speed) to determine the influence of time (M, L, E1, and E2) and estimate the main effects of gender and age, and/or their interaction on fatigue indicators in the experimental day. When main effects or interactions were significant, Post Hoc Tukey HSD tests were used to compare the baseline reference measures (M) with the post-work task measures (L and E1) and recovery measures (E2), and to compare post-work measures (E1 vs. E2). Significance of all tests was set at  $\alpha = 0.05$ . The measures subsequent to time M were expressed in percent of this reference. This analysis was also applied to compare the experimental and control days for the younger group. All data are expressed as mean (SE).

Subjective responses were assumed to be normally distributed and continuous as VA scales were continuous. Hence, ANOVAs were performed using a two steps process. First, ANOVAs were performed for each body part. Then evaluations associated with a significant time effect and highly correlated were considered for grouping/combination. The Cronbach coefficient alpha (CCA) was used to explore combined scales, which were then analyzed with ANOVAs and Post Hoc tests. Correlations between the size of the changes in subjective ratings and MTF, at times E1 and E2 relative to the baseline M, were also computed using Pearson's correlation.

### **3.3 Results**

ANOVA results for the GS and TA MTF, and COP Speed are summarized in Table 3.1.

Table 3.1. ANOVA for GS and TA MTF, and COP Speed.

Source	MTF GS		MTF TA		COP Speed	
	(r <sup>2</sup> adj 0.73)		(r <sup>2</sup> adj 0.45)		(r <sup>2</sup> adj 0.40)	
	F Ratio	p-value	F Ratio	p-value	F Ratio	p-value
Time	36.62	<b>&lt;.0001*</b>	6.31	<b>0.0008*</b>	3.96	<b>0.03*</b>
Age	0.19	0.67	1.53	0.23	0.08	0.78
Gender	0.48	0.5	0.09	0.77	0.63	0.44
Age*Time	2.03	0.12	1.88	0.14	0.21	0.81
Gender*Time	0.42	0.74	0.26	0.85	1.93	0.16
Age*Gender*Time	0.09	0.96	0.47	0.70	0.12	0.89

Note. Bold font and \* indicate significant values,  $\alpha = 0.5$

### 3.3.1 Muscle twitch force

**GS MTF.** The ANOVA (Table 3.1) showed a significant influence of standing work on MTF over time for the GS muscles on the experimental day. The main effects of age and gender, as well as their interactions with time, were not significant. Tukey HSD comparisons showed that GS MTF was significantly lower at E1 (68.39 (5.13)%;  $p < .001$ ) and at E2 (64.61 (4.99)%;  $p < .001$ ) than at baseline M (Figure 3.3a), and the decrease in MTF persisted at least 30 minutes after work as MTF was not significantly different between E1 and E2 ( $p = 0.82$ ). In addition, measures at M and L times did not differ significantly ( $p = 0.89$ ).

**TA MTF.** The ANOVA (Table 3.1) showed a significant influence of standing work on the MTF over time for the TA muscle on the experimental day. The main effects of age and gender, as well as their interactions with time, were not significant. Tukey HSD comparisons showed that TA MTF was significantly lower at E1 (74.0 (7.1)%;  $p = 0.03$ ) and at E2 (65.58 (6.08)%;  $p = 0.003$ ), than at baseline M (Figure 3.3b), and the decrease in MTF persisted at



least 30 minutes after work as MTF was not significantly different between E1 and E2 ( $p = 0.83$ ). In addition, measures at M and L times did not differ significantly ( $p = 0.98$ ).

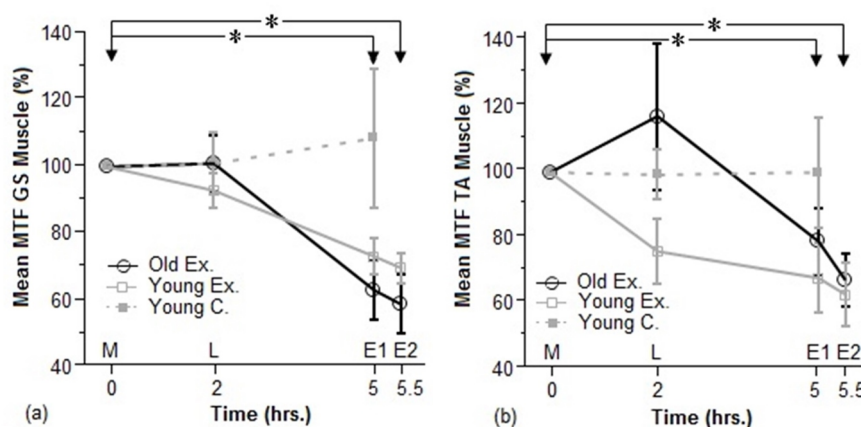


Figure 3.3. Changes in MTF, (a) Gastrocnemius-Soleus and (b) Tibialis Anterior, relative (%) to baseline (M). Ex. = experimental day and C. = control day. Vertical bars indicate SE. \* indicates a significant difference on the experimental day.

### 3.3.2 Postural stability

The ANOVA (Table 3.1) showed a significant influence of the standing work on the COP Speed over time on the experimental day. The main effects of age and gender, as well as their interactions with time, were not significant. Tukey HSD comparisons showed that the COP Speed was significantly higher at E2 (116.87 (5.49)%;  $p = 0.02$ ) but not at E1 (106.81 (5.39)%;  $p = 0.41$ ) when compared to baseline M (Figure 3.4).

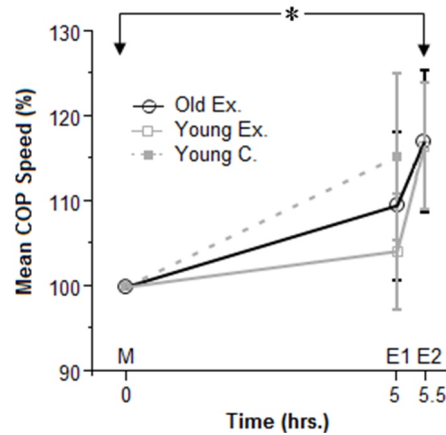


Figure 3.4. Changes in COP Speed were relative (%) to baseline (M). Ex. = experimental day and C. = control day. Vertical bars indicate SE. \* indicates a significant difference on the experimental day.

### 3.3.3 Subjective evaluation of discomfort -fatigue

Three combined scales based on a  $CCa > 0.8$  were created: 1) Hips area  $\ni$  low back, both hips and upper legs, 2) Knees  $\ni$  both knees, and 3) Lower legs area  $\ni$  both lower legs, ankles and feet. The corresponding ANOVAs results are presented in Table 3.2.

Table 3.2. ANOVA for Subjective Discomfort-Fatigue Ratings.

Source	Hips area ( $r^2_{adj}$ 0.42)		Knees ( $r^2_{adj}$ 0.66)		Lower legs area ( $r^2_{adj}$ 0.49)	
	F Ratio	p-value	F Ratio	p-value	F Ratio	p-value
Time	15.13	<b>&lt;.0001*</b>	6.66	<b>0.0003*</b>	40.71	<b>&lt;.0001*</b>
Age	2.40	0.13	3.13	0.09	7.32	<b>0.013*</b>
Gender	0.61	0.44	0.001	0.97	0.39	0.54
Age*Time	0.21	0.89	1.57	0.20	8.46	<b>&lt;.0001*</b>
Gender*Time	2.78	<b>0.04*</b>	1.29	0.28	0.63	0.60
Age*Gender*Time	0.71	0.54	0.90	0.44	1.27	0.28

Note. Bold font and \* indicate significant values,  $\alpha = 0.5$

**Hips area.** The ANOVA (Table 3.2) showed a significant influence of standing work on the subjective ratings of fatigue in the hips area. The Gender x Time interaction was significant, but Age x Time interaction was not. Post hoc comparisons showed that discomfort was a) significantly greater for both genders (Female  $p < .001$ ; Male  $p = 0.03$ ) immediately after standing work (E1) when compare to baseline M (Figure 3.5a), b) not significantly different between females and males at times L ( $p = 1.0$ ), E1 ( $p = 0.67$ ) and at E2 ( $p = 0.99$ ) c) not significantly different at L (Female  $p = 0.69$ ; Male  $p = 0.65$ ) and E2 (Female  $p = 0.08$ ; Male  $p = 1.0$ ) when compared to baseline M for both genders.

**Knees.** The ANOVA (Table 3.2) showed a significant influence of standing work on the subjective ratings of fatigue in the knees. Neither the main effects of gender or age nor their interactions were significant. Post hoc comparisons showed that ratings were not significantly greater at time L ( $p = 0.63$ ) but it was at E1 ( $p < .001$ ) when compared to baseline M. However, the perception of discomfort did not persist post-work, as ratings were not significantly different ( $p = 0.33$ ) between E2 and baseline M (Figure 3.5b).

**Lower legs area.** The ANOVA (Table 3.2) showed a significant influence of standing work on the subjective ratings of fatigue in the lower legs area. The Age x Time interaction was significant; in contrast the Gender x Time interaction was not significant. Post hoc comparisons showed that the perception of discomfort for the older group was significantly greater at times L ( $p < .001$ ) and E1 ( $p < .001$ ) but for the younger group only at E1 ( $p < .001$ ) when compared to baseline M. Ratings were greater for the older than the younger group at time E1 ( $p = 0.004$ ), but not at times L ( $p = 0.16$ ) and E2 ( $p = 0.53$ ). The perception of discomfort did not persist post-work for the younger group, as ratings at E2 were not significantly different from baseline M ( $p = 0.39$ ). For the older group, perception of discomfort decrease significantly ( $p < .001$ ) from E1 to E2. However, this decrease did not correspond to a complete return to baseline yet as perception at E2 is still different ( $p < .001$ ) from M (Figure 3.5c).

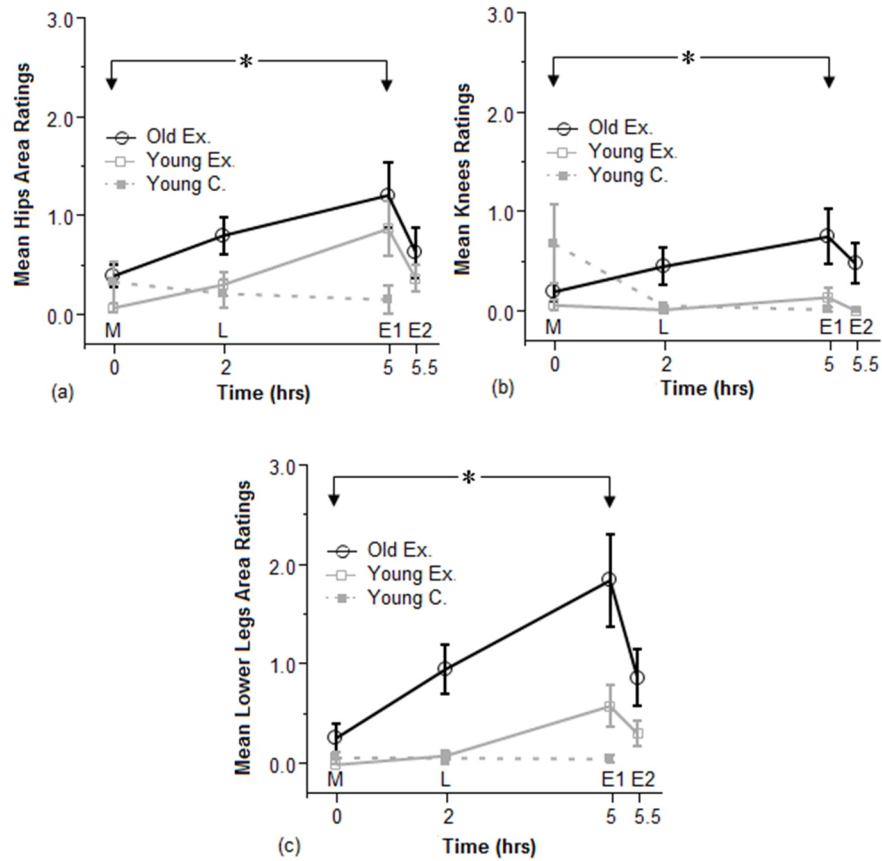


Figure 3.5. Changes in discomfort-fatigue ratings, (a) Hips area, (b) Knees, and (c) Lower legs area. Ex. = experimental day and C. = control day. Vertical bars indicate SE. \* indicates a significant difference on the experimental day.

**Overall fatigue.** The ANOVA ( $r^2_{adj} = 0.69$ ), showed a significant influence of standing work on the subjective evaluation of overall fatigue over time ( $F(3, 65.08) = 18.13$ ,  $p < 0.0001$ ). The Age x Time ( $F(3, 65.08) = 3.69$ ,  $p = 0.02$ ) and Gender x Time ( $F(3, 65.08) = 3.26$ ,  $p = 0.03$ ) interactions were significant. However, the three way interaction was not significant ( $F(3, 65.08) = 1.04$ ,  $p = 0.38$ ). Post hoc comparisons showed that the perception of discomfort relative to M was significantly higher at time E1 ( $p < 0.0001$ ) for the older group but not for the younger group ( $p = 0.39$ ). In addition, post hoc tests showed that the

perception of discomfort persisted only for the older female group ( $p = 0.0023$ ) when compared to the baseline (Figure 3.6).

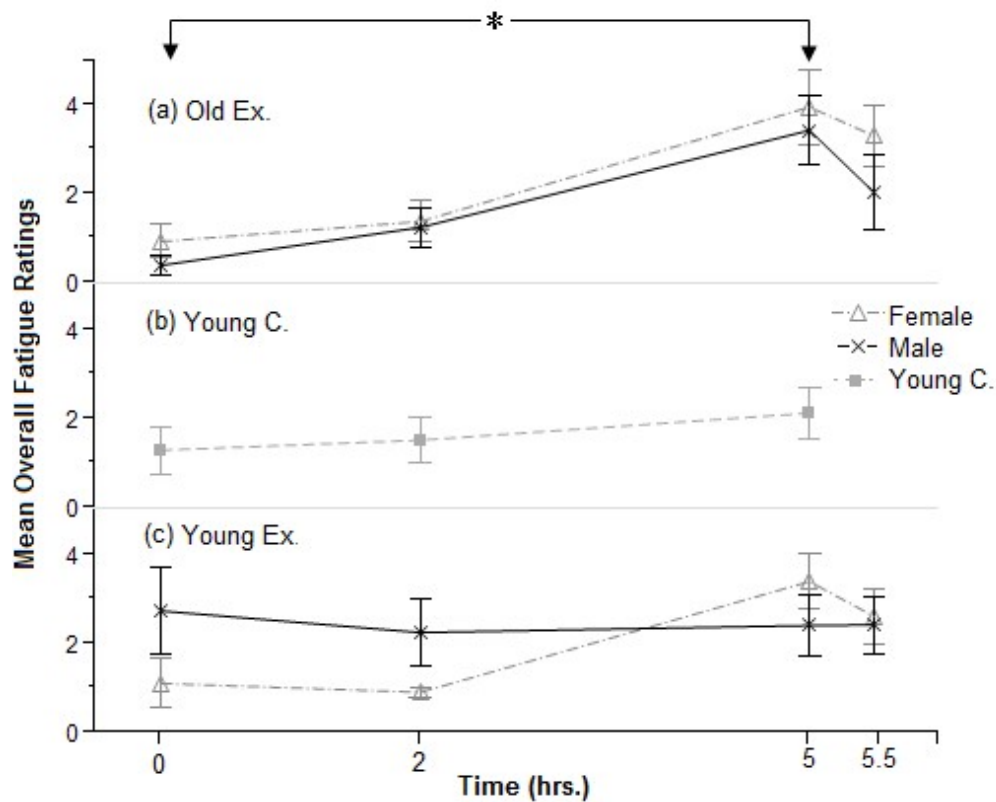


Figure 3.6. Overall Fatigue Ratings. Changes in discomfort-fatigue ratings, (a) Older group experimental day, (b) Younger group control day, and (c) Younger group experimental day. Ex. = experimental day and C. = control day. Vertical bars indicate SE. \* indicates a significant difference.

### 3.3.4 Correlation between subjective evaluation and MTF

The decrease in GS and TA MTF magnitude was not correlated ( $r^2_{adj} < 0.01$ ) to the increase in fatigue ratings in the lower legs area, knees, and hips area between M and E1. Similar results were found between M and E2 ( $r^2_{adj} < 0.01$ ) for each fatigue rating.

### **3.3.5 Control day (younger group)**

The ANOVA showed that variations in GS MTF over time on the control day were not significant ( $F(3, 30) = 1.28, p = 0.30$ ), as illustrated by Figure 3.3a. Neither the main effect of gender nor their interaction with time were significant. Similar outcomes were found for TA MTF. The variations in TA MTF over time were not significant ( $F(3, 27) = 0.17, p = 0.91$ ), neither were the main effect of gender nor the interaction with time, as illustrated by Figure 3.3b. In addition, COP Speed was not significantly different over time ( $F(1, 20) = 1.90, p = 0.17$ ), as illustrated by Figure 3.4. Furthermore, ratings did not vary significantly over time for fatigue perceived in the different body areas.

## **3.4 Discussion**

The present study investigated the long-term effects of fatigue in the lower limbs after five hours of standing work including rest breaks, as is observed in manufacturing plants. Persistence of the decrease in MTF magnitude and the increase of COP displacement speed observed 30 minutes post-work are indicators of the long lasting effects of muscle fatigue. Thirty minutes post-work recovery indicated by most of the subjective evaluations, contrasts with the objective measure showing fatigue persistence. Hence, we assume that five hours of standing work have a significant impact on lower limbs fatigue and the effect may not be perceived.

### **3.4.1 MTF and fatigue**

Previous upper limb studies noted the long-term fatigue effects of prolonged low-force contractions (Adamo et al., 2009; Adamo et al., 2002; Blangsted et al., 2005; Johnson et al., 2013). Fatigue effects of long duration have been associated with mechanisms taking place at the peripheral level, and they have been evidenced by electrical stimulations that bypass central influences. More specifically, the mechanism responsible for the decrease in muscle

twitch force is associated with the failure in excitation-contraction coupling (Enoka & Stuart, 1992; Westerblad, Bruton, Allen, & Lannergren, 2000), which exhibits a slow recovery (Edwards et al., 1977). The present study showed that, the MTF in the GS and TA muscles decreases significantly after prolonged standing and persists at least 30 minutes post standing work. Consistent with results obtained in the upper limbs, as mentioned above, the decrease in MTF indicates that prolonged low force exertions also have detrimental effects in lower leg muscles and the long-term effects of fatigue in the upper and lower limbs are likely to stem from the same mechanism. As fatigue has been shown to alter motor control/movements and postural control (Paillard, 2012), as observed here and in other studies (Johnston, Howard, Cawley, & Losse, 1998), then it may be presumed that changes in posture, even subtle, resulting from fatigue effects contribute to changes in the low back-hip relationship which in the long term may contribute to low back disorders. This assumption is in line with the perspective that fatigue is a precursor of musculoskeletal disorders (Armstrong et al., 1993; Edwards, 1988). The perniciousness of the long lasting effects appears to be related to a lack of their conscious perception, as indicated by the divergence of objective and subjective measures post work.

Furthermore, the decrease in MTF occurred similarly in the GS and TA muscles despite their difference in muscle fiber composition (Johnson, Polgar, Weightman, & Appleton, 1973) and antagonistic functions. Their respective fatigue suggests that the GS and TA muscles are to some extent used similarly while performing standing work. However, the variability was greater for the TA than GS MTF (see Figure 3.3). This difference probably stems from the difficulty of the measurement associated with a delicate placement of the force transducer (in term of orientation and location) over the TA muscle and the need to re-adjust the transducer for every repetition of the measure. As standing work induces swelling of the foot, then



transducer adjustments were needed for each series of measurements to maintain constant its pressure over the dorsal side of the foot (Figure 3.1). This introduced a source of variation. Therefore, since GS and TA MTF provide similar information and each measurement required significant preparation and testing time it is advisable to only use GS MTF.

There was no evidence that fatigue had developed after two hours of standing work with five minutes seated rest in between. Hence, this standing work duration including the rest breaks, may be acceptable, but five hours with the tested rest cycle may present some risk. It is expected that after a common eight-hour work shift the long lasting effects of fatigue from standing work will be more pronounced than found in this study. In addition, the absence of significant effects on MTF on the control day clearly supports the conclusion that long-term fatigue develops as a consequence of standing.

Although not significant, gender and age effects suggest possible tendencies of differentiation. This lack of significance may be due to the limited statistical power resulting from the modest number of subjects in the respective subgroups. However, previous studies concerning upper limb muscles did not reveal gender or age effects on MTF (e.g., Adamo et al., 2009; Adamo et al., 2002) from low level repetitive exertions. Gender or age influences on muscle fatigue (Wojcik, Nussbaum, Lin, Shibata, & Madigan, 2011) may result primarily from high force exertion tasks, which are associated with different mechanisms of fatigue, as acknowledge earlier (Edwards et al., 1977; Enoka & Stuart, 1992; Johnson et al., 2013; Jones, 1996). Hence, we assume that considering gender and age as major factors may not be a priority in the evaluation of fatiguing task involving low-level exertions, either sustained or intermittent, such as standing work.

### **3.4.2 Postural stability and fatigue**

Gribble and Hertel (2004) suggested that fatigue in the lower extremities, including the hips, impairs postural control. In addition, Freitas et al. (2005) found in adults that COP displacement speed increased after standing for 30 minutes. More recently, Gimmon, Riemer, Oddsson, and Melzer (2011) concluded that localized fatigue of plantar flexor muscles may alter postural stability while Wojcik et al. (2011) showed that fatigue in lower limb joint muscles resulting from high exertions affect postural control through an increase in joint torque variability. Therefore, it was hypothesized that fatigue in the lower leg muscles after five hours of standing may influence postural sway. In our study, when compared to baseline, the increase in COP displacement speed was not significant immediately after five hours of standing work but was significant 30 minutes post-work. This may not be a paradox as the long-term effects of fatigue may be more pronounced 30 minutes to an hour post fatiguing task (e.g., Adamo et al., 2009; Adamo et al., 2002; Sogaard et al., 2003). Furthermore, the increase in fatigue between E1 and E2 periods was not significant; however, a small increment in fatigue might have led to a further increase in postural control alterations that resulted in a significant effect at time E2. This assumption is partly supported by the fact that COP displacement speed also increased on the control day but was not significant at time E1. Overall, since COP displacement speed tends to increase both during the working day and the control day, it may be presumed that localized muscle fatigue may not be the only component contributing to a decrease in postural stability. Central effects acting on motor control functions (Gandevia, 2001) associated with a general fatigue of physical and/or mental origin may require further consideration.

### 3.4.3 Subjective evaluation and fatigue

Correlation between back and lower limb discomfort and prolonged standing work has been shown (Antle & Côté, 2013; Drury et al., 2008). We observed that perception of lower back and lower limbs discomfort was significantly higher immediately after standing work than at baseline. However, the perception of discomfort had vanished 30 minutes post work, except for minor residual discomfort in the lower legs area for the older group. This drop, taken alone, would indicate a recovery after 30 minutes of rest. However, the dichotomy between the majority of subjective evaluations and the MTF objective measure at time E2, along with the lack of correlation, indicates that an absence of perception does not mean an absence of significant fatigue. This phenomenon is in agreement with previous findings where perception of fatigue had vanished after 60 minutes (Adamo et al., 2002) or even 15 minutes (Adamo et al., 2009) recovery period. The results support the perspective that subjective perception may not be a good indicator of the long-term effects of fatigue.

The general fatigue ratings showed an influence of standing work on overall fatigue and to some extent gender and age effects on this were observed. The overall fatigue evaluation was higher for the younger than the older group at baseline. This difference was no longer present at the other times of measurement. Findings from Van Hooff, Geurts, Kompier, and Taris (2007) suggest that a single-item fatigue measure is valid to evaluate daily fatigue. However, based on the present results, such a general question does not adequately address the differentiation between general and localized muscle fatigue. An interpretation of this “morning” difference in perception is speculative, however, it could stem from differences in life-style between younger and older adults, resulting from differences in activities (other than the required no heavy physical exertion) during the 24 hours preceding the experiment. Finally, both possible non-controlled activities and the non-discrimination of localized muscle

fatigue and general fatigue could be sufficient to explain the significantly different perception of fatigue at time E2 by the older female participants and the lack of consistency of this result with the other findings. This reinforces our assumption that specific objective evaluations are preferable for quantifying long-term muscle fatigue.

### ***3.5 Conclusions***

Fatigue did not develop after the first two hours of standing work. However, it was strongly present after five hours of standing work with regular rest breaks, and persisted at least 30 minutes post-work. The MTF method is sensitive to fatigue of long duration. Changes in postural stability may indicate fatigue; however similar changes on the control day suggest the interference of factors other than long-term fatigue. The lack of congruence between subjective and objective methods underlines the strong limitation of subjective evaluation of the long-term effects of fatigue. In addition, at the very end of the working day, localized “muscle” fatigue and “general” fatigue may not be well distinguished subjectively. Finally, age and gender effects are not conspicuous. The findings are limited to the work cycle tested and different work cycles and other performance measures may be envisaged to further understand the effects of long-term fatigue.

#### **Key points**

- Previous studies investigated long-term fatigue during low-level exertions in the upper limbs; however, the extent to which long-term fatigue develops and persists in the lower limbs after prolonged standing work has received little attention.
- The results suggest that long-term fatigue develops after five hours of standing work with regular five-minute rest breaks and persists at least 30 minutes after a seated recovery period without being perceived.

- Subjective evaluation of discomfort may not be sensitive to the long lasting effects of fatigue in contrast with objective measurements.
- Specific objective tests such as MTF are preferable for quantifying long-term muscle fatigue.

### **Acknowledgements of the study**

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## 4. Long-lasting changes in muscle twitch force during simulated work

### while standing or walking

*(Maria-Gabriela Garcia, Rudolf Wall, Benjamin Steinhilber, Thomas Läubli, Bernard J. Martin)*

#### Abstract

**Objective:** Evaluate the long-lasting effects of prolonged standing work on a hard floor or floor mat and slow-pace walking on muscle twitch force (MTF) elicited by electrical stimulation.

**Background:** Prolonged standing work may alter lower leg muscle function, which can be quantified by changes in the MTF amplitude and duration related to muscle fatigue.

Ergonomic interventions have been proposed to mitigate fatigue and discomfort, however their influences remain controversial.

**Method:** Ten men and eight women simulated standing work in 320 minutes experiments with three conditions: standing on a hard floor or an antifatigue mat and walking on a treadmill, each including three seated rest breaks. MTF in the gastrocnemius-soleus muscles was evaluated through changes in signal amplitude and duration.

**Results:** The significant decrease of MTF amplitude and an increase of duration after standing work on a hard floor and on a mat persisted beyond 1 hour post work. During walking, significant MTF metrics changes appeared 30 minutes post work. MTF amplitude decrease was not significant after the first 110 minutes in any of the conditions; however, MTF duration was significantly higher than baseline in the standing conditions.

**Conclusion:** Similar long-lasting weakening of MTF was induced by standing on a hard floor and on an antifatigue mat. However, walking partially attenuated this phenomenon.

**Application:** Mostly static standing is likely to contribute to alterations of MTF in lower leg muscles and potentially to musculoskeletal disorders regardless of the flooring characteristics. Occupational activities including slow-pace walking may reduce such deterioration in muscle function.

#### ***4.1 Introduction***

Many service occupations, such as health care workers (Meijssen & Knibbe, 2007), and sales personnel (Pensri, Janwantanakul, & Chaikumarn, 2009) as well as many manufacturing jobs (Balasubramanian, Adalarasu, & Regulapati, 2008; Messing et al., 2015) require working in a standing posture. Standing work is very common in diverse workplaces around the world. Data from the European Survey on Working Conditions (Parent-Thirion et al., 2012) showed that more than 50% of the EU workforce stands for more than  $\frac{3}{4}$  of their working time (Graf et al., 2015). Prolonged standing has been associated with leg and lower back discomfort (Andersen et al., 2007; Drury et al., 2008) or pain (Graf et al., 2015; Waters & Dick, 2014), vascular problems (Sudol-Szopinska, Bogdan, Szopinski, Panorska, & Kolodziejczak, 2011; Tüchsen, Krause, Hannerz, Burr, & Kristensen, 2000) and musculoskeletal disorders (MSDs) (Riddle et al., 2003; Werner et al., 2010). Although the mechanisms leading to MSDs are not fully understood, muscle fatigue is considered as a precursor to musculoskeletal disorders; see Côté (2014), and Sjogaard and Sogaard (1998) for reviews.

Muscle fatigue has been generally defined as a reduction in force generation ability (Gandevia, 2001). Multiple mechanisms contribute to the development of muscle fatigue, and the particular mechanism(s) could be dependent on the task performed (Enoka & Duchateau, 2008). Activities that demand sustained or intermittent low levels of muscle exertion, even those lower than 5% of the maximal voluntary contraction (Blangsted et al., 2005), can lead to

the development of a component of muscle fatigue referred to, depending on the study, as low frequency fatigue, long-lasting fatigue or long-term muscle fatigue. This component of muscle fatigue is associated with a duration greater than 30 minutes post work (Adamo et al., 2009; Enoka & Stuart, 1992; Jones, 1996) and may persist up to 24 hours after the end of the working period (Edwards et al., 1977). Previous literature suggests that this component of muscle fatigue can be evidenced by a decrease in muscle twitch force (MTF ) amplitude induced by electrical stimulation at low frequencies, <20Hz (Adamo et al., 2009; Adamo et al., 2002; Edwards et al., 1977; Johnson et al., 2013). In addition, this long-lasting component of fatigue is also associated with an increase in muscle contraction and relaxation times, which is commonly called the duration (Johnson et al., 2013; Kim & Johnson, 2014). The measure of MTF duration is of particular importance when potentiation (increase in twitch force) induced by significant muscle activity is concurrent to fatigue phenomena which contribute to an increase in muscle twitch duration (Kim & Johnson, 2014; Rassier & Macintosh, 2000). Furthermore, this long-lasting component of fatigue has been linked to a failure of excitation contraction coupling (Jones, 1996; Sogaard et al., 2003; Westerblad et al., 2000). Other mechanisms with various time profiles may contribute to the alteration of muscle fatigue as a function of the characteristics of the task. A complete description of the complexity of the mechanisms underlying the reduction of muscle force generation during and following activity is beyond the scope of this work, however, changes in MTF duration and amplitude can indicate muscle function impairment due to prolonged standing or walking work. Muscle electrical stimulation methods, MTF included, have been used to quantify fatigue in the upper limbs (Adamo et al., 2009; Adamo et al., 2002; Bystrom & Kilbom, 1991; Crenshaw et al., 2010; Johnson et al., 2013; Kim & Johnson, 2014; Thomsen, Johnson, Svendsen, Kryger, & Bonde, 2007) and in the lower limbs (Brownie & Martin, 2015; Garcia,



Laubli, & Martin, 2015) to understand the consequences of occupational tasks. This type of method has also been used by Wawrow et al. (2011) in an animal model to investigate MSDs prevention methods. These authors, compared fatigue produced by different work/rest cycles in a rat medial longissimus muscles. A link between muscle fatigue and MSDs, and in particular the long lasting component of muscle fatigue, has been proposed by Edwards et al. (1977). Since then, the association between muscle fatigue and MSDs has received strong support (Côté, 2014; Gallagher & Schall, 2016).

Interventions consisting of altering the flooring conditions (Orlando & King, 2004; Redfern & Chaffin, 1995) or the introduction of dynamic standing, where the person intermittently walks about (Balasubramanian et al., 2009), have been proposed in an attempt to mitigate fatigue during standing work. Softer surfaces (Streepey, Gross, Martin, Sundravalli, & Schiller, 2000), floor mats (Aghazadeh et al., 2015; Cham & Redfern, 2001; King, 2002) or sole inserts (Brownie & Martin, 2015) may reduce the subjective discomfort felt in the lower limbs or back, when compared to hard floors. However, the influence these interventions have on the physiological components of muscle fatigue is still controversial (Redfern & Cham, 2000; Zander et al., 2004). The evidence of long-lasting fatigue from standing work has only received scientific attention recently. Indeed, we showed that the decrease in MTF amplitude in the gastrocnemius-soleus muscles induced by standing may not be apparent after 2 hours of work (Garcia et al., 2015) but is significant after 5 hours of standing, including regular 5 minute breaks and a lunch break (Brownie & Martin, 2015; Garcia et al., 2015). In these studies, decrease MTF amplitude persisted at least 30 minutes after the end of the working day and this effect was not perceived by the subjects. A similar lack of perception has been observed in comparable studies concerning the upper limbs (Adamo et al., 2009; Nakata et al., 1992; Rose, Neumann, Hägg, & Kenttä, 2014). A few

studies have compared muscle fatigue resulting from static standing and intermittent or slow-pace walking. Balasubramanian et al. (2009) reported that fatigue ratings in the legs and lower back after 60 minutes of standing work were significantly lower in intermittent walking than in a static standing posture. However, neither the effects of longer standing periods nor the long-lasting post standing effects have been investigated under walking conditions.

The goal of this study was to differentiate changes in MTF during two standing and one walking simulated workdays. Hence, the present study tested the hypothesis that changes in MTF amplitude and duration differ between standing work performed on a hard floor, or on a floor mat, and slow-pace walking on a treadmill.

## **4.2 Method**

### **4.2.1 Participants**

Eighteen healthy young adults (10 men and 8 women) between 18 to 35 years of age participated in this study after providing written informed consent approved by the ethics committee of the Medical Department of the University of Tübingen. One additional participant that experienced chest pain during the first experimental walking day was not included in the analysis. The participants mean age, height and weight ( $\pm$  SD) were 25 ( $\pm$  4) years, 174.3 ( $\pm$  10.2) cm and 68 ( $\pm$  11.4) kg, respectively. Prior to the study, the participants reported to be free of any neurological, vascular or acute musculoskeletal conditions. In addition, blood pressure and heart rate were checked before the beginning of the first experimental day. All participants received monetary compensation for taking part in the study.

### **4.2.2 Experimental protocol**

MTF metrics for the gastrocnemius-soleus (GS) muscles were quantified for each participant in three conditions, each tested on non-consecutive days and assigned in a random

order: 1) standing on a hard concrete floor covered with 3mm linoleum (Hard Floor), 2) standing on a commercial 95 Shore Durometer Type A antifatigue rubber mat of 19 mm thickness, and 90 x 60.5 cm area (Mat), 3) walking on a treadmill (Walk). In each condition work and rest periods were alternated according to the following schedule: two work periods (W) of 110 minutes were separated by a 35-minute lunch seated break, the second period was followed by a 10-minute seated break and this was followed by a third work period of 55 minutes (see Figure 4.1). Hence, the total workday duration was 320 minutes. During the work periods the participants performed tasks consisting of assembling pens on a worktable adjusted to elbow height (W1), watching a movie or reading (W2) and finally playing video games (W3). Task materials were placed close to the participants to minimize long reaches and torso flexion. The standing area was constrained to no more than 1.5 m<sup>2</sup>, as is common in industrial work. In both standing conditions participants were allowed to shift their body weight and move their legs; however, walking, defined as performing more than two consecutive steps, was not allowed. In the walking condition, the treadmill speed was determined as a function of stature using the Methods-Time Measurement (MTM) approach (Britzke, 2014) and maintained constant for each participant. Since the MTM speed recommendation does not consider working while walking, the speed was reduced by 50% to provide a comfortable pace not interfering with task performance, as confirmed by the participants. The mean walking speed  $\pm$  SD for all participants was 2.0 km/hr  $\pm$  0.19. Leaning and resting the arms on the worktable were not allowed in any conditions. During the breaks and for 1 hour after the last working period the participants remained seated. MTF was evaluated in the morning before the first work period as baseline (Bsl), at the beginning of the lunch break (L), and immediately (E1), 30 minutes (E2), and 1 hour (E3) after the last working period. Hence, the total duration of each experimental day was about 8 hours; a

lunch meal and beverages were provided. Participants were required to abstain from activities such as running, weight lifting and anything involving physical exertion for at least one day before each experimental day. The experimental days were performed with a minimum of 2 days and a maximum of 7 days apart for each participant.



Figure 4.1. Experimental time schedule. The horizontal lines represent the working periods (standing or walking) with their respective tasks (W1, W2 and W3), and the boxes represent the rest breaks. MTF metrics were obtained at times Bsl, L, E1, E2 and E3.

### 4.2.3 Apparatus and procedure

The apparatus and procedure used to measure MTF for the GS muscles were described in a previous study (Garcia et al., 2015). The participant was seated comfortably in an armchair with one foot rested on the floor while the other was placed on an inclined metal plate fixed to a strain gauge connected to an amplifier (Figure 4.2). The chair was adjusted to obtain a leg posture corresponding to a 60° knee flexion and 0° ankle dorsiflexion angle from the neutral anatomical position. A strap located over the knee was attached to the armchair to prevent upward leg movement during GS muscles stimulation. No effort was exerted in holding this relaxed posture as confirmed by participants and force baseline measures. Twitches were elicited in the GS by electrical stimulation delivered through a Digitimer Ltd stimulator (DS7A) driven by a pulse generator (DG2A). Pre-gelled 5 x 5 cm electrical stimulation electrodes (Axion™), were placed on the skin over the medial area of the gastrocnemius and soleus muscles, corresponding to the motor point area (Botter et al., 2011), and over the upper area of the Achilles tendon. The stimulated leg was randomly assigned for each participant.

The location of the electrode on the muscle was first estimated by palpation and manual resistance to plantar flexion and then by the area corresponding to the maximum tolerable discomfort induced by a 2 Hz stimulation yielding the maximum twitch force. The locations of the electrodes were marked on a transparent film together with reference marks such as moles for exact repositioning on succeeding experimental days. The stimulation intensity across participants ranged from 10 to 30 mA, with a pulse duration of 1ms. For each participant, the same stimulation intensity was used on all experimental days. The twitch forces were sampled at 1000 Hz and collected using custom software based on LabView (NI). MTF amplitude and duration ( $= \text{Contraction Time} + \frac{1}{2} \text{Relaxation Time}$ ) were calculated in real time to visualize the force signal, so the experimenter could determine potentiation and measurement periods; see Kim and Johnson (2014) study. At each measurement period these metrics were calculated as the average of three consecutive series of 30 twitches with a coefficient of variation under 3% after potentiation (induced by electrical stimulation), which corresponds to the steady-state phase of MTF (Adamo et al., 2002). The duration of the muscle stimulation period was about 4 minutes at each MTF evaluation.

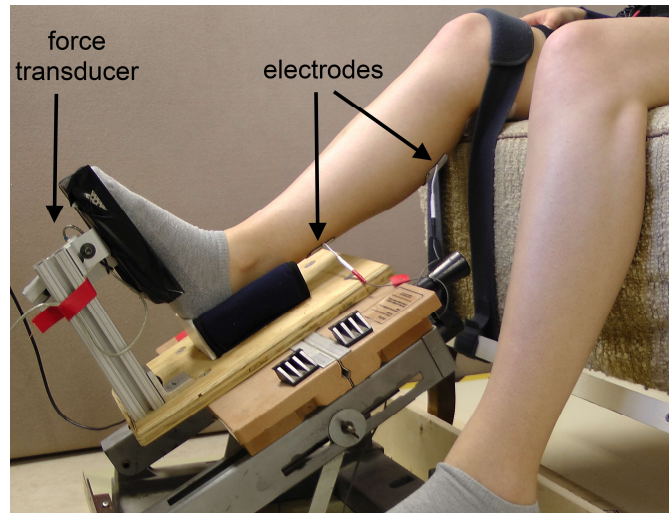


Figure 4.2. Experimental setup for measuring muscle twitch force in the gastrocnemius-soleus muscles.

#### 4.2.4 Data analysis

The MTF metrics for time L, E1, E2 and E3 were expressed as a percentage of the baseline measure using each participant as their own control. These data fulfilled the normality tests. A repeated measures analysis of variance (ANOVA) was performed for both MTF amplitude and duration to determine the main effects for time (Bsl, L, E1, E2 and E3) and condition (Hard Floor, Mat, and Walk) as well as their interactions. Post hoc Tukey HSD tests were used to identify times where MTF metrics significantly differ from the baseline. The level of significance was set to  $\alpha = 0.05$ . All data are expressed as means and standard errors. Data analyses were conducted using JMP 10.0 (SAS Institute Inc.).

### 4.3 Results

#### 4.3.1 MTF amplitude

The ANOVA (Table 4.1) revealed that the main effects for time, condition and their interaction were highly significant ( $p < .001$ ), indicating that MTF amplitude at the different measurement times differed depending on the condition (Hard Floor, Mat, Walk). Tukey

HSD comparisons showed that for the Hard Floor condition, MTF amplitude was significantly lower at E1 ( $M = 74.47\%$ ,  $SE = 5.64\%$ ;  $p < .0001$ ), E2 ( $M = 74.95\%$ ,  $SE = 6.43\%$ ;  $p < .0001$ ), and E3 ( $M = 71.83\%$ ,  $SE = 6.91\%$ ;  $p < .0001$ ), but not at L ( $M = 90.12\%$ ,  $SE = 4.34\%$ ;  $p = .75$ ) when compared to baseline. In addition, post hoc comparisons for the Hard Floor condition showed that the decrease in MTF amplitude did not change 30 minutes and 1 hour after work since E2 and E3 were not significantly different from E1 ( $p = 1.0$ ).

Similar results were found for the Mat condition since MTF amplitude was significantly lower at E1 ( $M = 70.42\%$ ,  $SE = 6.50\%$ ;  $p < .0001$ ), E2 ( $M = 70.72\%$ ,  $SE = 6.52\%$ ;  $p < .0001$ ), and E3 ( $M = 69.64\%$ ,  $SE = 6.64\%$ ;  $p < .0001$ ), but not at L ( $M = 92.92\%$ ,  $SE = 5.66\%$ ;  $p = .98$ ) when compared to baseline. Post hoc comparisons also showed that the decrease in MTF amplitude for this condition did not change 30 minutes and 1 hour after work since E2 and E3 were not significantly different from E1 ( $p = 1.0$ ). In contrast, for the Walk condition, MTF amplitude was not significantly different at E1 ( $M = 103.01\%$ ,  $SE = 2.80\%$ ;  $p = 1.0$ ), E2 ( $M = 95.74\%$ ,  $SE = 4.36\%$ ;  $p = .99$ ) and E3 ( $M = 93.91\%$ ,  $SE = 5.54\%$ ;  $p = .99$ ), when compared to baseline. In addition, MTF amplitude was not significantly different at L ( $M = 109.34\%$ ,  $SE = 3.05\%$ ;  $p = .82$ ) when compared to baseline. Finally, post hoc comparisons revealed that the Hard Floor and Mat conditions were not significantly different at each measurement time (L, E1, E2 and E3;  $p = 1.0$ ), but both significantly differed from the Walk condition at each measurement time (L, E1, E2 and E3;  $p < .05$ ), as shown in Figure 4.3.

Table 4.1. ANOVA for MTF amplitude.

MTF amplitude ( $r^2_{adj} = .89$ )			
Source	df	F Ratio	p
Time	4	13.57	<b>&lt;.0001*</b>
Condition	2	13.74	<b>&lt;.0001*</b>
Condition*Time	8	7.97	<b>&lt;.0001*</b>

Note. Bold font and \* indicate significant values,  $\alpha = .5$ .

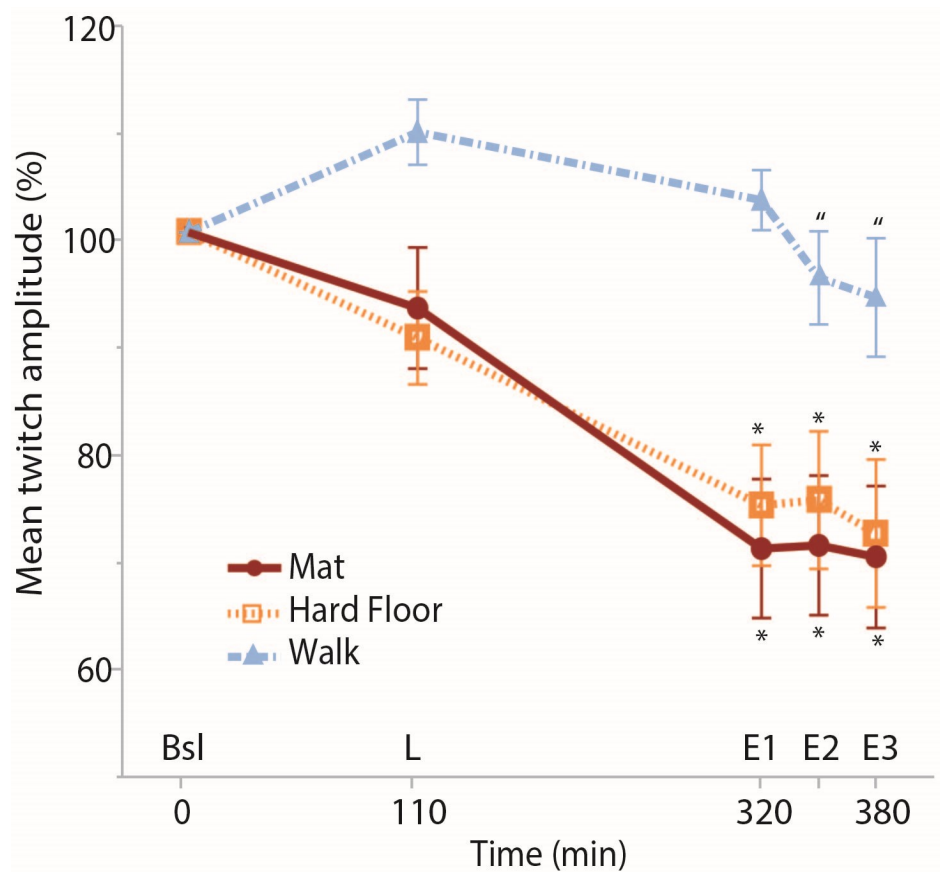


Figure 4.3. Changes in muscle twitch force amplitude for Mat, Hard Floor and Walk conditions, relative (%) to baseline (Bsl). Vertical bars indicate standard errors. Asterisk (\*) indicates a significant difference when compared to baseline (Bsl) within each condition and (") indicates a significant difference when compared to L, for the Walk condition.

The Walk condition data presented a different pattern than the other two conditions, especially at L and E1 (Figure 4.3). Thus an ANOVA was applied to this condition to



identify specific changes expected to stem from different mechanisms. This analysis revealed that the main effect for time was significant,  $F(4, 85) = 4.41$ ,  $p = .003$ ,  $r^2_{adj} = .50$ . Post hoc comparisons showed that MTF amplitude differed significantly at E2 ( $M = 95.74\%$ ,  $SE = 4.36\%$ ;  $p = .01$ ) and E3 ( $M = 93.91\%$ ,  $SE = 5.54\%$ ;  $p = .003$ ) when compared to L ( $M = 109.34\%$ ,  $SE = 3.05\%$ ).

#### **4.3.2 MTF duration**

The ANOVA (Table 4.2) showed that the main effects for time, condition and their interaction were highly significant ( $p < .001$ ), indicating that MTF duration at the different measurement times differed depending on the condition (Hard Floor, Mat, Walk). Post hoc comparisons showed that for the Hard Floor condition, MTF duration was significantly longer at L ( $M = 112.36\%$ ,  $SE = 1.91\%$ ;  $p < .0001$ ), E1 ( $M = 112.76\%$ ,  $SE = 2.05\%$ ;  $p < .0001$ ), E2 ( $M = 121.48\%$ ,  $SE = 2.35\%$ ;  $p < .0001$ ), and E3 ( $M = 125.84\%$ ,  $SE = 2.56\%$ ;  $p < .0001$ ), when compared to baseline. Post hoc comparisons for the Hard Floor condition also showed that MTF duration continues to increase after work, as MTF duration was significantly longer at E2 and E3 when compared to E1 ( $p < .001$ ). Similar results were found for the Mat condition since MTF duration was significantly longer at L ( $M = 109.59\%$ ,  $SE = 2.38\%$ ;  $p = .0001$ ), E1 ( $M = 114.10\%$ ,  $SE = 2.92\%$ ;  $p < .0001$ ), E2 ( $M = 119.38\%$ ,  $SE = 2.43\%$ ;  $p < .0001$ ) and E3 ( $M = 124.45\%$ ,  $SE = 2.28\%$ ;  $p < .0001$ ), when compared to baseline. In addition, the post hoc comparisons showed that MTF duration at E2 was not statistically different from E1; however, MTF duration continues to increase for at least 1 hour after work, as MTF duration was significantly longer at E3 than E1 ( $p < .0001$ ). In contrast, for the Walk condition MTF duration was significantly longer only at E2 ( $M = 108.12\%$ ,  $SE = 2.10\%$ ;  $p = .003$ ) and E3 ( $M = 115.81\%$ ,  $SE = 2.29\%$ ;  $p < .0001$ ), but not at L ( $M = 97.18\%$ ,  $SE = 1.41\%$ ;  $p = .98$ ) and E1 ( $M = 99.74\%$ ,  $SE = 1.55\%$ ;  $p = 1.0$ ), when compared to baseline.

Finally, post hoc comparisons revealed that the Hard Floor condition was not significantly different from the Mat condition at each measurement time (L, E1, E2 and E3;  $p > .98$ ), but both were significantly different from the Walk condition at each measurement time (L, E1, E2 and E3;  $p < .05$ ), as shown in Figure 4.4.

Table 4.2. ANOVA for MTF duration.

MTF duration ( $r^2_{\text{adj}} = .91$ )			
Source	df	F Ratio	p
Time	4	73.09	<b>&lt;.0001*</b>
Condition	2	14.54	<b>&lt;.0001*</b>
Condition*Time	8	7.97	<b>&lt;.0001*</b>

Note. Bold font and \* indicate significant values,  $\alpha = .5$ .

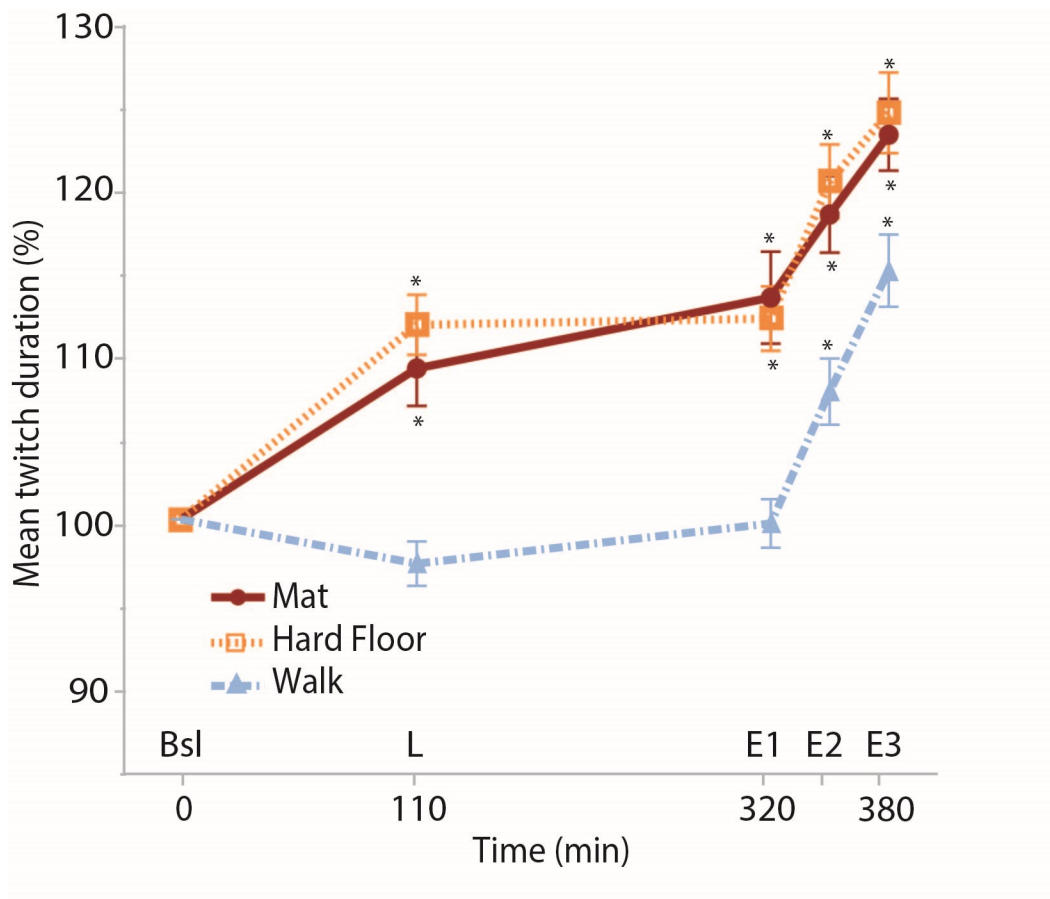


Figure 4.4. Changes in muscle twitch force duration for Mat, Hard Floor and Walk conditions, relative (%) to baseline (Bsl). Vertical bars indicate standard errors. Asterisk (\*) indicates a significant difference when compared to Bsl within each condition.

#### 4.4 Discussion

The present study was conducted to differentiate MTF duration and amplitude changes in the lower legs during and up to one hour after three non-seated work conditions, each performed during a workday of 320 minutes with scheduled rest breaks: standing on a hard floor, standing on an antifatigue mat and walking on a treadmill. The results showed that long-lasting effects indicated by a significant decrease in MTF amplitude and an increase in duration after the standing workday that persisted at least an hour after work, were similar for both standing on the hard floor and antifatigue mat conditions. However, this pattern differed

from the walking condition, where a significant difference of MTF amplitude and duration was observed at L when compare to the standing conditions, and for which a significant lengthening of MTF duration occurred only after the end of the workday. This variation pattern suggests stages of combined potentiation and fatigue. No sign of significant decrease in MTF amplitude was observed after 110 minutes of standing or walking; however, a significant increase in duration was present in the standing conditions.

#### **4.4.1 Standing on a hard floor or on an antifatigue mat and MTF**

The present findings concerning both standing conditions showed that MTF amplitude decreased significantly and MTF duration increased significantly after 320 minutes of standing work. These outcomes did not change within the 1 hour post work recovery period. These findings corroborate our recent study (Garcia et al., 2015) where a long-lasting reduction of MTF amplitude was also apparent after 5 hours of standing on a hard floor including regular breaks and persisted more than 30 minutes post work. Some studies suggested that softer floor conditions may alleviate fatigue (King, 2002; Madeleine et al., 1998; Redfern & Cham, 2000). However, other studies have presented opposite results (Aghazadeh et al., 2015; Orlando & King, 2004; Zander et al., 2004). These studies did not evaluate the long-lasting effects following work, most were limited to standing exposures of less than 2 hours and, for many, fatigue evaluation was based on self-reported perception. The similarity in MTF results with and without an antifatigue rubber mat is consistent with an analogous study involving a shorter work cycle and different flooring surfaces (Brownie & Martin, 2015). The use of softer foot-floor interfaces like floor mats (Cham & Redfern, 2001; Wiggermann & Keyserling, 2013) may lessen the perception of discomfort, however, our results confirm that this intervention method do not appear to alleviate lower leg muscle fatigue, as shown by the long-lasting decrease in amplitude and lengthening of MTF duration.

It is worth noting that in a control condition in which participants remained mostly seated during a workday but where the same MTF measurement protocol was used, the MTF amplitude did not decrease (Garcia et al., 2015). Hence, the long-lasting degradation of muscle force generation, as assessed by the MTF objective measure, is primarily associated with maintaining a prolonged standing posture.

The present and previous results (Garcia et al., 2015) also concur to show that 2 hours of standing work do not seem to adversely affect muscle function, at least on these measures, since the MTF amplitude did not decrease significantly in the different conditions (hard floor, mat), with or without a rest break in between. However, the concurrent lengthening of MTF duration may suggest an initial combined state of muscle potentiation and fatigue. This phenomenon is discussed below in further detail.

#### **4.4.2 Standing, walking and MTF**

Instead of proposing changes in floor characteristics for mostly static standing work, some studies have proposed the incorporation of walking to reduce the consequences of fatigue (Balasubramanian et al., 2009); however, related studies are scarce. Konz, Rys, and Harris (1988) suggested that walking breaks are beneficial during prolonged standing work but their conclusions were based only on subjective evaluation. The EMG analysis by Balasubramanian et al. (2009) compared stationary standing and intermittent walking over 1 hour periods and concluded that fatigue in the lower-limb muscles is more predominant in stationary standing than in walking. This conclusion has been corroborated here by the less pronounced long-lasting alteration of MTF after the workday of slow-pace walking than after the standing conditions.

Walking at a slow-pace induced first a divergence in the development of the MTF amplitude when compared to the standing conditions and no change in MTF duration, as

measured after 110 minutes, which contrasted with the standing conditions. Both measures then remained constant till the end of the task (E1). When walking ended, MTF duration increased significantly and MTF amplitude decreased significantly, relative to L, during the hour of post work seated rest. Such a pattern parallels observations related to prolonged low level finger activity in dynamic typing or mousing tasks (Kim & Johnson, 2014) and prolonged wrist activity in a repetitive ulnar deviation task (Johnson et al., 2013). The divergence or convergence of the two MTF metrics most likely result from interactions between potentiation induced by muscle activity and the concurrent development of fatigue (Green & Jones, 1989; Hamada, Sale, MacDougall, & Tarnopolsky, 2000; Kim & Johnson, 2014; Rankin et al., 1988). During the development of fatigue the muscle may typically go through three temporal stages 1) potentiation, 2) potentiation plus fatigue, and 3) fatigue (Garner et al., 1989; Johnson et al., 2013; Kim & Johnson, 2014). The first stage is characterized by an increase of MTF amplitude and a decrease of its duration, the second by an increase of both amplitude and duration or a decrease of both, and the third by a decrease of amplitude and an increase of duration (Kim & Johnson, 2014).

According to the results of the present study, walking initially leads to muscle potentiation, however, as walking continues fatigue is likely evolving concomitantly, MTF duration consequently increases and amplitude decreases. As time goes on potentiation decreases and gradually ends with muscle rest/relaxation (post work). Such a development fits with the interpretation that after the end of the walking condition fatigue dominates, as expressed by the post work decrease in MTF amplitude and increase in duration (See Fig 4.3-4.4). A conceptual model of the corresponding fatigue-potentiation concurrence/coexistence, derived from previous work (Garner et al., 1989) has been proposed by Johnson et al. (2013) and illustrated in Kim and Johnson (2014) for repetitive upper limb activity. This model is

supported by the results associated with the walking condition and thus can also be applied to the cyclic activity of lower leg muscles. Overall, the development of fatigue appears attenuated by walking at a slow-pace, when compared to the standing conditions. These results show the benefit of walking but also show that fatigue is only partially alleviated by dynamic low level muscle activity. In the walking condition, although MTF amplitude is not significantly lower at E3 than Bsl, the equivalence of MTF duration at E3 and E2 to the standing condition indicates that fatigue effectively persists post walking and may not be negligible.

A mostly static standing posture is likely to promote sustained intramuscular pressure periods that can alter blood flow and oxygenation as observed during static low level muscle exertions of the lower leg by Sjogaard, Kiens, Jørgensen, and Saltin (1986), and intramuscular pressure may be lower in walking than a standing condition when low forces are exerted (Vedsted, Blangsted, Sogaard, Orizio, & Sjogaard, 2006). Both blood flow and oxygen contribute to the modulation of muscle fatigue (Hepple, 2002; Murthy, Kahan, Hargens, & Rempel, 1997; Sjogaard, Savard, & Juel, 1988). Therefore, variations in blood flow and blood pressure, which are higher after 30 minutes of static standing (Antle & Côté, 2013), and oxygenation may contribute to the reduction of fatigue in the walking condition. Both the changes in blood flow and the resulting edema, observed at the ankle level (Hansen et al., 1998), may influence the mechanical properties of the muscle and ankle joint. However, a detailed account of changes in mechanical properties or muscle metabolism as a function of activity parameters is beyond the scope of this study since the net outcome of the multiple interactions is expressed by the measure of MTF.

Some limitations apply to this study. Extrapolation to different work cycles or work requiring heavy load manipulation would require further investigations. Furthermore,

standing is simultaneously loading the circulatory and musculoskeletal system of the lower legs, thus circulatory impairments could interact with alterations in muscle function and it was not possible to differentiate these effects within this study. The vascular effects associated with standing work (Antle & Côté, 2013; Tüchsen, Hannerz, Burr, & Krause, 2005) may also contribute to muscle fatigue and disorders via various mechanisms. Experimental studies are necessary to determine the extent to which different phenomena and their respective underlying mechanisms interact to exacerbate or attenuate muscle fatigue resulting from standing or walking work. A possible bias associated with the influence of vascular effects on tissue electrical properties is possible. However, it is reasonable to assume that such a mechanism has a minor influence on the present results since a relatively long stimulus and a constant current were used to compensate impedance variation. In sum, detailed quantification of all factors affecting MTF may be undertaken to further the understanding of muscle fatigue in standing conditions.

#### ***4.5 Conclusions***

Alterations of MTF of the lower leg were present after a 320-minute workday of standing on a hard floor or on an antifatigue floor mat and persisted at least 1 hour into the resting period after the working day. These alterations were not evident after the first 110 minutes of standing work; however, a combined state of potentiation and fatigue may have been present. Slow-pace walking led to a potentiation state of the muscle, which may attenuate the weakening of MTF during this activity; however, degradation of muscle function seems to be present at least 1hr post work. Long-lasting alteration of MTF appears to be better mitigated by walking than a rubber mat, however it may not be wise to assume that walking alone represent an ultimate solution since vascular effects must also be considered.



## **Key points**

- A significant alteration of muscle twitch force was found after five hours of standing work and it persisted for more than an hour after the standing work ended.
- The tested antifatigue mat does not appear to alleviate muscle fatigue effectively.
- Slow-pace walking may reduce the long-lasting alteration of muscle twitch force amplitude and duration but it may not be considered as a unique prevention method to alleviate the negative effects of prolonged standing work.
- The results indicate that both muscle twitch amplitude and duration are also important measures when evaluating the integrity of lower leg muscle function in walking and standing work.

## **Acknowledgments of the study**

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## 5. Conclusion

### *5.1 Overview and general discussion*

One of the major goals of ergonomics interventions is to reduce the risks of MSDs and other health problems related to the workplace. Most of the research done on work-related MSDs has focused on the upper extremities and the low back with little attention given to the lower limbs. This dissertation makes an important contribution to the field of ergonomics by identifying indicators, related to working-conditions, that predict the prevalence of lower limb pain. It further determines whether standing at work is a predictive indicator of lower limb pain. In addition, it highlights the importance of studying lower limb pain through the evaluation of its impact in measures related to health status and socioeconomic loss. The present dissertation focused on prolonged standing at work since it has been established that this work situation is associated with MSDs, vascular issues, and discomfort in the lower body (e.g. Waters and Dick, 2014). The effectiveness of prevention methods for prolonged standing, as assessed by objective measures, is still controversial (Redfern & Cham, 2000). Moreover, very limited research has objectively explored the effects of prolonged standing and associated consequences resulting from muscle fatigue. Thus, this dissertation presents scientific evidence of the effects of prolonged standing in lower leg muscle fatigue and body part discomfort considering age and gender influences. Finally, this dissertation evaluates the effectiveness of methods to prevent long-lasting fatigue by comparing three standing work conditions: standing on hard floor, standing on an antifatigue mat, and slow-pace walking on a treadmill.

This section first synthesizes the findings of the three studies within this dissertation and then addresses the methodological aspects and the implications of the overall dissertation.

### 5.1.1 Lower limb pain

The study presented in Chapter 2 focused on the prevalence of lower limb pain, its potential predictors and its impact in occupational health measures. The findings clearly identified specific working-conditions indicators in particular physical exposures that led to a model able to predict lower limb pain. The analysis found that a relevant amount of lower limb pain cases, as well as a noticeable amount of absence days from work among the EU workforce, could be attributed to the work environment. Acknowledging the potential risks indicators of work-related lower limb pain may be useful for the development of effective workplace interventions to mitigate occupational health issues.

Among the observed indicators, standing for the majority of the workday had a high impact on lower limb pain. The importance of standing, as an exposure variable to work-related lower limb pain, is also supported by the laboratory findings in Chapter 3 and 4. Even when controlling for the effects of other risk indicators like heavy lifting presented by the model in Chapter 2, the laboratory studies showed that prolonged standing alone has significant effects on discomfort and fatigue of the lower limb (Chapters 3 and 4).

### 5.1.2 Prolonged standing and fatigue

The laboratory studies presented in Chapters 3 and 4 investigated the effects of five hours of prolonged standing, including rest breaks, on indicators of muscle fatigue. The first study also considered possible age and gender effects, and compared the effects of standing against a seated “office” day, only for the younger participants. Overall, the conclusions regarding each measurement are:

***Muscle twitch force.*** A significant reduction of muscle twitch force, immediately after five hours of standing, persisted at least 30 minutes after a seated recovery break. However, leg muscle fatigue did not develop during the seated work day of equal duration. This

contrast presents clear evidence of long-lasting fatigue associated with prolonged standing work even when regular rest breaks and a common lunch break were included in the schedule. Although the standing work-rest schedule differed between the study in Chapter 3 and the one in Chapter 4, both had the same total amount of standing (275 minutes) and seating (45 minutes total) time. In both studies the effects on fatigue were similar; thus, there is no benefit of following one schedule (Figure 3.2 or 4.1) over the other. Fatigue did not seem to develop within the first two hours of work, regardless of the break in between (see Figure 3.2 and 4.1). Finally, 30 minutes to 1-hour post-work was not enough time to recover from the effects of prolonged standing on lower leg fatigue. Hence, it may be concluded that the total duration of seated breaks was either too short or not adequately distributed, or standing time was too long in the quasi-static situation to avoid the development and favor the recovery of long-lasting fatigue. The distribution of the seated breaks could play an important role in fatigue control, which should be explored in future studies.

Prevention in prolonged standing effects may be guided by these findings which suggest that two hours of standing work seems to be acceptable. However, five hours or more - with the current schedules common in industry - appear to be detrimental for long-lasting fatigue of the lower leg.

Finally, age and gender effects were not apparent. It is important to remember that fatigue is task dependent and so are age and gender effects (Enoka & Stuart, 1992). Thus, the present results indicate that, in the context of mostly static prolonged exertion of low level, the fatigue mechanisms involved are not sensitive to muscle fiber composition or certain contractile properties that may vary with age and gender (Hunter et al., 2004; Hunter & Enoka, 2001; Yoon, Doyel, Widule, & Hunter, 2015). The results also indicate that the excitation-contraction coupling associated with the long lasting component may not be

sensitive to age and gender physiological differences. This is not the case for tasks involving high level muscle exertions (e.g Maikala, Ciriello, Dempsey, and O'Brien (2010) study). Due to a relatively small number of subjects in each group, the limited power of the analysis may present some limitations for the investigation of age and gender effects. Our future study will attempt to verify this possible issue.

***Postural stability.*** Although not significant, an increase in the center of pressure displacement speed was observed after five hours of standing work; the increase was significant, however, 30 minutes post work. This may not be surprising as previous studies suggests that the long-lasting component of fatigue seems to be more pronounced after 30 minutes post work (Adamo et al., 2009; Adamo et al., 2002). These results are congruent with previous observations indicating a decrease in postural stability associated with increased leg muscle fatigue (Gimmon et al., 2011). However, a similar tendency was also observed in the seated “office” day. This apparent discrepancy could mean that factors associated with a “central fatigue” do not affect the muscle per se, but that only the control of the muscle is responsible for the minor postural control alteration observed at the end of the seated control day.

As suggested by previous literature, the extent of fatigue measured depends on the method used to test it (Jones et al., 2004a). Thus, postural stability may not be sensitive enough to quantify the long-lasting component of fatigue when compared to MTF, for example. Furthermore, as with MTF, age and gender effects were not significant.

***Subjective evaluations.*** Fatigue was clearly perceived during and immediately after five hours of standing work; however, for most participants, this perception vanished after seated rest for 30 minutes post work. Some minor differences between age groups were observed (i.e., some persistence of fatigue perception for older individuals) post work after rest;

however, no gender effect was present. Overall, the lack of fatigue perception after post work rest suggests that the long lasting component of fatigue is not perceived at the cognitive level. This result is in line with similar findings concerning upper limb muscle fatigue (Adamo et al., 2009; Adamo et al., 2002). In addition, it has also been reported that subjective perception of fatigue is lower when standing on antifatigue mats than hard floor (Brownie & Martin, 2015; Redfern & Cham, 2000) despite the fact that the objective measure (MTF) evidenced fatigue as in Chapter 4 and Brownie and Martin (2015). This dichotomy between perceptive and motor outcomes indicates that subjective methods may not be reliable to evaluate long-lasting muscle fatigue. Therefore, prevention strategies should not rely solely on subjective measures, but instead should be based on objective measures of the fatigue mechanisms associated with the work.

### **5.1.3 Intervention strategies for prolonged standing**

The second experimental study (Chapter 4) compared walking, standing over a hard floor, and standing work over an antifatigue mat. This latter condition, the antifatigue mat, is commonly used to attenuate the effects of prolonged standing; however, several studies have presented controversial results on this intervention. The findings in Chapter 4 showed that muscle twitch force decreased significantly after five hours of standing work regardless of the floor type; this decrease persisted at least one hour post-work recovery period. Moreover, standing on hard floor or on an antifatigue mat led to comparable effects on muscle fatigue. A similar result was observed by Brownie & Martin (2015). Taken together, these results suggest that, in term of long-lasting fatigue indicators, standing on an antifatigue mat present the same detrimental consequences as standing on hard floor. In contrast, slow-pace walking led to a lower level of long-lasting fatigue when compared to quasi-static standing. Therefore, muscle fatigue, induced by prolonged standing, may be better attenuated by

interventions involving walking – or low-force dynamic activities – than by antifatigue mats. Future studies should validate the impact of antifatigue mats in long-lasting fatigue after prolonged standing by using other commercially available mats with different characteristics, especially in terms of stiffness.

The present results show the importance of post-work measurements to evidence the long-lasting effects of standing or walking work and point out the need to extend these measures to determine the necessary recovery time. To our knowledge, these are the first studies related to lower limb fatigue that have incorporated a post-work measurement - with the exception of Brownie and Martin (2015). Long-lasting fatigue has been more commonly investigated in upper limb than lower limb muscles (see Adamo et al., 2009; Adamo et al., 2002; Kim & Johnson, 2014). Intervention strategies for standing work have not been evaluated with post-work measurements. Chapter 4 addressed this issue and showed that post-work recovery, when using an antifatigue mat or when walking, was taking longer than an hour. Hence, it is of great importance to perform post-work measurements to evaluate whether an intervention promotes a reduction of muscle fatigue and shortens or facilitates recovery.

#### **5.1.4 Methodological considerations**

Methodological limitations have been mentioned in Chapter 2, 3 and 4. Some considerations are now further highlighted. Long-lasting muscle fatigue has been associated with mechanisms presenting a slow recovery, or long lag, as outlined in Chapter 3 and 4. This component of fatigue must be measured using specific methods, including electrical stimulation as used in this dissertation (Adamo et al., 2009; Edwards et al., 1977; Jones, 1996; Kim & Johnson, 2014), or spectral analysis of EMG activity produced by low level muscle contractions (Blangsted et al., 2005; Sogaard et al., 2003). The major advantage of electrical

stimulation is that the induced muscle contraction is independent of influences of the central nervous system and therefore exhibits only the behavior of peripheral mechanisms at the muscle level. Although the long-lasting component of fatigue has been primarily associated with the failure of the excitation-contraction coupling (Enoka & Stuart, 1992; Gandevia, 2001), other phenomena may also contribute to the decrease in MTF in lower leg muscles since edema may be formed and affect blood flow or muscle oxygenation. Further research needs to investigate possible diverse physiological mechanisms, such as those related to a vascular component, specific to the standing posture. Nevertheless, reduction in “supplies” (e.g. oxygen and nutrients) to the muscles contributes to a decrease in power capability, which is captured by the time profile of the twitch force.

Another aspect to consider with electrical stimulation is that the electrical stimulus propagation through the tissues may activate sensory receptors and nerves mediating pain. Thus, it can induce a certain level of discomfort. Although this was not a major obstacle for our studies, a few individuals were not comfortable with the stimulation and declined to participate after a brief testing period. In addition, it was observed that by using larger size electrodes, as done in the study presented in Chapter 4, the level of discomfort was lower. Nevertheless, this potential discomfort should be taken into account for future studies, in particular in field studies, where the number of participants is limited within the participating organizations and time constraints are usually a significant limiting factor.

Further experiments should explore the effects of prolonged standing with other objective methods such as surface electromyography and quantify the correlation between motor performances and the long-lasting component of fatigue. This other method may not inflict the discomfort of the electrical stimulation; thus, it may be easier to use it in field studies. Nevertheless, methods implicating voluntary contraction are “biased” by the central



component of fatigue, which may bias the estimation of what is happening at the muscle level. Previous studies suggest that areas in a muscle adapt differently to fatigue and present spatial differences in the activity within a muscle, thus common surface electromyography (EMG) tests performed with bipolar electrodes may have some limitations as well (Falla & Farina, 2007; Farina, Leclerc, Arendt-Nielsen, Buttelli, & Madeleine, 2008). Both types of methods present advantages and disadvantages since electrical stimulation does not reflect how the muscle is driven by the central nervous system when fatigued. Therefore, possible mechanisms affecting central factors (e.g. motivation, motor cortex, spinal cord, motorneuron) that may exacerbate fatigue (Jones et al., 2004b) during prolonged standing should be investigated in future studies.

### **5.1.5 Implications for jobs characterized by prolonged standing**

Muscle fatigue induced by prolonged standing and its long persistence were evidenced in Chapter 3 and 4. Since the accumulation of fatigue in the muscles is a precursor of musculoskeletal disorders (see Côté, 2014 for review), jobs including prolonged standing may affect the health of the workers. This is in agreement with the epidemiology study presented in Chapter 2 where the relation between prolonged standing at work and lower limb pain was brought to light. Thus, any individual exposed to prolonged standing at work, regardless of age or gender, may be vulnerable to work-related health issues. Hence, effective intervention strategies are needed to reduce muscle fatigue induced by prolonged standing. The commercially called antifatigue mats do not appear to be effective. Perhaps other alternatives such as sit-stand work cycles with dynamic activities, or sit-stand-walk work distribution may alleviate the effects. Future studies of prolonged standing also need to clearly differentiate standing and walking, static versus dynamic leg movements, when evaluating intervention strategies.

The present findings may help to develop guidelines for prolonged standing. Jobs that require workers to stand for the majority of the day - or at least more than two consecutive hours - may benefit from such guidelines; in particular, if the occupational task involves quasi-static standing instead of walking. The findings of this dissertation have already contributed towards updating the guidelines for prolonged standing among the Swiss workforce – an initiative proposed by the State Secretariat of Economic Affairs SECO.

This dissertation also provides scientific insights to prolonged sitting studies. Prolonged sitting is commonly observed in office work. In the past decade a big movement in the media, derived from new epidemiological data, has highlighted that sitting most of the workday has huge detrimental health effects and should be avoided (Levine et al., 2005). Thus, sit-stand workstations have increased in popularity. However, workers should be aware of the effects of prolonged standing when using this work posture as an alternative to prolonged sitting. Otherwise, sitting health problems may be replaced by standing issues. Thus, in regard to the present results, individuals using sit-stand desks should be made aware of some recommendation such as avoiding work in a standing posture for more than 2 consecutive hours, especially if little movement is involved. A reasonable recommendation, based on this dissertation's findings, will be to include movement and dynamic activities such as walking within the workday schedule.

## ***5.2 General Conclusion***

Lower limb pain is a work-related health problem with a high prevalence and major impact in work absenteeism and worker's expectations. Special considerations should be taken into account for occupational risks prevention. Its high association with prolonged standing at work may guide the focus of future intervention strategies. The effects of prolonged standing at work on lower limb muscle fatigue and discomfort are significant. The

long-lasting component of fatigue and its persistence could be objectively measured following five hours of standing work with seated rest breaks in between. The use of antifatigue mats does not appear to attenuate muscle fatigue; however, dynamic activities like slow-pace walking showed an attenuation effect. Showing the effects of prolonged standing through indicators of muscle fatigue and the importance of lower limb pain are practical contributions of this dissertation to occupational health and ergonomics.

## **6. Outlook**

This dissertation has contributed to the field of ergonomics and occupational health with substantial insights regarding prolonged standing lower limb pain and fatigue. However, new questions have emerged and several areas require further research.

Chapter 2 contributed to the literature related to work-related lower limb pain with a model of risk indicators at work. Research in this area should extend validation of the findings in other populations outside the European Union and investigate further specific risk factors related to lower limb pain at work. It may also be of interest to differentiate the parts of the lower limbs that are affected the most (knees, feet, hips, etc.) since the survey design used in Chapter 2 did not provide this distinction.

Specific areas for future studies regarding Chapter 3 and 4 have been described in the previous section. Overall, it is clear that studies on the effectiveness of interventions for prolonged standing work are needed. Future research in prolonged standing should also include field studies to evaluate the efficacy and determine its practicability in real work environments. Some of these studies have been planned and are described in following section.

## ***6.1 Proposed experimental design for future lab and field studies***

In order to guide future experimental and field studies related to prolonged standing work the following experimental design are proposed to help to: 1) evaluate the effects of different work-rest cycles, combined with active or passive intervention strategies, to reduce fatigue without altering the total amount of work time; 2) test intervention strategies in the field and determine their efficacy, acceptability and practicability; 3) quantify optimal stand-sit-move distribution to provide recommendations for adequate job posture rotations as a function of job context; 4) provide realistic time for exposure (5 hours) and breaks (15 minutes) common in industry; 5) evaluate fatigue not only during or immediately after standing work, but also 1 to 24 hours after work, for the investigation of long-lasting effects and corresponding time recovery profiles.

The proposed design is based on six work cycles that vary between shorter exposures of standing work interrupted by shorter breaks to longer exposures of standing work interrupted by longer breaks (Figure 6.1). The measurement periods are at baseline before the standing task (Bsl), after about two or three hours of standing before the lunch break (L), immediately after the standing workday (E1), and after a seated recovery period of one hour (E2).

Additionally, we recommend performing a measurement on the next following morning (D) since the long-lasting component of fatigue could last up to 24 hours (Edwards, et. al, 1977). With this approach, the influence of different work-rest cycles in fatigue indicators could be evaluated as well as the effectiveness of active or passive breaks during standing work.

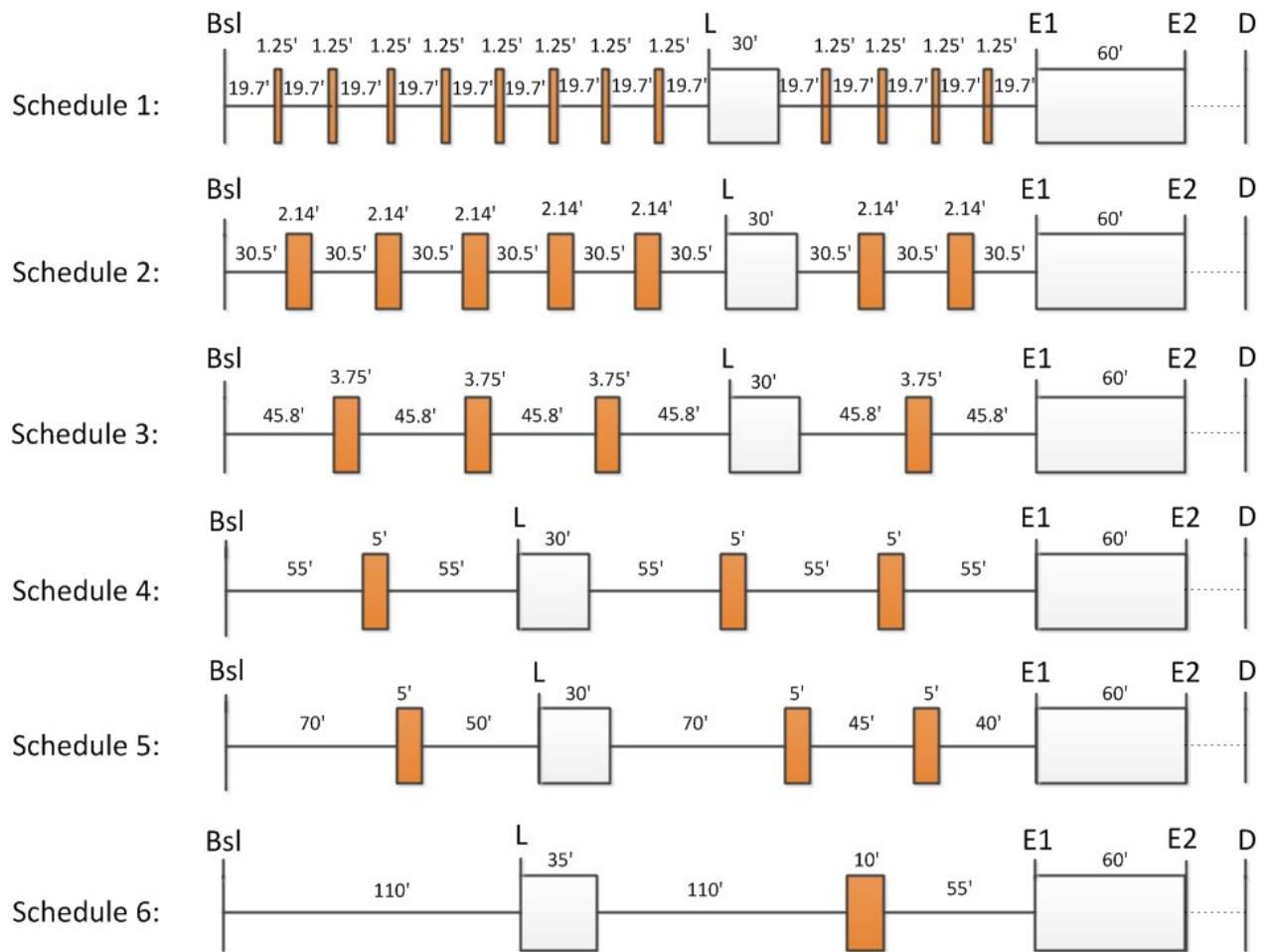


Figure 6.1. Work–rest schedules and measurement times. Bsl=baseline morning, L=lunch, E1= immediately after work, E2= 1 hour post work, D= morning of day after work.

Two laboratory studies will compare three of the six schedules incorporating active and passive breaks, respectively, on physiological measures on the lower legs. Another planned study will determine the effects of the distribution of sit-stand-walk on muscle fatigue using two work schedules and alternating standing, walking, and sitting times equally through the workday (Figure 6.2). All laboratory studies will use objective measures to quantify and analyze the effects of prolonged standing on muscle fatigue - in particular its long-lasting component. The measures include MTF, 2D EMG, foot/leg volume, isometric force control, muscle oxygenation, and postural stability. Through this proposed design, scientific insight

about the effects of prolonged standing work - and in particular the post-work effects - could be observed to guide the evaluation of potential prevention methods.

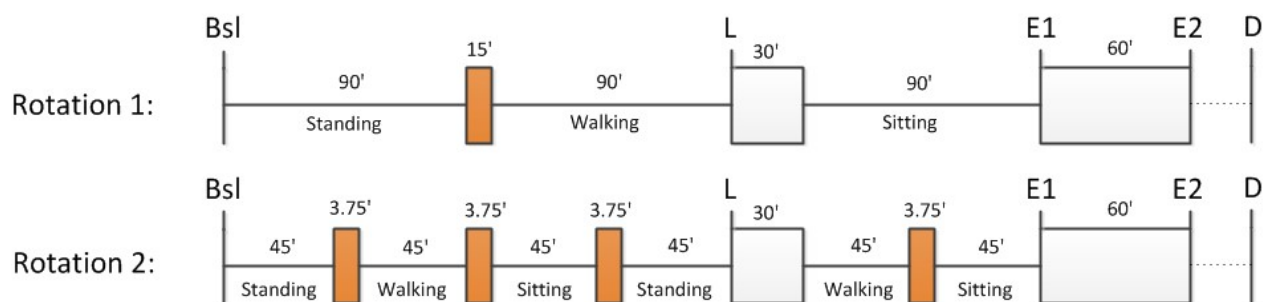


Figure 6.2. Sit-stand-walk schedules and measurement times: Bsl=baseline morning, L=lunch, E1= immediately after work, E2 = 1 hour post work, D= morning of day after work.

Two field studies are planned to assess, in real work conditions, the advantages or disadvantages of work cycles and active interventions on the mitigation of muscle fatigue due to standing work. This will allow for the laboratory results to be easily transferred to real work conditions and the development of appropriate guidelines to reduce the detrimental effects of prolonged standing at work. All these studies are included in a recent grant application to the Center of Diseases Control and Prevention of the National Institute for Occupational Safety and Health (NIOSH) in the United States.

## 7. Journal publications, conference proceedings and press releases

As described in the preface of this thesis chapter 2, 3 and 4, contain a peer-reviewed version of three scientific papers respectively. In addition, parts of this dissertation were presented in different international scientific conference related to occupational health and ergonomics. After the scientific publication of the study in Chapter 3 several journalists contacted the research team for interviews in order to create press releases related to the study. These may reflect the relevancy of the findings also for the general public. The list of

journal publications, scientific conference proceedings and the various published press releases are presented below.

Journal publications:

- Garcia, M.G., Graf, M., & Läubli, T. (in press). Lower Limb Pain among Workers: A Cross-Sectional analysis of the Fifth European Working Conditions Survey. *International Archives of Occupational and Environmental Health*.
- Garcia, M. G., Läubli, T., & Martin, B. J. (2015). Long-Term muscle fatigue after standing work. *Human Factors*, 57(7), 1162 – 1173. doi: 10.1177/0018720815590293.
- Garcia, M. G., Wall, R., Steinhilber, B., Läubli, T., & Martin, B. J. (2016). Long-Lasting Changes in Muscle Twitch Force during Simulated Work While Standing or Walking. *Human Factors*, 58(8), 1117 – 1127. doi: 10.1177/0018720816669444.

Conference Proceedings:

- Garcia, MG., Läubli, T., & Martin, B. (2014). Muscle fatigue and standing work: A pilot study. Proceedings of the 18th Symposium Arbeitmedizin und Arbeitswissenschaft für Nachwuchswissenschaftler. Magdeburg, Germany: Otto-von-Guericke University Magdeburg.
- Wall, R., Seibt, R., Garcia, MG., Klusmann, A., Läubli, T., Martin, B., Rieger, M., & Steinhilber, B. (2015). Effekte einer mehrstündigen Stehexposition auf ausgewählte Messgrößen physiologischer Beanspruchung. Proceedings of the 19th Symposium Arbeitmedizin und Arbeitswissenschaft für Nachwuchswissenschaftler (pp.16). Rostock, Germany: University of Rostock Press.
- Garcia, MG., Wall, R., Seibt, R., Steinhilber, B., Rieger, M., Läubli, T., & Martin, B. (2015). Evaluation of prolonged standing work in three conditions. Proceedings of the

19th Symposium Arbeitmedizin und Arbeitswissenschaft für

Nachwuchswissenschaftler (pp.32). Rostock, Germany: University of Rostock Press.

- Garcia, G., Läubli, T., Graf, M., & Martin, B. (2015). Long lasting muscle fatigue after standing work. Proceedings of the 19th Triennial Congress of the International Ergonomics Association. Melbourne, Australia.
- Garcia, MG., Läubli, T., & Martin, B. (2015). Five hours of standing work induces long-term muscle fatigue and musculoskeletal discomfort. Proceedings of the 23th Erfurter Tage Wissenschaftliches Symposium zur Prävention von arbeitsbedingten Gesundheitsgefahren und Erkrankungen. Erfurt, Germany.
- Garcia, MG., Wall, R., Steinhilber, B., Läubli, T., & Martin, B. (2016). Long-term leg muscle fatigue in standing work: Effects of two ergonomic interventions. Proceedings of the 9th International Conference on the Prevention of Work-Related Musculoskeletal Disorders (PREMUS). Toronto, Canada
- Garcia, MG., Graf, M., & Läubli, T. (2016). Arbeitssituation und Schmerzen in den unteren Extremitäten in der Europäische Union. Proceedings of the 20th Symposium Arbeitmedizin und Arbeitswissenschaft für Nachwuchswissenschaftler. Freiburg, Germany: University of Siegen.

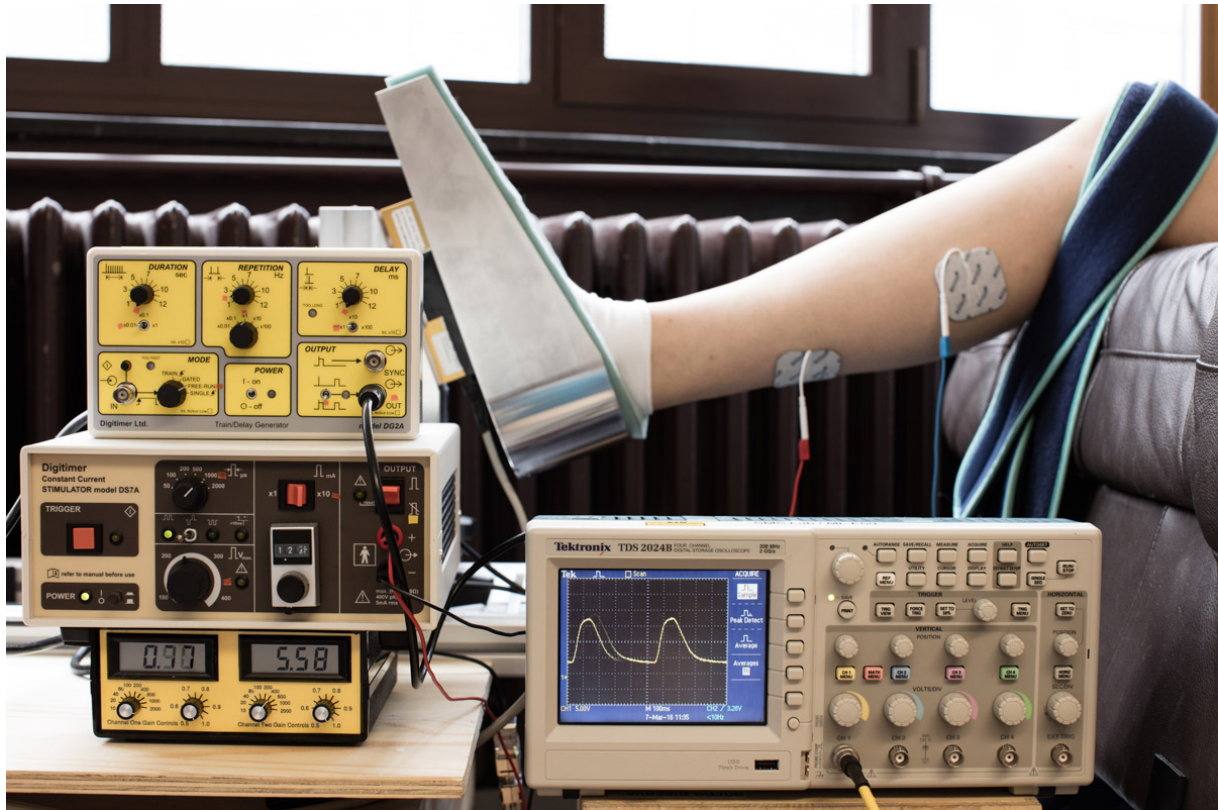
#### Press Releases:

- Paddock, C. Prolonged standing at work can cause health problems too. *Medical News Today*. Published July 15, 2015.
- Ross, M. Nonstop standing at work may cause muscle fatigue. *Pharmacy Times*. Published July 22, 2015.



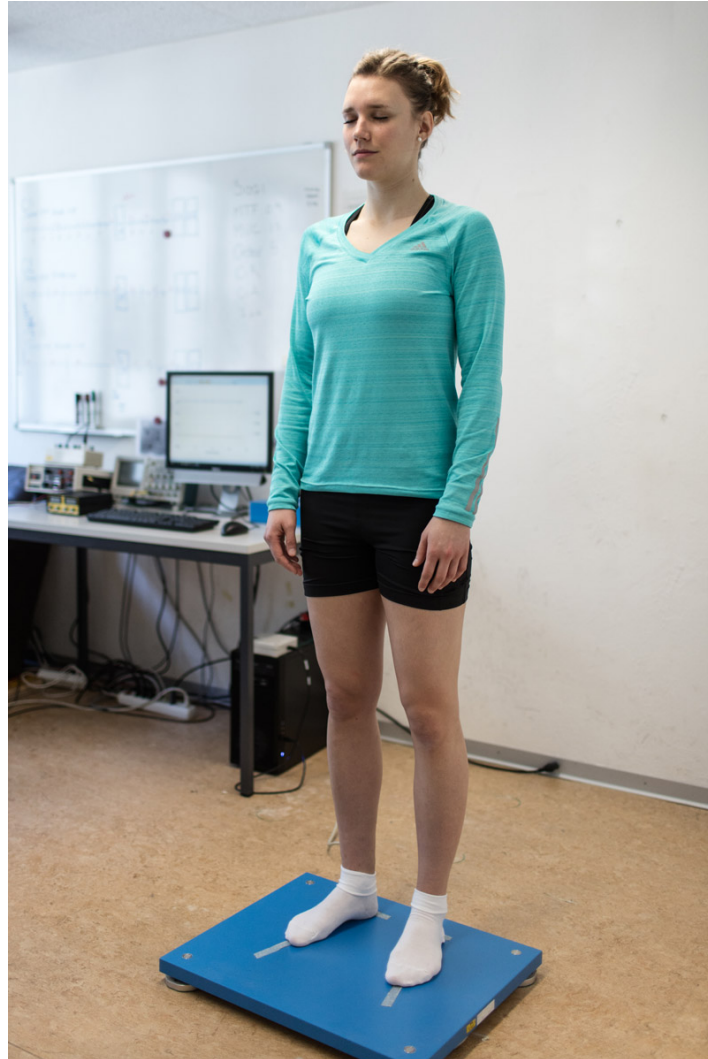
- Quinlan, C. Like sitting, standing in the workplace may have long-term health consequences. *Human Factors and Ergonomics Society News*. Published July 13, 2015.
- Mozes, A. Standing all day at work? It may take toll on health. *Health Day*. Published July 28, 2015.
- *CBS Atlanta*. Prolonged standing at work can lead to long-term health problems. Published July 28, 2015.
- Benz, M. Prolonged standing associated with musculoskeletal disorders and health problems. *Medical Research*. Published July 22, 2015.
- Depra, D. Standing too long can cause long-term health problems says study. *Tech Times*. Published July 19, 2015.
- Brook, C. Sitting or standing? Both have consequences for workers. *Business News Daily*. Published July 15, 2015.

## Appendix A: Experimental setup for measuring muscle twitch force in the gastrocnemius-soleus muscles through electrical stimulation.



*Photo by Stefan Schneller*

## Appendix B: Experimental setup for postural stability test.



*Photo by Stefan Schneller*

## Appendix C: Subjective evaluation of discomfort

Figure from behind

LEFT		RIGHT	
Neck	No Discomfort	Head	No Discomfort
Shoulder	No Discomfort	Shoulder	No Discomfort
Upper Back	No Discomfort	Upper Back	No Discomfort
Elbow	No Discomfort	Elbow	No Discomfort
Lower Back	No Discomfort	Lower Back	No Discomfort
Hand/ Wrist	No Discomfort	Hand/ Wrist	No Discomfort
Hip/ Upper Leg	No Discomfort	Hip/ Upper Leg	No Discomfort
Knee	No Discomfort	Knee	No Discomfort
Lower Leg	No Discomfort	Lower Leg	No Discomfort
Ankle	No Discomfort	Ankle	No Discomfort
Foot	No Discomfort	Foot	No Discomfort

**Instructions:**

For each body area presented in the diagram, please place a vertical bar (|) through the corresponding line according to your level of discomfort. If you feel discomfort on the front part of your body, mark it in the appropriate field as well.

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