STUDIES IN SPORT, PHYSICAL EDUCATION AND HEALTH

260

Ying Gao

Sit-Stand Workstations: Effects on Occupational Sitting Time, Potential Health Benefits, and Acute Postural Physiology

JYVÄSKYLÄN YLIOPISTO

STUDIES IN SPORT, PHYSICAL EDUCATION AND HEALTH 260

Ying Gao

Sit-Stand Workstations: Effects on Occupational Sitting Time, Potential Health Benefits, and Acute Postural Physiology

Esitetään Jyväskylän yliopiston liikuntatieteellisen tiedekunnan suostumuksella
julkisesti tarkastettavaksi yliopiston Liikunnan salissa L302
syyskuun 29. päivänä 2017 kello 12.

Academic dissertation to be publicly discussed, by permission of
the Faculty of Sport and Health Sciences of the University of Jyväskylä,
in building Liikunta, auditorium L302, on September 29, 2017 at 12 o'clock noon.

UNIVERSITY OF JYVÄSKYLÄ

JYVÄSKYLÄ 2017

Sit-Stand Workstations:
Effects on Occupational Sitting Time, Potential Health Benefits, and Acute Postural Physiology

STUDIES IN SPORT, PHYSICAL EDUCATION AND HEALTH 260

Ying Gao

Sit-Stand Workstations: Effects on Occupational Sitting Time, Potential Health Benefits, and Acute Postural Physiology

UNIVERSITY OF JYVÄSKYLÄ

JYVÄSKYLÄ 2017

Editors
Taija Juutinen
Faculty of Sport and Health Sciences, University of Jyväskylä
Pekka Olsbo, Ville Korkiakangas
Publishing Unit, University Library of Jyväskylä

Permanent link to this publication: http://urn.fi/URN:ISBN:978-951-39-7156-4

URN:ISBN:978-951-39-7156-4
ISBN 978-951-39-7156-4 (PDF)

ISBN 978-951-39-7155-7 (nid.)
ISSN 0356-1070

Jyväskylä University Printing House, Jyväskylä 2017

ABSTRACT

Gao, Ying
Sit-stand workstations: effects on occupational sitting time, potential health benefits, and acute postural physiology
Jyväskylä: University of Jyväskylä, 2017, 101 p.
(Studies in Sport, Physical Education and Health
ISSN 0356-1070; 260)
ISBN 978-951-39-7155-7 (nid.)
ISBN 978-951-39-7156-4 (PDF)

Given that a high amount of sedentary behavior is a global health issue, reducing sitting time is emerging as a novel intervention strategy and a workplace health priority. Sit-stand workstations have been introduced to the workplace, and can be used to rotate between sitting and standing postures at work. It is important to develop and evaluate sit-stand interventions that aim to induce behavioral changes and potential health benefits, in order to effectively implement them into practice. Therefore, this thesis examined whether and to what extent sit-stand workstations can reduce occupational sitting and improve health indexes in a real workplace. The thesis included four studies in field and laboratory settings using several methodological approaches such as EMG and accelerometry to examine: 1) validity of self-report occupational sitting time (n = 70); 2) intervention effectiveness (n = 45); 3) comparison of muscle activity patterns and spinal loading (n = 24); 4) acute physiological responses to sitting and standing (n = 18). Overall, occupational sitting represented ~80% or less of daily work hours among office-based workers. A validation study using long-term questionnaire and short-term daily recall showed that while at the group level both of these self-reported measures are acceptable (< 3% difference compared to thigh-mounted accelerometry) for assessing the proportion of work time spent sitting, they are not necessarily reliable at an individual level due to large individual variability. When the questionnaire was used in a 6-month intervention study, working at a sit-stand workstation led to a ~7% reduction in occupational sitting, and improved perceived musculoskeletal comfort and work ability in office workers. About 42% of the participants who had a sit-stand desk used its function on a daily basis and showed ~14% reduction in sitting time. The cross-sectional comparison study showed that office workers using sit–stand workstations had ~15% less muscle inactivity time and ~11% more light muscle activity time during one work day, but the same amount of spinal shrinkage compared to office workers using sit workstations. In a laboratory-based randomized crossover trial, two hours of standing as compared to seated work increased muscle activity, energy expenditure and circulating glucose level after glucose loading. The results highlighted fuel switching in favor of fat oxidation during standing, in spite of extra carbohydrate availability. In conclusion, using sit-stand workstations seems to be a promising strategy to reduce occupational sitting time and improve health-related outcomes, although more studies are required to address the best practices for implementing these workstations into workplace settings.

Keywords: EMG, intervention, muscle inactivity, occupational sitting, postural physiology, self-report, workplace

Author's address
Ying Gao
Neuromuscular Research Center
Faculty of Sport and Health Sciences
P.O. BOX 35, FI-40014
University of Jyväskylä
Jyväskylä, Finland
ying.y.gao@jyu.fi

Supervisors
Professor Taija Juutinen Finni, PhD
Neuromuscular Research Center
Faculty of Sport and Health Sciences
University of Jyväskylä
Jyväskylä, Finland

Associate Professor Neil Cronin, PhD
Neuromuscular Research Center
Faculty of Sport and Health Sciences
University of Jyväskylä
Jyväskylä, Finland

Reviewers
Professor Pascal Madeleine, PhD
Department of Health Science and Technology
Aalborg University
Aalborg, Denmark

Associate Professor Hans H.C.M. Savelberg, PhD
Health, Medicine and Life Sciences
Maastricht University
Maastricht, Netherlands

Opponents
Professor Marie H. Murphy, PhD
Sport and Exercise Sciences Research Institute
School of Health Sciences
Ulster University
Northern Ireland, United Kingdom

ACKNOWLEDGEMENTS

Back in the autumn of 2012 I received the invitation to start my studies at the Faculty of Sport and Health Sciences, University of Jyväskylä. Excited about my future prospects, I moved to Finland and started what eventually became a five year PhD, from 2012 to 2017. I still remember the day I departed from my hometown of Hangzhou, China to Jyväskylä, Finland, which was November 1st, 2012. It was a sunny day, snow covered the landscape that I saw after an eight hour flight. During these years, I have appreciated the wonderful opportunity to study at the University of Jyväskylä and enhance my academic research skills. It has been an important and valuable period of my life. Step by step I joined the Finnish research community and adapted to a new environment and the Finnish culture. I really enjoyed the whole progress, day by day. All of the difficulties that I have faced, and problems that I have resolved, now seem to have given me valuable experience. Beside my own contribution, I would like to express my gratitude to all people who helped me during these years.

Firstly, I would like to express my sincere thanks to my primary supervisor, Professor Taija Juutinen Finni, who spent countless time wondering about my progress and giving me valuable suggestions. All of the discussions eventually shaped my research framework and guided my research direction. You also left me enough space to make my own decisions during these years. Importantly, every time when I felt I might not make it, your strong encouragement inspired me to continue, and finally to succeed. I have always felt your trust, which made me more confident. Your excellent merits have been a model for my learning. With the same appreciations I would like to thank my secondary supervisor, Associate Professor Neil Cronin. I remember every time I visited your office, no matter how many things you had on your hands, you stopped to listen to me. I always gained comfort from talking to you, especially when I was confused and depressed. Both of you shared your experience and helped me a lot during this period. It means a lot to me, and it is a privilege to have you as my supervisors.

I am grateful to all the staff and students from the faculty. Thanks to those professors who were involved in my study, Nina Nevela, Heikki Kainulainen and Sarianna Sipilä, as well as those with whom I worked during research visits abroad, Professors Gisela Sjøgaard and Karen Søgaard. Thanks to the technical staff, Jouni Tukiainen, Risto Puurtinen, Pirkko Puttonen, Markku Ruuskanen and Sirpa Roivas, and the secretaries, Katja Pylkkänen and Minna Herpola. Thanks to Marko Havu for assistance with data analysis. I also want to take this opportunity to thank my workmates, Arto Pesola, Arto Laukkanen, Mika Silvennoinen, András Hegyi, Annamária Peter, Lauri Stenroth, Noora Haarala and others who I may not have mentioned here. You are all important to me, and I hope our friendship will be everlasting and solid gold in the future.

I am also grateful to my thesis reviewers, Professor Pascal Madeleine and Associate Professor Hans Savelberg, who spent the summer time giving their

constructive criticism and kind comments. Furthermore, it is a great honor to have Professor Marie Murphy as my opponent, and I look forward to our discussions. I would like to express my sincere gratitude to all of those who have contributed to this thesis.

I want to thank the Chinese Scholarship Council for their financial support of my doctoral studies. I also thank Professor Wang Jian from Zhejiang University for his support.

I would like to thank Matti Kääriäinen for sharing the years even during my toughest period. One could not have hoped for such an endless support which you gave and stayed by my side.

Finally, I wish to extend my deepest love and appreciation to my parents, family and all of those who love me. I missed you so much during the period of my studies, and I hope you are proud of me and my work.

To all, thank you very much.

Jyväskylä, August 2017
Ying Gao 高莹

ORIGINAL PUBLICATIONS

The thesis is based on the following original articles, which are referred to in the text by their Roman numerals:

I Gao Y, Cronin NJ, Nevala N & Finni T. 2017. Validity of long-term and short-term recall of occupational sitting time in Finnish and Chinese office workers. Journal of Sport and Health Sciences. In Press, doi: 10.1016/j.jshs.2017.06.003.

II Gao Y, Nevala N, Cronin NJ & Finni T. 2016. Effects of environmental intervention on sedentary time, musculoskeletal comfort and work ability in office workers. European Journal of Sport Science 16 (6), 747−754.

III Gao Y, Cronin NJ, Pesola AJ & Finni T. 2016. Muscle activity patterns and spinal shrinkage in office workers using a sit–stand workstation versus a sit workstation. Ergonomics 59 (10), 1267−1274.

IV Gao Y, Silvennoinen M, Pesola AJ, Kainulainen H, Cronin NJ & Finni T. 2017. Acute metabolic response, energy expenditure and EMG activity in sitting and standing. Medicine & Science in Sports & Exercise 49 (9), 1927−1934.

ABBREVIATIONS

ANOVA	Analysis of variance
BF	Biceps femoris
BMI	Body mass index
CI	Confidence interval
CV	Coefficients of variation
EE	Energy expenditure
EMG	Electromyography
FFA	Fat free acids
GM	Gastrocnemius medialis
HDL-C	High-density lipoprotein cholesterol
HR	Heart rate
iAUC	Incremental area under the curve
LDL-C	Low-density lipoprotein cholesterol
LES	Lumbar erector spinae
LM	Lumbar multifidus
METs	Metabolic equivalents
RER	Respiratory exchange ratio
SD	Standard deviation
SOL	Soleus
TA	Tibialis anterior
tAUC	Total area under the curve
TES	Thoracic erector spinae
VCO_2	Carbon dioxide production
VL	Vastus lateralis
VO_2	Oxygen consumption

CONTENTS

ORIGINAL PAPERS

1 INTRODUCTION

Because of advancing methodologies and developing bodies of knowledge on sedentary behavior, a growing number of studies have focused on directly measuring sedentary behavior and differentiating its effects independent of physical activity (Gibbs et al. 2015; Pate, O'Neill & Lobelo 2008; Hamilton et al. 2008). Sedentary behavior, e.g. a sitting or reclining posture, is usually defined as an activity with low energy expenditure (≤ 1.5 Metabolic equivalents, METs) (Sedentary Behaviour Research Network 2012). After controlling for time spent in moderate to vigorous physical activity, sedentary behavior is independently associated with increased risks of various deleterious health outcomes (Biswas et al. 2015; Ekelund et al. 2016). In addition to the health impact of a high amount of sedentary behavior, evidence suggests that increases in metabolic risks may be apparent following bouts of uninterrupted sedentary behavior (Saunders et al. 2012). Related to these consequences, there are potential benefits of replacing sedentary time with non-exercise ambulatory activity, and including frequent brief breaks consisting of light- or moderate-intensity activity (Benatti & Ried-Larsen 2015; Chastin et al. 2015; Hamilton, Hamilton & Zderic 2007).

Indeed, sitting is the most common sedentary behavior in adults; most adults spend time sitting across specific domains, such as work, leisure, domestic, and transport (Owen et al. 2011). An occupational environment often requires prolonged sitting time, and occupational sitting is a major contributor to total daily sitting time among office workers (Bennie et al. 2015; Clemes et al. 2014; Parry & Straker 2013). In some occupations, such as call center work, workers can spend more than 80% of work hours in seated positions (Toomingas et al. 2012). In Finland, 46% of women and 51% of men sit for at least 6 hours in one workday (Sjöström et al. 2006). Furthermore, sedentary work is often performed in a static posture for long continuous periods, which is regarded as a cause of discomfort and pain in the musculoskeletal system, such as the upper limbs, neck and back pain (Vieira & Kumar 2004; Magnusson & Pope 1998; Bernard 1997). Thus, it is important to promote interventions in the work environment to reduce sitting as a new workplace health priority in order to positively affect workers' health and productivity.

With the development of ergonomic office furniture, sit-stand workstations have been rapidly introduced to the workplace in recent years. Sit-stand workstations allow users to adjust their work postures between sitting and standing during task performance throughout the day. Several studies have reported that working with a sit-stand workstation can reduce self-reported (Pronk et al. 2012) and objectively measured sitting time at work (Chau et al. 2014b; Dutta et al. 2014), which is predominantly replaced by standing (Alkhajah et al. 2012; Healy et al. 2013; Straker et al. 2013). Recently some prospective studies reported that standing is linked to lower all-cause and cardiovascular disease mortality (Katzmarzyk 2014; Van der Ploeg et al. 2014). Although sitting and standing both involve low levels of energy expenditure, standing requires more muscle activity in the lower extremities than sitting (Hamilton, Hamilton & Zderic 2007). Even short bouts of light muscle activity can decrease cardio-metabolic risk factors (Dunstan et al. 2012; Duvivier et al. 2013). Greater muscle inactivity time has also been shown to be adversely associated with several cardio-metabolic biomarkers in healthy office workers (Pesola et al. 2015), suggesting a potential effect of using sit-stand workstations on metabolic health. However, a recent Cochrane review showed that sit-stand workstations provide health benefits from standing at work, but the quality of the evidence is very low (Shrestha et al. 2016). While intermittent muscle contractions may be one of the key mechanisms of improvements in markers of metabolic health (Hamilton, Hamilton & Zderic 2007; Pesola et al. 2015), the role of muscle activity has not been assessed in the majority of intervention or experimental studies (Benatti & Ried-Larsen 2015; Saunders et al. 2012). Furthermore, with respect to the potential health benefits associated with reducing sitting, the effects of extended standing and different work postures on musculoskeletal issues are additional potential outcome measures that can be used to assess the effects of using sit-stand workstations on musculoskeletal health. Therefore, more studies using multidisciplinary methodologies are required to elucidate why standing might/might not independently reduce the health risks of sitting.

Since the workplace has been recognized as an important setting, common sedentary occupations like office workers would be suitable target groups for interventions aiming to reduce sedentary behavior. Unless otherwise specified, in this thesis, occupational sedentary behavior refers to this particular sitting behavior during work time. For an ecologically valid setting, the question still remains whether working with sit-stand workstations can effectively reduce occupational sitting time and improve health indexes. Thus, interdisciplinary studies of behavioral changes and postural implications are needed, based on a sedentary behavioral research framework (Marshall & Ramirez 2011), and combined with postural considerations. This thesis included field and laboratory studies with methodological approaches from biomechanics and exercise physiology to evaluate the effects of using a sit-stand workstation as part of novel intervention strategies aimed at reducing occupational sitting time and inducing potential health benefits. The aim of the current thesis was to study whether and to what extent using sit-stand workstations could reduce occupational sitting time and improve health indexes in a real workplace. Specifically, the thesis investigated occupational sitting with multidisciplinary methodology and related it to health outcomes, work ability and postural physiology.

2 REVIEW OF THE LITERATURE

2.1 Sedentary behavior

2.1.1 Definitions and measures

The term *sedentary behavior* was defined in 2012 by the Sedentary Behavior Research Network as any waking behavior in a sitting or reclining posture with energy expenditure less than 1.5 METs (Sedentary Behaviour Research Network 2012). It was highlighted that sedentary behavior is distinct from *physical inactivity*, which can be described as performing insufficient amounts of moderate to vigorous physical activity (Sedentary Behaviour Research Network 2012), e.g. not meeting specified physical activity guidelines (Haskell et al. 2007). For adults, the recommendation updated in 2007 is a minimum of 30 minutes on five days per week for moderate intensity physical activity or a minimum of 20 minutes on three days per week for vigorous intensity physical activity, and a minimum two days per week for activities that maintain or increase muscular strength and endurance (Haskell et al. 2007). The definition of sedentary behavior includes both intensity (energy expenditure ≤ 1.5 METs) and posture (sitting or reclining). The intensity fits within the context of an overall activity pattern, where non-sedentary waking behavior is categorized as light (1.6 – 3.0 METs), moderate (3.0 – 6.0 METs), or vigorous (> 6.0 METs) physical activity (Norton, Norton & Sadgrove 2010). Furthermore, it is consistent with the fundamental construct of the term *sedentary* that originates from the Latin "sedere", which means to sit. In light of posture-based hypotheses, upright behaviors with potentially overlapping MET values, such as standing, which are at the low end of the human movement spectrum, may be considered distinct from sedentary behavior. Although agreement on postural components of sedentary behavior has not yet been established, there are potentially important hypotheses to examine, e.g. whether standing would contribute to better health than sitting (Gibbs et al. 2015).

Sedentary time is commonly measured in three ways: 1) in terms of specific behaviors (e.g. watching television, using a computer); 2) the time spent in a specific domain (e.g. work, leisure, domestic, transport); 3) overall sedentary time throughout the day (Healy et al. 2011). When sitting behavior usually occurs at work, *occupational sitting time* is specifically measured as time spent sitting during work hours.

Although quantifying human behaviors generally poses challenges, different subjective and objective methods are available to measure sedentary behavior, and all of these measures could be important to advance science in this field. Atkin et al. (2012) summarized various different available methods including subjective measures (e.g. self-report questionnaires, diaries and logs) and objective measures (e.g. accelerometers, posture monitors, heart rate monitors and combined sensing, and multi-unit monitors), and highlighted their advantages and limitations. However, distinct information is offered by different methods, and it is necessary to develop and evaluate reliable and valid methods for measuring sedentary behavior. With regards to common uses in free living situations in many population-based studies among adults, self-report methods and objective device-based accelerometry will be further discussed related to the assessment of sedentary behavior.

Questionnaires are a popular self-reported method for assessing sedentary behavior. Among the most commonly used are the International Physical Activity Questionnaire (Rosenberg et al. 2008), Global Physical Activity Questionnaire (Cleland et al. 2014), Sedentary Behavior Questionnaire (Rosenberg et al. 2010), Occupational Physical Activity Questionnaire (Reis et al. 2005), or Occupation Sitting and Physical Activity Questionnaire (Chau et al. 2012). They can be implemented on a large scale with low cost and their administration does not alter the behavior under investigation. However, questionnaires rely on subjective perception of habitual sedentary behavior that is possibly susceptible to random and systematic reporting errors resulting in under- or overestimation of the items being assessed (Matthews et al. 2012b). Although the majority of questionnaires have shown acceptable to fair or good test-retest reliability, they still exhibit a weak or low correlation between sedentary time and the criterion measure (Healy et al. 2011). Compared with questionnaires using recall over the past week or longer, *short-term recall* (e.g. 24-hour recall and past day recall) or *behavioral logs* (e.g. time use records) can reduce some of the reporting errors in estimates of usual levels of sedentary behavior (Matthews et al. 2012b). However, the disadvantages, such as participant burden, systematic reporting errors and administration costs, have limited their use in population-based research (Matthews et al. 2012b). Thus more work is needed to evaluate and compare the differences in varying time frames of assessment, such as short-term recall on a daily basis versus long-term recall in habitual patterns in order to improve the assessment of self-reported sedentary behavior (Matthews et al. 2012b). Studies are required to develop and evaluate validated self-reports of behavior-specific, domain-specific or total sedentary behavior and where possible in different sub-populations (Healy et al. 2011).

Accelerometry is developing as an important method used for the objective monitoring of sedentary behavior. It can reduce measurement errors and provide full information about patterns of activity, which includes not only total sedentary time but also how this is accumulated (Healy et al. 2008; Chastin & Granat 2010). Accelerometers are usually small, lightweight and feasible devices that can be worn during normal daily life. There are many available accelerometer devices on the market which are widely used to date (Godfrey et al. 2008). Most of them use piezoelectric sensors to detect accelerations in one to three orthogonal planes (anteroposterior, mediolateral, and vertical) via body movement, and can convert recorded accelerations to a quantifiable digital signal referred to as counts by summing over a time frame or epoch (Chen & Bassett 2005). Several considerations have been discussed concerning using accelerometers in field based research (Trost, Mciver & Pate 2005; Matthews et al. 2012a). Standardized procedures and data processing are still in development, because of the importance of feasible utility and the ability to perform comparisons between different studies and populations (Healy et al. 2011; Atkin et al. 2012). For example, the hip- or waist-mounted accelerometers of ActiGraph are often used. Sedentary time is derived from activities through the low movement counts at a specified cut-point. Although the most accurate cut-point is yet to be established, counts per minute less than 100 are typically classified as sedentary time (Freedson, Melanson & Sirard 1998). However, this is still not a gold standard for identifying sedentary behavior because of the misclassification of low intensity non-sedentary behaviors as sedentary behavior. For example, periods of standing still may be misclassified as sedentary time.

Instead, methods of identifying postural allocations using an accelerometer for sensing inclination have recently been developed. This approach can determine body posture on the basis of thigh inclination and acceleration to classify time spent sitting/lying and upright (standing or walking) (e.g. using ActiPAL). Their criterion validity for measuring sitting time in both laboratory (Grant et al. 2006) and free living settings (Kozey-Keadle et al. 2011; Lyden et al. 2012) has been established, and the ability to accurately determine body position is high compared to direct observation. This method yields excellent reliability and high validity, with a mean percentage difference of 0.19% (limits of agreement range from -0.68% to 1.06%) for total time spent sitting compared with direct observation (Grant et al. 2006). Several studies have examined thigh-mounted accelerometers across different device brands that are capable of identifying sitting and upright postures (Edwardson et al. 2016a; Steeves et al. 2015; Rowlands et al. 2014; Skotte et al. 2014). Some studies reported high accuracy of raw acceleration data processing using open source algorithms in a range of postures and activities, and in laboratory and free living settings (Edwardson et al. 2016a; Rowlands et al. 2014). This potentially facilitates the comparison of results across different monitors when data transformation is carried out post processing. As one of the key recommendations suggested by a workshop entitled "Research Evidence on Sedentary Behavior", a research priority is to improve and standardize methods of assessing sedentary behavior (Gibbs et al. 2015).

Muscle activity and inactivity have been reported in recent studies, and may be important and distinct contributors to sedentary behavior (Pesola et al. 2015; Finni et al. 2014; Hamilton, Hamilton & Zderic 2007). *Muscle inactivity* can be defined as time when the muscle activity intensity remains below a specified threshold. In one study the threshold was defined as 90% of the individual's muscle activity amplitude during standing (Tikkanen et al. 2013). These individual muscle inactivity thresholds were comparable with their absolute thresholds of 2% EMG_{MVC} (Tikkanen et al. 2013). When sitting quietly, large locomotor muscles are mainly inactive. There is a distinction between standing and sitting whereby thigh muscle activity is several folds higher during standing than sitting (Tikkanen et al. 2013), even though inter-individual variability is high (Pesola et al. 2016). Thus, the quantification of muscle activity can provide new insights into research in sedentary behavior and its relationships with health outcomes (Thyfault et al. 2015).

2.1.2 Epidemiological findings linking sedentary behavior with health impacts

In 2003 − 2006, a large population-based sample from the "National Health and Nutrition Examination Survey" assessed sedentary time using objective accelerometer measures, and found that more than half of the waking day, or 7.7 hours/day, was spent on sedentary time (Matthews et al. 2008; Schuna, Johnson & Tudor-Locke 2013). They also compared with accelerometer measured variables across categories including self-reported moderate-to-vigorous activity, usual occupational/domestic activity and leisure time sedentary behavior. On average, adults who self-reported that they met physical activity guidelines accumulated more objectively measured physical activity and similar amounts of sedentary time relative to those who reported not meeting the guidelines. However, they found that adults who self-reported their daily occupational/domestic activity as "mostly sitting" or accumulating ≥ 3 h/d in leisure time spent on sedentary behavior accumulated fewer accelerometer counts and more sedentary time than those who described their usual occupational/domestic activity as "stand, walk, lift, or carry" or < 3 h/d in leisure sedentary behavior (Schuna, Johnson & Tudor-Locke 2013).

In a recent epidemiology study including more than one billion adults from 54 countries, Rezende et al. (2016) found that sitting for more than 3 h/d was associated with a 3.8% increased risk of all-cause mortality, which equated to 433,000 deaths/year. Similarly, Chau et al. (2013) used meta-analysis to quantify the association between daily total sitting time and all-cause mortality risks. When physical activity was taken into account, they found that there was a dose-response relationship between per hour increase in time spent sitting and all-cause mortality (Chau et al. 2013). Each additional hour of daily sitting was associated with an overall 2% increased risk of all-cause mortality after physical activity adjustment, even up to 5% risk for adults sitting more than 7 h/d (Chau et al. 2013). When physical activity was not taken into account, 2% and 8% higher risk per hour were related with total sitting > 4 − 8 and > 8 h/d (Chau et al. 2013). It seems that physical activity partly attenuates the adverse associations between total daily sitting time and all-cause mortality, especially in those who sit the most. Chau et al. (2013) also found that sitting time was associated with a 5.9% greater risk of all-cause mortality (using calculation of population attributable fraction) after adjusting for physical activity. These findings suggest that a higher amount of daily total sitting time is associated with greater risk of all-cause mortality in a dose-response manner, and physical activity seems to attenuate this hazardous association. An additional meta-analysis reported that sedentary time was independently associated with increased risks of several deleterious health outcomes including all-cause mortality, cardiovascular disease incidence or mortality, cancer incidence or mortality, and type 2 diabetes incidence in adults, after adjustment for physical activity (Biswas et al. 2015). In their analysis, Biswas et al (2015) included 47 articles, of which 44 applied a prospective cohort design and sedentary time was mostly quantified using self-report. However, the adverse outcomes associated with sedentary time were of greater magnitude among persons who participated in lower levels of physical activity compared with higher levels (Biswas et al. 2015). Thus, it highlighted that the recommended physical activity levels do not fully counteract the hazards of a high amount of sitting time, and that deleterious effects of sitting are stronger for those who are physically inactive compared to those who are active.

Given the consistency of research findings reported so far linking too much sitting to poor health, the health impacts of reducing sitting time are now being researched. Rezende et al. (2016) estimated that eliminating sitting time would increase life expectancy by a weighted mean of 0.23 years among the 54 countries worldwide, ranging from 0.15 years in Southeast Asian countries, 0.29 years in Europe countries, to 0.4 years in Western Pacific countries. The percentage of all-cause mortality worldwide would decrease if sitting time was reduced at different levels (Rezende et al. 2016). Based on reductions of 10%, 25% and 50% of mean sitting time per day, all-cause mortality would be accordingly reduced by 0.6%, 1.3% and 2.3%, respectively (Rezende et al. 2016). Absolute reductions in mean sitting time equal to 30 minutes, 1 hour and 2 hours per day would have an instant impact, decreasing all-cause mortality by 0.6%, 1.1%, and 1.9%, respectively (Rezende et al. 2016). In a large prospective cohort study of post-menopausal women, Lee et al. (2016) examined mortality rates according to changes in sitting time over six years. Compared with women who maintained high amounts of sitting time (≥ 10 h/d) over six years, those who maintained lower levels of sitting (≤ 9 h/d) over time had a 51% lower risk of all-cause and 48% of cancer mortality. Interestingly, reducing sitting time from ≥ 10 h/d to ≤ 9 h/d resulted in a 29% lower risk of all-cause mortality and a 27% lower risk of cancer mortality (Lee, Kuk & Ardern 2016). These findings indicated, among middle-aged and older women, that reducing sitting time is beneficial for survival of those who have high amounts of physical inactivity and sedentary time (Lee, Kuk & Ardern 2016). Thus, considering the increasing trend of sedentary time (particularly too much sitting), interventions aimed at reducing sitting time have been proposed as an important public health strategy (Proper et al. 2011; Owen et al. 2011; Owen et al. 2010).

Recently emerging epidemiological studies have examined whether there are benefits of replacing sedentary behavior with either purposeful exercise or a broad range of everyday activities. Mekary et al. (2013) estimated the substitution effect of replacing equivalent time spent in one activity with another one on health benefits. Similarly, work was done by Matthews et al. (2015) followed over 150,000 older adults. They reported that the reduction in mortality was around range of 20% − 40% when replacing 1 h/d of sitting with an equal amount of purposeful exercise or non-exercise activities among less active participants (< 2 h/d of overall activity) (Matthews et al. 2015). For those who were more active (≥ 2 h/d of overall activity), the mortality benefit was a 9% lower risk when replacing sitting time with 1 h/d exercise (Matthews et al. 2015). Further studies conducted using accelerometer-based measures of sedentary time and physical activity also reported the benefits in terms of mortality of replacing sedentary time with light- and moderate-to-vigorous intensity activity (Matthews et al. 2016; Fishman et al. 2016). In particular, among less active adults who accumulated less than 5.8 h/d of total activity, replacing 1 h/d of sedentary time with either light or moderate-to-vigorous intensity activity was associated with 18% and 42% lower risk of mortality, respectively (Matthews et al. 2016). Although the method used estimates the potential benefits of replacing sedentary time and does not the actual health impacts on changing sedentary behaviors, it provides useful insight to help develop interventions that aim to reduce sitting time by replacing with physical activity (Keadle et al. 2017). Another study also highlighted that light intensity activity during everyday living, even "baseline activities" (Powell, Paluch & Blair 2011), may be a healthy substitute for sedentary behavior. In this respect, the minimum threshold for health enhancing physical activity should be rethought (Powell, Paluch & Blair 2011).

A recent study found that adults engaged in an average of 47 bouts of active and sedentary behaviors per day, and that the average amount of time spent standing and ambulating was about 6.5 h/d, which was mostly accumulated in several bouts of activity (Levine et al. 2008). Standing up interrupts a sedentary bout and is thus hypothesized to reduce the health risks of sedentary behavior. Some prospective studies supported this hypothesis and found that standing is linked to lower all-cause and cardiovascular disease mortality (Katzmarzyk 2014; Van der Ploeg et al. 2014). These studies included large samples from Canadian adults and Australian adults, and found similar dose-response associations, suggesting that increasing standing time may help to alleviate the health risks of excessive sitting (Katzmarzyk 2014; Van der Ploeg et al. 2014). Stamatakis et al. (2015) reported that replacing sitting with either standing or walking led to a reduced mortality risk of 4% or 10% respectively. However, their study relied on self-report measures that may not be sufficiently accurate (Stamatakis et al. 2015). A recent cross-sectional study using the ActivPAL monitor, which is highly accurate for capturing postural allocations (Grant et al. 2006), showed that replacing sitting with either standing or stepping had beneficial effects on high-density lipoprotein cholesterol and triglycerides (Healy et al. 2015). It suggested that replacing 2 h/d of sitting time with standing, stepping, or both, may benefit cardio-metabolic health. In particular, standing showed beneficial associations with lipids, as well as fasting glucose and 2-h post loading of plasma glucose (Healy et al. 2015). As standing is a common behavior, a simple alternative to sitting may represent different physiological states (Hamilton, Hamilton & Zderic 2004). However, it is still unclear if and why standing might provide potential health benefits (Hamilton, Hamilton & Zderic 2007). Thus, experimental studies are required to provide insight into possible physiological mechanisms underlying these associations based on epidemiological findings.

2.1.3 Experimental studies of underlying physiological mechanisms

Epidemiological findings have provided specific hypotheses relating to too much sitting, particularly the importance of reducing the total amount of sitting time and prolonged periods of uninterrupted sitting. It should be noted that sedentary behavior is distinct from physical inactivity, since decades of experimental studies have been dedicated to inactivity physiology research. This has provided the platform on which possible underlying mechanisms can be further elucidated concerning the deleterious biological and physiological consequences of prolonged sitting. Physical inactivity is a primary cause of 35 separate pathological and clinical conditions (Booth, Roberts & Laye 2012). Human studies involving ground-based bed rest (Bergouignan et al. 2011), space flight (Fitts, Riley & Widrick 2000) and lowering daily ambulatory activity in free living humans (Thyfault & Krogh-Madsen 2011), as well as animal experimental models (Bey & Hamilton 2003), among of which impose physical inactivity for a defined period of time, have been able to investigate mechanisms of adaptation to short- or long-term analogs of biological and physiological responses. These include muscle atrophy and functional loss, reduced capacity to use fat as substrate or produce energy, insulin resistance in muscle, impaired lipid trafficking and hyperlipidemia, a shift in muscle fiber types toward the fast-twitch glycolytic type, ectopic fat storage, and increased central and peripheral adiposity (Bergouignan et al. 2011; Thyfault & Krogh-Madsen 2011; Fitts, Riley & Widrick 2000), and suppressed skeletal muscle lipoprotein lipase activity in animals (Bey & Hamilton 2003). The following events can be hypothesized to explain the physical inactivity-induced metabolic alterations, thus suggesting metabolic inflexibility (Bergouignan et al. 2011). Although the mechanisms underlying the health hazards of sitting are not completely known, an improved body of knowledge includes sedentary behavior and positive energy balance, postprandial glycemic load, increased oxidative stress, liver and intramuscular lipid accumulation, and insulin resistance at the muscle level, which are contributors to increased cardio-metabolic risks (Pesola 2016).

On the basis of these insights from inactivity physiology research, emerging experimental studies have provided evidence for the effects of reducing and breaking up sedentary time on biomarkers of cardio-metabolic risks. It is well documented that acute bouts of sedentary behavior (ranging from 2 hours to 7 days) may induce rapid and deleterious changes in triglyceride levels, insulin sensitivity, and glucose tolerance (Saunders et al. 2012). Excessive sitting has been identified as a highly prevalent risk behavior, and prospective experimental studies have provided considerable evidence regarding the impact of prolonged sitting time on cardio-metabolic health profile (Benatti & Ried-Larsen 2015). There are potential benefits of replacing sitting time with physical activity, even with non-exercise ambulation and including frequent brief breaks of light- or moderate-intensity activity (Benatti & Ried-Larsen 2015). However, it is also highlighted that the positive outcomes on cardio-metabolic profile may be dependent on type, intensity and frequency of physical activity (Benatti & Ried-Larsen 2015). Reports on the findings and recommendations of the "Physiology of Sedentary Behavior and its Relationship to Health Outcomes" group suggested studies of sedentary behavior with respect to the behaviors that are needed for optimal health (Thyfault et al. 2015).

Several randomized cross-over studies have consistently shown that there are clinically significant improvements in postprandial glucose responses following a high frequency of short interruptions, e.g. 2 – 3 min bouts per 20 – 30 minutes during prolonged sitting involving either light- or moderate-intensity ambulation, standing, or simple resistance activity (Benatti & Ried-Larsen 2015). In a recent meta-analysis of observational and experimental studies, Chastin et al (2015) examined the relationship between breaks in sedentary behavior and cardio-metabolic health in adults. They identified a total of 13 studies, 6 of which were experimental studies, and confirmed that interrupting prolonged sitting both with light- and moderate-to-vigorous intensity physical activity has beneficial acute effects on glycemic control, where pooled results of interruptions significantly lowered postprandial glucose by 17.4% and 1.4%, and insulin level by 14.9% and 23.8%, respectively (Chastin et al. 2015). These results suggest that breaking up prolonged sitting with light-intensity physical activity like walking may be adequate for counteracting some acute detrimental effects of sedentary behavior on cardio-metabolic health.

Standing up from a seated position represents the end of a sitting period, which is a strong stimulus for the body. However, inconsistent conclusions may arise when examining different durations of standing breaks, e.g. whether it requires a sufficient level of activity to induce acute benefits of breaking up prolonged sitting time (Chastin et al. 2015). When sitting and standing were alternated with equal durations every 30 minutes, standing attenuated postprandial glycaemia without affecting insulin responses (Thorp et al. 2014), but not for short bouts of 2 minutes standing up after every 20 minutes sitting (Bailey & Locke 2015). There is a mild increase in energy expenditure during standing when compared with sitting (Júdice et al. 2016), which may improve clearance of circulating nutrients. However, the increase in energy expenditure when transitioning from sitting to standing is negligible (Mansoubi et al. 2015), and neither the amount of energy expenditure (Blankenship, Granados & Braun 2014; Duvivier et al. 2013) nor changes in energy balance (Thorp et al. 2014) can solely explain the improved glucose regulation following light-intensity physical activity like standing. This suggests that mechanisms other than increased energy expenditure bring about the potential health benefits of standing.

Given hypotheses on posture-based mechanisms, specifically both standing and ambulation, to maintain upright postures skeletal muscle activity levels are greater compared with a sitting or reclining posture. Thigh muscle activity is several folds higher during standing than sitting, especially for obese adults (Pesola et al. 2016). Skeletal muscle tissue is mainly responsible for plasma glucose disposal in postprandial conditions (DeFronzo, Jacot & Jequier 1981), and static standing increases muscle activity compared to sitting, with high inter-individual variability (Pesola et al. 2016). Sustained contractile activity in the lower limbs during standing may help to promote the translocation of GLUT-4 glucose transporters from intracellular compartments to the plasma membrane to facilitate muscle glucose uptake (Sakamoto & Holman 2008). Breaking up sitting with light intensity walking improves contraction-mediated glucose uptake compared to uninterrupted sitting (Bergouignan et al. 2016). If the gains in muscle activity during standing and walking were similar, this finding could explain the improved glucose tolerance independent of changes in insulin sensitivity. Moreover, increased fat oxidation during physical activity might improve glucose tolerance indirectly through improved muscle lipid uptake, trafficking and oxidation, which serves to clear insulin-inhibiting fat metabolites within muscle cells (Bergouignan et al. 2013). Therefore, standing may benefit glucose tolerance through mechanisms linked to either increased carbohydrate or fat oxidation, but these mutually inhibitory mechanisms have not been quantified concurrently with muscle activity and metabolic markers during standing. Concurrent measurement of these potential mechanisms is required to explain why in some studies standing has not elicited metabolic benefits (Bailey & Locke 2015; Miyashita et al. 2013), and thus to elucidate whether standing is a healthy alternative to sitting.

2.1.4 Determinants of sedentary behavior and modifying the workplace environment

When experimental studies give important physiological insight into the risks of sedentary behavior and possible substitutes of physical activity to eliminate those risks, the next step in sedentary behavior research is to develop and evaluate effective intervention studies which aim to reduce overall sedentary time and change habitual patterns of sedentary accumulation. Thus, it is important to firstly understand which factors influence sedentary behaviors.

Distinct from planned and structured exercise behavior, behavioral settings as the determinants of a high amount of sitting time are linked to physical and social contexts where sitting occurs (Barker 1968). An ecological model has been proposed by Owen et al. (2011) as a framework to understand the relevant determinants of sedentary behavior. It assumes that there are multiple levels of influence on sedentary behavior, including individual, social, organizational/community, environmental, and policy within various contexts. The importance of the behavioral settings is highlighted. These behavioral settings can be identified in different domains: workplace, leisure, domestic and transportation contexts. Moreover, particular sedentary behaviors may occur commonly in a variety of settings, such as watching television and other screen-focused time in the domestic environment, prolonged sitting in the workplace and time spent sitting in automobiles (Owen et al. 2011).

Sedentary behaviors can be strongly influenced by environmental attributes in a variety of contexts including work, leisure, domestic and transport (Owen 2012). At the environmental level, research focused on specific sedentary behaviors in particular contexts has reported correlations between environmental attributes and adults' sedentary behaviors, and it is noted that the determinants of sedentary behavior are unique in different environments such as neighborhood and occupational environments (Koohsari et al. 2015; De Cocker et al. 2014). Modifying environments can provide an important strategy for interventions aiming to reduce sedentary behavior. This is also supported by a recent review which focused on behavioral change strategies used in sedentary behavior reduction interventions in adults (Gardner et al. 2016). It was suggested that future interventions should consider the external environments which largely determine sedentary behavior; in other words, people would be willing to reduce their sedentary time if the environment were modified (Gardner et al. 2016).

With a particular focus on sedentary behavior at work, the workplace has been proposed as one of the key settings for interventions aiming to reduce sedentary behavior (Healy et al. 2012). An increasing number of studies have recently reported on workplace interventions. It is important to identify the effectiveness of workplace interventions to reduce sitting time. Previous studies have focused on increasing workplace physical activity as the primary outcome, for example using a standing desk (Speck & Schmitz 2011) or walking workstation (Thompson et al. 2008; Levine & Miller 2007), operating a stepping device in the office (McAlpine et al. 2007), and sitting on a dynamic chair (Ellegast et al. 2012) or a therapy ball instead of a traditional office chair (Beers et al. 2008). However, research simply targeting exercise behaviors does not reduce sedentary behavior (Chau et al. 2010; Conn et al. 2009), indicating the importance of primarily targeting sedentary behavior independent of physical activity for sedentary reduction interventions (Gardner et al. 2016; Prince et al. 2014; Martin et al. 2015). Conclusive evidence for the impact of workplace interventions on reducing sitting time as primary outcomes is much needed.

Two recent meta-analyses evaluated the combined effectiveness of workplace interventions targeting reducing sitting time as their primary outcomes (Chu et al. 2016; Shrestha et al. 2016). Chu et al. (2016) identified 26 controlled intervention studies with a total of 4568 participants. The pooled intervention effect was a significant workplace sitting time reduction of about -40 min/8 h workday, favoring the intervention group (Chu et al. 2016). Followed by multi-component strategies (-89 min/8 h workday), environmental strategies alone still induced substantial reductions in workplace sitting time of -73 min/8 h workday, compared to just -15 min/8 h workday for educational/behavioral strategies, suggesting the promising effectiveness of implemented environmental modifications in the workplace (Chu et al. 2016). Comparable with a previous review, Neuhaus et al. (2014) particularly focused on activity-permissive workstations, and reported a 77 min/8 h workday reduction in workplace sitting (Neuhaus et al. 2014a). However, inconsistent with a recent Cochrane review, they were skeptical about the effect of an environmental modification alone, and they reported that there is very low to low quality evidence suggesting that sit–stand workstations may decrease workplace sitting without having adverse effects in the short or medium term (Shrestha et al. 2016). Thus, more studies are needed to examine the effectiveness of sit-stand workstations in the real workplace.

Collectively, modifying a workplace environment by installation of active workstations such as height adjustable sit-stand workstations has been proposed as a potential strategy to reduce sedentary behavior at work. Examining the influence of an environmental modification alone on sedentary behavior could be helpful in developing efficient interventions targeted at reducing sedentary time in a real workplace. While there has been a major shift toward office workstations, it is often with little consideration for ergonomic or biomechanical factors, or their work postural implications (Callaghan et al. 2015). Therefore, combined with the field of ergonomics, physical ergonomic factors associated with sedentary work are still important considerations to evaluate regarding the improvement of musculoskeletal health. Specific examples of prolonged sitting and standing in the workplace will be discussed in the next section. The theoretical debate with respect to the negative impacts of prolonged sitting and standing and the many contributing factors is complex. Thus, a brief overview of the various mechanisms is outlined in the following section to provide an indication of the theories involved and the postural related implications.

2.2 Consequences of prolonged sitting and standing

2.2.1 Static posture

There is no posture that can be comfortably maintained for long periods of time. Any prolonged posture can lead to static loading of the lumbar spine, the muscles and joint tissues, and consequently cause discomfort, pain or even injury when overload occurs (Magnusson & Pope 1998; Vieira & Kumar 2004). In the office environment, sitting and standing are the two basic forms of working postures. Workers may restrict their body movement and postural changes due to job requirements and confined workstations. Continuous sitting or standing at work is one such restriction that is commonly observed in various offices.

Sustained static or constrained postures can contribute to the development of muscle imbalance, fatigue, discomfort and pain (Valachi & Valachi 2003; Todd, Bennett & Christie 2007). Although a consensus as to whether static posture is causative of or resultant from musculoskeletal disorders is yet to be reached, study has investigated potential exposure-response relationships (Kwon et al. 2011). Several negative health outcomes are associated with static postures after long periods of exposure, either in prolonged sitting or standing and sedentary work. In many cases, the exposure was described subjectively and/or in combination with other work-related risk factors (Bernard 1997, 6-34). There is at least reasonable evidence of a causal relationship between several risk factors and the development of work-related musculoskeletal disorders including heavy physical work, smoking, high body mass index, high psychosocial work demands, and the presence of co-morbidities, as well as the most commonly reported biomechanical risk factors including excessive repetitions, awkward postures, and heavy lifting (Da Costa & Vieira 2010). In light intensity office work, performing computer work and postures outside of neutral position are particularly identified as problematic for musculoskeletal issues (Wahlström 2005).

In office work, sitting is the predominant static posture and musculoskeletal symptoms are commonly reported in relation to neck-shoulder disorders, e.g. tension neck syndrome and trapezius myalgia (Larsson, Søgaard & Rosendal 2007). A forward head posture (Gonzalez & Manns 1996) can be a resultant adaptation among office workers, and a positive relationship has been reported between neck flexion and musculoskeletal symptoms in the neck and trapezius region (Kilbom, Persson & Jonsson 1986). Compared with neutral head posture, the forward head posture involves significantly increased EMG activity in the upper and lower trapezius during isometric shoulder flexion (Weon et al. 2010). Furthermore, as muscles adapt to being held at lengthened or shortened lengths over time, such prolonged static postures may result in muscle imbalance, leading to structural damage and pain (Valachi & Valachi 2003). When performing intensive computer work, prolonged, low level static muscular contractions can cause accumulation of metabolites and muscle fatigue, and even muscle ischemia or necrosis (Sjøgaard, Lundberg & Kadefors 2000).

Development of local muscle fatigue and discomfort is considered a limitation of monotonous and long lasting static work, even though the work can be regarded as light intensity (Bosch, De Looze & Van Dieën 2007). In a static posture, blood flow is reduced and prolonged muscle contractions at a low level can increase intramuscular pressure, due to absence of oxygenation and nutrition, resulting in accumulation of metabolites and local muscle fatigue (Sjøgaard, Lundberg & Kadefors 2000). According to the ‘Cinderella hypothesis’ which follows Henneman’s size principle, in low-intensity muscle contractions, type I motor units are recruited first and remain active during static tasks (Hägg 1991; Henneman, Somjen & Carpenter 1965). Thorn et al. (2002; 2007) reported that low threshold motor units were recruited first, and were then continuously active within the trapezius muscle over long periods of static contraction. This was also the case in symptomatic computer users (Thorn et al. 2007; Thorn et al. 2002). A work-rest schedule including frequent and short breaks from sitting for a data entry task resulted in the smallest increase in trapezius muscle activity (Balci & Aghazadeh 2004). Furthermore, studies by Samani et al. (2009; 2010) have shown that the activity of the trapezius muscle can be reorganized following active pauses.

Prolonged static postures have been identified as risk factors for low back pain, either in prolonged sitting or standing (Manchikanti 2000). Studies have associated inadequate working postures and overloading (e.g. awkward and slumped postures over time) with increased intervertebral disc pressures, which is a risk factor that may lead to degenerative changes within the lumbar spine and development of low back pain or injury (Valachi & Valachi 2003; Todd, Bennett & Christie 2007). More discussion related to spinal loading in prolonged sitting and standing can be found in section 2.2.2.

Long lasting static postures at work result in limited ambulation, which affects blood circulation and accelerates edema formation, particularly in the lower extremities (Akihiko et al. 1996; Chester, Rys & Konz 2002). Prolonged sitting and standing have also been reported to contribute to insufficient blood and lymph flow, which cause a series of problems such as leg swelling, discomfort or pain, varicose veins and skin ulcers (Akihiko et al. 1996; Beebe-Dimmer et al. 2005; Sudoł-Szopińska et al. 2011; Jawien 2003). Muscle and lymph pumps are activated by intermittent muscle contractions, which is an important mechanism to increase venous blood flow and reduce venous stasis in order to counteract the formation of edema in the lower limbs (Stranden 2000). Immobility and muscle inactivity are major factors that limit activation of the muscle-venous pump, and thus lead to more venous stasis and swelling (Stranden 2000). Although both prolonged standing and sitting at work increase the risk of developing chronic venous disorders, working in a standing posture is associated with a higher risk than prolonged sitting (Sudoł-Szopińska et al. 2011). In general, leg swelling is greater when standing still than when sitting because of higher hydrostatic pressure, which is the gravitational force exerted by blood between the heart and the foot. When a stationary standing posture is maintained for long periods, high interstitial pressure due to prolonged muscle contractions also leads to increased leg swelling. During prolonged sitting, the pressure of the chair on the veins in the hip and thigh may be one of the dominant reasons for increased leg swelling, which restricts the blood circulation (Shvartz et al. 1980; Akihiko et al. 1996; Stranden 2000). Modest leg activity has been identified as an effective factor to counteract and prevent local edema formation in the lower limbs, either in standing or seated working postures (Lin, Chen & Cho 2012; Noddeland & Winkel 1988). While the activation of lower limb muscles is important, muscles have been shown to be inactive for up to 90% of a bout of sitting, and the amount of muscle inactivity is even higher for overweight compared to normal weight people (Pesola et al. 2016).

2.2.2 Spinal loading

A static posture performed for sustained periods has been regarded as a risk factor for the development of musculoskeletal disorders, particular back problems, either in prolonged sitting or standing (Pope, Goh & Magnusson 2002). As little as half an hour of prolonged sitting has been linked with an increased level of low back discomfort (Grondin et al. 2013), and sitting time for more than 6 hours per day at work has been associated with chronic low back pain in office workers (Spyropoulos et al. 2007). Both field (Andersen, Haahr & Frost 2007; Roelen et al. 2008; Tissot, Messing & Stock 2009) and laboratory studies (Gallagher, Campbell & Callaghan 2014; Marshall, Patel & Callaghan 2011; Sorensen et al. 2015; Nelson-Wong & Callaghan 2010) have reported that prolonged standing is related to low back pain, and pain development can occur in back healthy people while performing light work tasks in standing. Individuals who develop low back pain during prolonged standing can experience symptoms within 15 to 45 min (Nelson-Wong & Callaghan 2010; Marshall, Patel & Callaghan 2011). Thus, perceived discomfort and back pain are indicators of overuse and require appropriate recovery time.

The forces that load the spine have been associated with the risk factors to develop low back pain (Corlett 2006; Kerr et al. 2001). Loads may be due to body weight, forces from surrounding muscles and ligaments, intra-abdominal pressure and any other external load (Todd, Bennett & Christie 2007). Spinal loading can be summarized as 1) axial forces that apply compression or tension to the spine along its longitudinal axis; 2) lateral shear forces on the spine (from side to side); 3) anterior-posterior shear forces that load the spine in the forward and backward direction; 4) torsional forces that twist the spine. When the imposed load exceeds the structure or tissue tolerance, it can cause damage. Previous studies have suggested that cumulative spinal loading may be associated with risk of low back disorders at work (Kumar 1990; Coenen et al. 2013; Vieira & Kumar 2004).

Increased spinal loading can be due to gravity and the shape of the spine. In an upright standing position, the weight of the upper body produces very little moment to displace the trunk, where the back extensor muscles generate an extensor moment to counteract a flexion moment from the spine to maintain posture. In a standing position, the pelvis is relative in a vertical position. When sitting down from a standing position, the pelvis rotates backward and lumbar lordosis decreases. Reduced lumbar lordosis can produce an increased moment and deformation of the disk itself due to flattening of the lumbar spine, which contributes to increased disc pressure. Thus, the lowest pressure is found in the upright straight positon. Furthermore, other support factors can influence disc pressure, such as seat-back inclination, lumbar support and use of an armrest (Pope, Goh & Magnusson 2002; Harrison et al. 1999; Corlett 2006). However, Claus et al (2008) reported that lumbar intradisc pressure in sitting is unlikely to pose a threat to non-degenerate discs, and that sitting is no worse than standing for disc degeneration or low back pain incidence. If sitting is a greater threat for development of low back pain than standing, the mechanism is unlikely to be greater disc pressure (Claus et al. 2008). Similarly, several studies have reported that although posture itself may not be related to low back pain, working postures in association with other factors such as awkward postures show a significant increase in the risk of back injury (Da Costa & Vieira 2010; Bakker et al. 2009). Static muscular contraction may also be an important factor in determining the postural load, and may be associated with the risk of musculoskeletal disorders (Wahlström 2005; Corlett 2006).

Continuous spinal loading can cause the intervertebral discs to lose height due to radial bulging of the annulus fibrosus and by expelling fluid from the nucleus pulposus and annulus fibrosus. Reducing the intervertebral disc height can decrease its capacity to absorb or transmit forces, whilst also increasing loading on other structures of the spine, such as facet joints and spinal ligaments. Spinal shrinkage has been used in ergonomic evaluation of working situations to reflect short-term effects of spinal loading (Eklund & Corlett 1984; Corlett et al. 1987; Van Dieën & Toussaint 1993). Spinal shrinkage is an indicator of intervertebral disc compression, and activities with greater compressive loads increase spinal shrinkage (Eklund & Corlett 1984; Corlett et al. 1987; Van Dieën & Toussaint 1993). Spinal shrinkage in moderate physical activity tasks and their strong correlation has been well documented (Salami et al. 2010). Previous studies reported that physical work factors are related to increase the load on the spine, which can reflect to increase the shrinkage of the spinal discs (Pope, Goh & Magnusson 2002; Kerr et al. 2001). These physical work factors can be heavy lifting, asymmetric trunk loading, twisted and uncomfortable work postures, frequent forward bending, and constant bending (Igic, Ryser & Elfering 2013). For example, there is a high correlation between carrying weights and spinal shrinkage (Salami et al. 2010). However, few studies have explored spinal shrinkage across light intensity physical activity tasks in a real workplace. Previous studies compared the effects of trunk movement and postural changes on spinal shrinkage in work situations (Paul & Helander 1995; Van Dieën & Oude Vrielink 1998; Van Dieën, De Looze & Hermans 2001), and standing has been shown to cause more spinal shrinkage (Van Deursen et al. 2005) or less recovery of shrinkage than sitting (Beynon & Reilly 2001). Although there is a lack of normative data on typical workday spinal shrinkage, standing is associated with increased spinal shrinkage (Igic, Ryser & Elfering 2013), and spinal shrinkage is greater at work performed in a standing compared to a sitting position (Leivseth & Drerup 1997). Thus, suggestions to encourage more standing at work should be made with caution.

Work-rest schedule has an impact on spinal shrinkage in standing work (Paul & Helander 1995; Van Dieën & Oude Vrielink 1998). Previous studies reported that shorter but more frequent standing breaks from sitting may cause spinal loading (Helander & Quance 1990). After 4 h of sedentary work, shrinkage was shown to be smallest with two rest breaks of 20 or 40 min compared with more frequent and shorter breaks (Helander & Quance 1990). Office workers who stood in 30 minute sessions experienced significantly less shrinkage than those who stood in 15 minute sessions (Paul & Helander 1995). Therefore, considering that the effects of a sit-stand paradigm on spinal shrinkage are likely to depend on postural loading and exposure time (Leivseth & Drerup 1997), it is important that future studies explore suitable sit-stand schedules for regular changes in posture, with changes occurring throughout the day.

Collectively, both prolonged sitting and standing are associated with potential negative health and musculoskeletal issues. It is well documented that prolonged sitting may lead to musculoskeletal disorders, such as discomfort, pain in different body regions, and lower extremity swelling, and prolonged standing may also lead to low back problems, as well as edema or discomfort in the lower limbs (Magnusson & Pope 1998; Bernard 1997). Merely changing posture from sitting to standing may not actually eliminate the fundamental issues in stationary positions for extended periods from the ergonomic perspective.

In the last few years, a number of studies have been conducted on improving musculoskeletal health in the workplace. Recent recommendations have suggested that reducing seated exposure and rotating frequently between sitting and standing can be considered as the solution to sedentary office work (Callaghan et al. 2015). Based on the underlying ergonomic theory of postural variation, using a sit-stand workstation to alternate between sitting and standing postures at work seems to be a promising solution to mitigate work-related health issues. Further studies about implementing sit-stand workstations into a real workplace are discussed in the next section.

2.3 Sit-stand interventions: using sit-stand workstations at work

With a rapidly growing market share, height adjustable sit-stand workstations have been commonly introduced into office settings in recent years. As opposed to traditional sit workstations or standing only workstations, sit-stand workstations aim to reduce sitting and increase breaks due to the possibility to work periodically from a sitting position or a standing position. Workers can freely select a sitting or standing position according to their needs and tasks, and adjust the desk height easily, which consequently increases standing and opportunities for movement. Modifying work environment by installation of sit-stand workstations offers potential strategy to reduce sedentary behavior. Ergonomic interventions have also included sit-stand workstations for many years and the majority of evidence focuses on musculoskeletal disorders and work performance (Karakolis & Callaghan 2014). Thus, interacting with the ergonomic field, posture-related musculoskeletal health and work efficiency in the workplace are still important parameters when evaluating the effects of using sit-stand workstations regarding reduction of occupational sitting by increasing standing time.

A systematic review by MacEwen et al. (2015) noted that there are still substantial gaps in our knowledge regarding the utility of such ergonomic workstations to reduce sitting time and promote health benefits (MacEwen, MacDonald & Burr 2015). Tew et al. (2015) performed a search yielding a total of 8497 articles, of which only five were studies including sit-stand workstation interventions. They reported that there was insufficient evidence to draw conclusions regarding the effects of installing sit-stand workstations on sedentary behavior and associated health outcomes (Tew et al. 2015). Both of these systematic reviews were actually researched before 2014 (MacEwen, MacDonald & Burr 2015; Tew et al. 2015), and since then, progressive interest in active workstations has increased, and further research has expanded the knowledge base of active workstations, especially sit-stand workstations (Shrestha et al. 2016). Collectively, it is necessary to provide an overview of existing literature on sit-stand workstations, with consideration of their use for reducing sitting and the associated health- or work-related outcomes.

2.3.1 Metabolic benefits

Few studies have examined the effects of using sit-stand workstations on metabolic-related outcomes. Alkhajah et al. (2012) conducted a pilot intervention study and investigated cardio-metabolic risk factors when using a sit-stand workstation compared to a sit workstation. They assessed body mass index (BMI), waist and hip circumferences, body fat composition as well as fasting total cholesterol, high-density lipoprotein cholesterol, triglycerides, and glucose levels at baseline and after three-month intervention (Alkhajah et al. 2012). Along with a reduction in sitting time and increased standing, there was a significant increase in high-density lipoprotein cholesterol in the intervention group compared to the control group, but not others, suggesting that using a sit-stand workstation may lower the risk of heart/cardiac diseases (Alkhajah et al. 2012). A study examining the benefits of standing in a real work setting showed that compared to seated work, continued standing for 185 minutes attenuated postprandial glycemic loading by 43% (Buckley et al. 2014). A similar modest attenuation of the postprandial glucose response was found in overweight/obese office workers who alternated bouts of sitting and standing every 30 minutes during an 8-h period of sedentary work (Thorp et al. 2014). These results provide encouraging evidence to support the idea that replacing sitting with standing may provide benefits for metabolic biomarkers. Although findings from experimental studies suggest that the benefits of standing may depend on the duration and accumulation patterns at the individual level (Benatti & Ried-Larsen 2015), not all studies on standing have elicited metabolic benefits (Bailey & Locke 2015; Miyashita et al. 2013). For sit-stand interventions to positively affect cardio-metabolic function, more studies are required to differentiate the independent effects of sitting and standing at work.

As mentioned earlier, standing requires more muscle activity in the lower extremities than sitting (Hamilton, Hamilton & Zderic 2007). It has been shown that even short bouts of light muscle activity can improve cardio-metabolic parameters (Dunstan et al. 2012; Duvivier et al. 2013). Greater muscle inactivity time was adversely associated with high-density lipoprotein cholesterol and triglycerides in healthy office workers (Pesola et al. 2015). Given the physiology of sedentary behavior and its association with health outcomes, some studies have paid attention to how reducing sedentary behavior actually affects muscle activity and inactivity (Tikkanen et al. 2013; Pesola et al. 2015; Pesola et al. 2014) but the role of muscle activity has not been assessed in the majority of experimental and intervention studies. Collectively, more studies are required to examine whether there are potential benefits of sit–stand workstations for metabolic health.

2.3.2 Musculoskeletal benefits

A static posture performed for sustained periods is regarded as a risk factor for the development of musculoskeletal disorders, either in prolonged sitting or standing. When using a sit-stand workstation, the reduction of sitting time is reallocated mostly to increased standing (Alkhajah et al. 2012; Healy et al. 2013; Straker et al. 2013). The effects of increased standing on musculoskeletal health need to be considered in relation to the feasibility of implementation in a real workplace. Therefore, in the ergonomic field, adjusting body posture frequently throughout the workday is a proposed strategy to improve musculoskeletal health. The effects of a range of interventions have been examined, from those as basic as adjusting seated position, which is commonly used for "dynamic sitting", to more extreme interventions such as changing whole body posture from sitting to standing and increasing breaks. The use of sit-stand workstations has also been examined in ergonomics for several years, and most studies have mainly focused on the effects of the sit-stand paradigm (Karakolis & Callaghan 2014).

A review by Karakolis and Callaghan (2014) identified a total of 14 studies concerning sit-stand interventions, all of which involved a comparison of outcome measures between sit-stand work and either prolonged seated work, prolonged standing work or both. They found that 12 of the 14 identified studies observed at least some benefits of using a sit-stand work paradigm (Karakolis & Callaghan 2014). Seven of the studies reported perceived discomfort scores either in local regions, the whole body or both. Apart from one study (Ebara et al. 2008), the other six indicated that implementing sit-stand workstations in an office environment could lead to lower levels of perceived discomfort, including three studies where there was a statistically significant difference between sit-stand work and sitting only (Husemann et al. 2009; Vink et al. 2009; Hedge & Ray 2004). Thus, their review concluded that sit-stand workstations are likely effective at reducing perceived discomfort (Karakolis & Callaghan 2014). Furthermore, using sit-stand workstations enables to change working positions, as the shifts promote variations at work in both sitting and standing postures (Toomingas et al. 2012), which is seen as a way to improve musculoskeletal health (Madeleine 2010; Srinivasan & Mathiassen 2012). However, the major challenge is to implement a sit-stand work paradigm in a real workplace, where an optimal ratio of sitting and standing time may or may not have already been established. Furthermore, there are several researchers who are skeptical about the effect of sit-stand workstations, as this paradigm did not yield beneficial effects on musculoskeletal discomfort in a short-term task (Ebara et al. 2008), or even in a long-term follow-up study (Saarni et al. 2009). There is an increase in the risk of work-related musculoskeletal disorders due to lack of education on how to correctly use the adjustable workstation (Green & Briggs 1989). Ergonomics training combined with a sit-stand workstation has been found to prevent discomfort in office workers (Robertson, Ciriello & Garabet 2013). This indicates that using a sit-stand workstation may require ergonomic support to reduce incidence of musculoskeletal disorders, and in order to determine the actual effectiveness of interventions in the workplace. Therefore, it should be confirmed in an ecological setting whether using sit-stand workstations can effectively improve musculoskeletal health.

2.3.3 Work performance

Two systematic reviews reported that using a sit-stand workstation does not cause a decrease in work performance (Karakolis & Callaghan 2014; MacEwen, MacDonald & Burr 2015). The first one by Karakolis and Callaghan (2014) identified eight studies including productivity outcomes. They found that three of these studies reported an increase in productivity during sit-stand work, four reported no effect on productivity and one had mixed productivity results (Karakolis & Callaghan 2014). The later review included some more recent studies, and concluded that work performance in most studies was stable and did not decrease over time when standing at work (MacEwen, MacDonald & Burr 2015). The previous studies included in these reviews assessed various work tasks and cognitive performance in both a laboratory setting and a real workplace, including light repetitive tasks (Hasegawa et al. 2001), intensive computer work (Hedge & Ray 2004), screening signal detection tasks (Drury et al. 2008), computer-based transcription tasks (Ebara et al. 2008), computer data entry tasks (Husemann et al. 2009), speech quality (Cox et al. 2011), and normal office work (Alkhajah et al. 2012; Pronk et al. 2012). Straker et al. (2009) compared workstation designs in various conditions including sitting, standing, walking and cycling while performing computer-based keyboard and mouse tasks. They found that the performance during standing was not different from sitting, although it was lower when walking and cycling compared with sitting (Straker, Levine & Campbell 2009). The lack of negative impact on work performance may be because sit-stand workstations allow the desk surface height to be adjusted rapidly and safely between sitting and standing positions with minimal disruption of work performance, which facilitates either a consistent productivity level or a potential increase. For example, some electronically adjustable sit-stand workstations require less than 10 s to adjust desk height.

2.3.4 Feasibility outcomes

Several studies have investigated user experience of sit–stand workstations while also measuring changes in sitting time in a natural work setting (Alkhajah et al. 2012; Pronk et al. 2012; Grunseit et al. 2013). Most have reported high usability and acceptability (Alkhajah et al. 2012; Grunseit et al. 2013). For example, Alkhajah et al. (2012) reported that the majority of intervention participants either agreed or strongly agreed that the sit-stand workstation was easy to use (94%), enjoyable (83%) and comfortable (83%) after having used it for three months. One study comparing seated, treadmill walking, cycling and standing in each of the workstation conditions found that the standing performed work was overwhelming the most feasible option when compared to the seated work (Straker, Levine & Campbell 2009).

As this is a relatively new area of intervention evaluation, only a few studies have included qualitative data to evaluate the use of sit-stand workstations in desk-based office workers (Chau et al. 2014a; Grunseit et al. 2013). According to qualitative feedback from 42 participants who used adjustable sit-stand workstations for four weeks, the workstation was generally perceived to be acceptable and feasible (Chau et al. 2014a). Participants were largely motivated to use sit-stand workstations, mostly because of curiosity, interest in potential health benefits, and the relevance to their own and their organization's work (Chau et al. 2014a). Factors that encouraged or enabled participants to work whilst standing were a supportive work environment, perceived physical health benefits, and perceived work benefits (Chau et al. 2014a). A majority of participants were in favor of using sit-stand workstations in future, although some cited negative responses related to specific design issues rather than the act of having to stand at work (Chau et al. 2014a). For further improvement, some suggestions included to "have more desk space, less movement in the workstation when in the standing position, and to better adjust the unit for taller participants" (Chau et al. 2014a). Aside from design issues, barriers to using sit-stand workstations in a standing position included feeling self-conscious and concern about disturbing others in an open plan office (Chau et al. 2014a). Grunseit et al. (2013) reported that for the majority of participants, installation of sit-stand desks throughout a medium sized organization were well received and resulted in a reduction of self-reported sitting time after three months. The maintenance of using sit-stand function was strongly driven by perceived health benefits, improved work productivity and desk setup instructions (Grunseit et al. 2013). However, they also found that three of 18 participants had tried using a sit-stand desk in the standing position only infrequently (less than daily) and one had not tried it at all (Grunseit et al. 2013). A low level of habitual use of a sit–stand workstation may not be sufficient for sustained reductions in workplace sitting time (Gilson et al. 2012). Interestingly, Wilks et al found that personnel were generally positive about the sit-stand workstation, but less than 20% of the workers used the sit–stand function on a daily basis, and the frequency was even lower among older participants (Wilks, Mortimer & Nylén 2006). This indicates that some barriers do exist for standing at work and these should be explored if sit-stand workstations are to be successfully implemented into the workplace. Furthermore, both quantitative and qualitative results have revealed that participants did not show a particular preference to adjust sitting or standing for specific work tasks, suggesting that adjustable sit-stand desks are suitable for a range of office workers whose occupations involve different tasks (Grunseit et al. 2013). Regarding common usage patterns, Chau et al. (2014a) reported that most participants used the sit-stand workstations for task-based routines, time-based routines, and no particular routine. Thus, it still poses challenge to transform these results into practical recommendations in a real workplace setting.

Collectively, epidemiological and physiological research on sedentary behavior has demonstrated health consequences of excessive sedentary behavior, which are independent of those attributable to lack of physical activity. With a particular focus on sedentary behavior at work, modifying the workplace environment has been proposed in order to develop effective sedentary reduction interventions as a new workplace health priority. It has become apparent that using sit-stand workstations could be a feasible and promising strategy to reduce occupational sitting time. For an ecologically valid setting, however, the question remains whether such interventions with environmental modification alone can effectively reduce sedentary time and improve health indexes over a sustained period of time. Moreover, with the rapid evolution towards increased standing time at work, there is often little consideration of ergonomic or biomechanical factors and postural consequences, as well as how workers will respond and utilize the function in the real workplace. Following a thorough search of current literature, there is growing evidence showing the effects of using a sit-stand workstation on sedentary time, health- and work-related outcomes. Despite encouraging findings concerning the practical aspects of their use, more investigations into the potential positive and negative attributes of sit-stand workstations are necessary in an ecological setting and in laboratory studies in order to successfully translate effective interventions into practice.

3 AIMS OF THE STUDY

The purpose of this doctoral thesis was to study whether and to what extent using sit-stand workstations could reduce sedentary behavior and improve health indexes in a real workplace. It combined a validation study (I), a 6-month controlled intervention study (II), a cross-sectional comparison study (III) and a randomized crossover acute study (IV) to investigate occupational sitting time, health outcomes (musculoskeletal comfort, spinal loading and muscular activity), work ability and postural physiology.

It was assumed that intervention-induced changes would effectively reduce occupational sitting time and improve health indexes in office workers over a sustained period of time and in an ecologically valid setting. Sit-stand workstations offer the possibility to reduce sitting time and improve musculoskeletal comfort, as well as increasing satisfaction and work ability during sedentary work. Working with a sit-stand workstation could promote more light muscle activity time and less inactivity without negative effects on spinal shrinkage. Regarding the acute physiological effects of sitting and standing at work, it was expected that continued standing compared with sitting would increase energy expenditure through greater muscle activity in the lower limbs, reduce glucose response without effects on insulin response, and increase fat oxidation despite glucose loading. Specific research questions to be answered were:

1. How valid are questionnaires for assessing occupational sitting time via long-term recall and short-term daily recall in Finnish and Chinese office workers? (I)

2. What are the effects of providing sit-stand workstations in an ecological setting on occupational sitting time, musculoskeletal comfort, work ability and user experience? (II)

3. How do patterns of muscle activity and spinal shrinkage differ between users of sit-stand workstations and those using standard sit workstations? (III)

4. What are the acute physiological effects on energy expenditure, muscle activity and metabolism when standing instead of sitting at work? (IV)

In all studies, the PhD candidate was involved in the planning phase, conceiving and designing of the studies together with the research teams. She was responsible for translating the questionnaire to Chinese, was solely responsible for recruiting the participants, performing all data collection, analyzing the data, and drafting and writing the papers.

4 METHODS

4.1 Participants

The main part of the study was carried out in the Faculty of Health and Sport Sciences, University of Jyväskylä between 2012 − 2016. Research work was mainly done in Finland, but part of the data was also collected in China. The flow chart of the recruitment and study sample is shown in Figure 1.

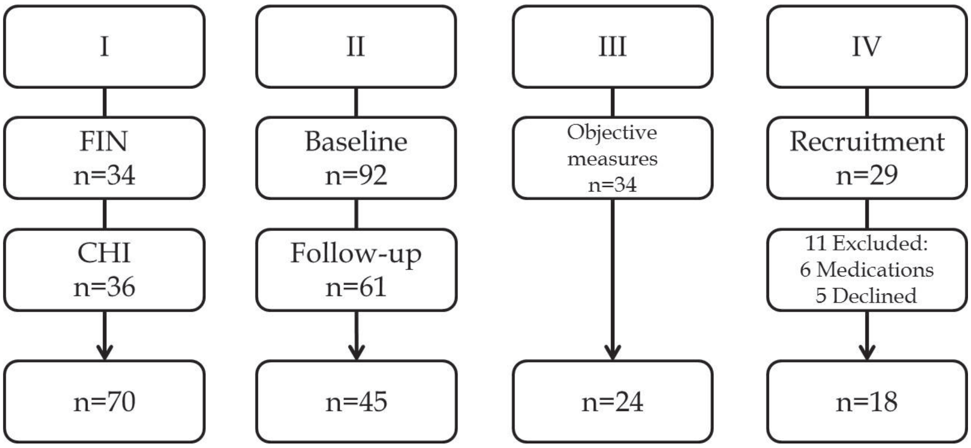

FIGURE 1 Flow chart of the recruitment and study sample.

Baseline characteristics of eligible participants for each study are presented in Table 1. Detailed descriptions of participants and recruitment are given in the relevant articles (I − IV). Employees working in the faculty (n = 170) were asked to fill out a web-based questionnaire. The baseline questionnaire was returned by 92 employees and the 6-month follow-up questionnaire by 61 employees. Those who completed the questionnaire only once were excluded, leaving 45 individuals who were finally included in Study II. Those who completed the follow-up questionnaires were asked to participate in objective measurements while additional volunteers were also recruited giving a total sample of 70 participants in Study I, which included a Finnish sample (FIN, n = 34, 82% Finnish) and a Chinese sample (CHI, n = 36, 100% Chinese). Of the FIN group, 24/34 participants were finally included in Study III with sufficient data from objective measurements. For Study IV, 18/29 participants were healthy middle-aged females who met the inclusion criteria. Their age ranged from 40 to 65 years old, a factor that contributes to a heightened diabetes risk (Dunstan et al. 2002).

4.2 Ethics

Ethical approval for Studies I, II, and III was received from the Ethics Committee of the University of Jyväskylä (19/10/2012). The trial registration number was ISRCTN43848163 for Study II. Ethical approval for Study IV was granted by the Ethics Committee of the University of Jyväskylä (27/3/2015). Participants were informed about the procedures, as well as the risks and benefits of the studies, and all of them provided written informed consent before any measurements. Participants were volunteers with the right to withdraw from the study at any time without specifying a reason and without consequences. No monetary incentive was offered to the participants.

TABLE 1 Baseline characteristics of study participants.

	Study I		Study II		Study III		Study IV
	FIN	CHI	Intervention	Control	Sit-Stand	Sit	
N	34	36	24	21	10	14	18
Age (years)	39.6 ± 11.5	26.9 ± 4.6	47.8 ± 10.8	39.0 ± 8.5	41.0 ± 11.5	35.3 ± 9.5	49.4 ± 7.9
Height (cm)	170.5 ± 8.6	166.3 ± 7.9	168.7 ± 10.2	168.0 ± 7.9	170.2 ± 6.9	169.8 ± 7.5	164.6 ± 7.2
Body mass (kg)	68.2 ± 10.8	58.6 ± 12.4	70.6 ± 12.6	65.7 ± 11.9	67.4 ± 10.7	69.6 ± 10.8	63.2 ± 7.8
BMI (kg/m^2)	23.4 ± 2.5	21.0 ± 3.0	24.8 ± 3.9	23.3 ± 3.8	23.2 ± 3.4	24.0 ± 2.5	23.4 ± 2.8
Proportion of females	58.8 (20)	58.3 (21)	70.8 (17)	81.0 (17)	60.0 (6)	57.1 (8)	100.0 (18)
Education							
below college level	0.0 (0)	0.0 (0)	8.3 (2)	0.0 (0)	0.0 (0)	0.0 (0)	16.7 (3)
college or university level	5.9 (2)	73.5 (25)	25.0 (6)	9.5 (2)	0.0 (0)	7.1 (1)	16.7 (3)
academic graduate level	94.1 (32)	32.4 (11)	66.7 (16)	90.5 (19)	100.0 (10)	92.9 (13)	66.7 (12)
Self-rated health							
very good or rather good	88.2 (30)	38.9 (14)	70.8 (17)	76.2 (16)	100.0 (10)	85.7 (12)	88.9 (16)
average, rather poor or very poor	11.8 (4)	61.1 (22)	29.2 (7)	23.8 (5)	0.0 (0)	14.3 (2)	11.1 (2)
Use of sit-stand workstation	38.2 (13)	0.0 (0)	100.0 (24)	0.0 (21)	100.0 (10)	0.0 (14)	38.9 (7)

Data are shown as Mean ± SD or % (number); Height, body mass and BMI were obtained from questionnaires in Studies I and II, and objectively measured in Studies III and IV.

4.3 Study designs

The main characteristics of Studies I, II, III and IV are outlined in Table 2. For detailed study protocols please see the original articles.

TABLE 2 Characteristics of Studies I, II, III and IV.

Study	Setting	Explanatory variables	Main outcome variables
I	Validation	Questionnaire, Daily recall, Accelerometry	Occupational sitting time, Validity, Day-to-day variation of occupational sitting time
II	Intervention	Questionnaire	Occupational sedentary behavior, Musculoskeletal comfort, Work ability, User experience of the sit–stand workstation
III	Comparison	Questionnaire, EMG shorts, Stadiometry	Occupational sitting time, Quadriceps and hamstring muscle inactivity and activity time, Spinal shrinkage
IV	Acute experiment	Surface EMG, Indirect calorimetry, Venous blood samples	Muscle activity level, Energy expenditure, Metabolic markers

The validation study (I) assessed the validity of two brief instruments for measuring occupational sitting time. It evaluated the criterion validity of an internet-administered questionnaire (regarding the past 3-months sitting) and daily recall (regarding sitting within the past day, on five consecutive days) to assess long-term and short-term occupational sitting time, respectively, by comparing their results with thigh-mounted accelerometry in Finnish and Chinese office-based workers.

The intervention study (II) used a 6-month controlled intervention design with one intervention group and one control group in a real-world, natural setting. Part of the faculty personnel had recently moved to a renovated building, which was furnished with sit–stand workstations. Prior to this move, they worked in similarly furnished offices as the faculty members who continued to work in the original buildings, which were equipped with traditional sit workstations. Individuals who used sit–stand workstations during the 6-month intervention period comprised the intervention group. They were given brief verbal instructions on how to operate the workstation, but no other instructions or counselling. Faculty personnel who used traditional sit workstations throughout the study formed the control group. The study examined the effects of an environmental change on occupational sedentary behavior, musculoskeletal comfort and work ability, and the usability of sit–stand workstations in office work via the self-reported questionnaire.

The cross-sectional comparison study (III) was performed in a real work environment and participants were assessed during one workday whilst performing normal office tasks. The study compared the activity of lower extremity muscles and spinal shrinkage between office workers who used either a sit–stand workstation or a traditional sit workstation. Quadriceps and hamstring muscle inactivity and activity time, and spinal shrinkage, were assessed during one normal workday in an ecologically valid setting.

The randomized crossover controlled study (IV) was conducted in a laboratory setting. The timeline of this study is shown in Figure 2. Briefly, after a preparatory phase of quiet siting for 45 minutes, participants performed two hours of desk work either sitting or standing (on separate measurement days, a minimum washout of six days) after overnight fasting. Surface electromyography, respiratory gas exchange and venous blood samples were assessed following glucose loading (75 g). Acute physiological responses to two hours of sitting and standing were also assessed including muscle activity, energy expenditure, fat and carbohydrate oxidation, glucose tolerance and insulin response after glucose loading.

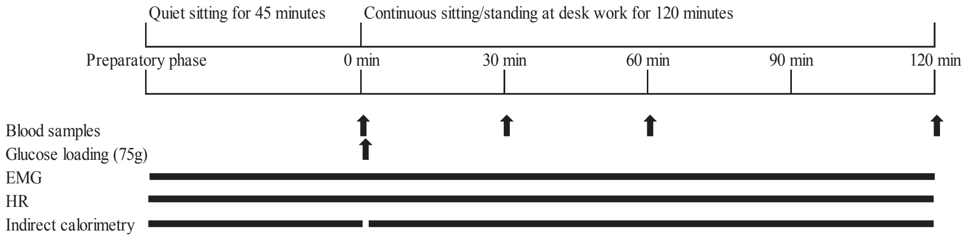

FIGURE 2 Timeline of the measurement day. After the preparatory phase (45 minutes quiet sitting), fasting blood samples were taken before glucose loading (0 min). Blood samples were then retaken at 30, 60, and 120 min.

4.4 Sit-stand workstations

In this project participants used electronically adjustable sit-stand workstations (ISKU, Finland), which are designed to allow workers to sit and stand autonomously while working (Figure 3 a). They can be placed in various and versatile environments, and have a maximum allowed load (100 kg) capacity perfectly suitable for normal office use. The desk is 180 cm long and 80 cm wide, and can be adjusted from 63 cm to 128 cm relative to the ground. In Figure 3 b, the workstation is adjusted for standing work at a height of 100 cm. An adjustment panel on the side of the desktop has two buttons for upward and downward movement (Figure 3 c). There is an electrical engine system installed under the desk (Figure 3 d), which powers height adjustments when the buttons are pressed. There is a storage basket for wires and a place to fix a desktop computer under the desk. With these sit-stand workstations, workers can select a sitting or standing position depending on their needs, which consequently increases opportunities for body movement. In particular, standing up from a seated position can break up prolonged sitting and reduce sitting time.

FIGURE 3 Electronically adjustable sit-stand workstation (ISKU, Finland). The participant used a sit-stand workstation for office work (a). The workstation was adjusted for standing work at a height of 100 cm (b). Adjustment panel with two buttons for height adjustments (c). Electrical engine system and storage basket for wires (d).

4.5 Measurements and data analysis

4.5.1 Basic characteristics

Participants' socio-demographic, work-related and health-related characteristics were collected based on questionnaires. In Studies III and IV, participants' height and body composition (InBody 720, Biospace Ltd, Seoul, Korea) were measured in a fasted condition yielding body mass, skeletal muscle mass, body free fat mass, body fat mass, percent body fat, waist-to-hip ratio and BMI.

4.5.2 Questionnaires

The Internet-administered questionnaire was implemented electronically using MrInterview (SPSS DimensionNet) in Studies I, II and III. This system was based on the E-mail distribution of a link to the actual survey and replies via a web browser on the Internet. The questionnaire included a total of 65 questions in the first wave (Finnish version) and 43 questions in the second wave (Finnish, English and Chinese versions). It covered background factors, computer use, sedentary time, physical activity level (Haskell et al. 2007), perceived health and musculoskeletal comfort (Price et al. 1983), and self-rated work ability (Tuomi et al. 1998). For example, the Internet-administered questionnaire posed the question "How much of your entire workday, on average, did you sit during the last 3 months? (0−100% of worktime)" (long-term recall). The daily recall of occupational sitting time, which was assessed after each workday, involved a single-item question: "How much of your entire workday, on average, did you sit today? (as a percentage 0−100%)" (short-term recall). In Study II, data concerning some missing responses were excluded (n = 1 or n = 2/variable), and for the leisure sitting time missing data and responses over 8 hours were excluded (n = 4).

In Study IV, the background questionnaires were completed on paper. In addition, physical fitness was assessed with a non-exercise questionnaire (NASA/JSC Physical Activity Scale during the last month; PA-R-1m) (Ross & Jackson 1990).

4.5.3 Diaries

Daily activity logs were used during work hours in Studies I and III. Participants filled in the time they came to/left the office, the exact time when they put on/took off the device and other events, e.g. toilet visits. If participants removed the device during work time, this information was also to be marked down in the log, accompanied by the reasons. In addition, participants were asked about the type of their workstation, and those who used a sit-stand workstation were required to mark down the time when it was used to sit/stand at work. In Study IV, the logs were kept during waking hours only to mark down the device wear/nonwear time and sleep time.

Food diaries were assessed one day before the measurements in Study IV, including time of meals, and volume and type of food and drinks consumed. They were also instructed to obey the same diet the day before the second measurement day. Dietary records were analyzed using web-based dietary recall (Nutri-Flow Oy, 2015, http://nutri-flow.fi/, Finland) to determine energy intake and macronutrient content including fat, protein and carbohydrate. This was used to confirm that the two measurement days were preceded by similar energy intake and macronutrient contents.

4.5.4 Accelerometry

A triaxial accelerometer (X6-1a, Gulf Coast Data Concepts Inc., Waveland, MS, USA) was used in Studies I and IV. The accelerometer was thigh-mounted to assess occupational sitting time during work hours in Study I and waist-mounted to monitor daily physical activity during waking time in Study IV.

In Study I, the accelerometer was secured to the mid-anterior thigh using a flexible bandage (Pharmacare SPORT, Oriola Oy, Finland) for five consecutive work days representing a typical work week, except when sick or not at work. Thigh-mounted accelerometer data, recorded during the same days as the daily activity log, were used to classify an individual's activity into sitting or activity (standing/walking), and to calculate these values as % of recorded work time. The initial utilities setting of the accelerometer was low gain (+/− 6 g) at a sampling frequency of 20 Hz with 16 bit resolution (sensitivity at 0.000183105 g), and the internal clock of the accelerometer was synchronised with a local online computer. All data analysis was performed using a custom-made script called OpenSALTO (https://github.com/mhavu/OpenSALTO), where data were transformed into a polar coordinate system. Inclination in the sagittal plane was low-pass filtered with 1 Hz cutoff. Sitting and upright positions (standing/walking) were discriminated on the basis of the angle of inclination of the thigh relative to gravity. A threshold of 45° from horizontal was set for the transition from sedentary to upright posture or the reverse, as done previously (Skotte et al. 2014). The analysis was set to detect a given posture with a minimum 5 s duration. This method is highly valid for classifying body postures to measure sitting time in adults by comparison with direct observation (mean difference of 0.19%, limits of agreement: -0.68% − 1.06%), both in the laboratory (Grant et al. 2006) and in the free-living setting (Kozey-Keadle et al. 2011; Lyden et al. 2012). The method was also confirmed in pilot tests to work accurately with the device used in the present study. All results were exported to Microsoft Excel with date- and time-stamped information, where non-wear time was discarded based on individually reported non-wear episodes in their logs. Data were considered valid if participants wore the accelerometer for at least three work days during working hours, which is considered to be sufficient to determine habitual physical activity among adults (Trost, Mciver & Pate 2005). Accelerometer data were compared on a day-to-day basis with short-term recall results so that 3 − 5 comparisons were performed for each participant, while the questionnaire for long-term recall was compared to the accelerometer data averaged over the measurement days.

In Study IV, the accelerometer was carried on the right side of the waist in a firmly worn adjustable elastic belt for two days before each measurement day. Individuals were asked to wear the device during waking hours, except water based activities. A resultant vector $\sqrt{x^2 + y^2 + z^2}$ of the triaxial accelerometer signal was calculated, band pass filtered (0.25 Hz to 11 Hz), and values below 0.05 g were threshold filtered. Integration and filtering of accelerometer signals were performed in MATLAB software (MathWorks, MA, USA). In the present study, data were converted into general count values in 1-min epochs with accelerometer counts less than 100 counts/min classified as sedentary time, 101–1952 counts/min as light-intensity activity, and more than 1952 counts/min as moderate-to-vigorous intensity activity (Freedson, Melanson & Sirard 1998).

4.5.5 Stadiometry

In Study III, the stadiometer was designed to measure stature with 0.01 mm accuracy (measuring range of 158 to 191 cm) in a standing posture whilst participants leaned on a frame tilted back 15° from the vertical (Rodacki, Cíntia de Lourd Nahhas et al. 2001). Individually preset posture of the spine at levels of C4 (cervical lordosis curve), T8 (thoracic kyphosis) and L3 (lumbar lordosis curve) with adjustable support enabled precise control of the depth of each spinal contour when measured before and after the workday (Figure 4).

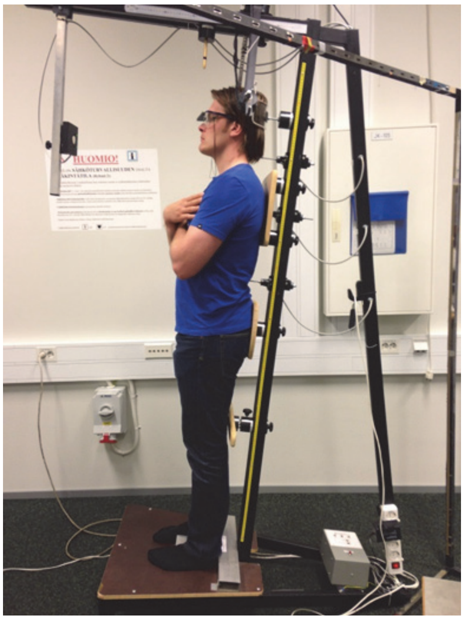

FIGURE 4 A stadiometer (University of Jyväskylä, Finland) was used to assess stature twice at the beginning and end of the work day.

Stature was taken as the average of the last two 30 s measurements sampled at 20 Hz. Pre-post work time stature loss was calculated and used to reflect spinal shrinkage during the workday (Leivseth & Drerup 1997). In Study III, the average standard deviation of the repeated stature measurements was 0.19 ± 0.08 mm for before work measures and 0.21 ± 0.11 mm for after work measures. Thus, the repeatability of the measures was considered acceptable (Rodacki, Címtia de Lourd Nahhas et al. 2001; Healey et al. 2005). In Figure 5, example stadiometer data from one participant are shown, including three 30 s recordings.

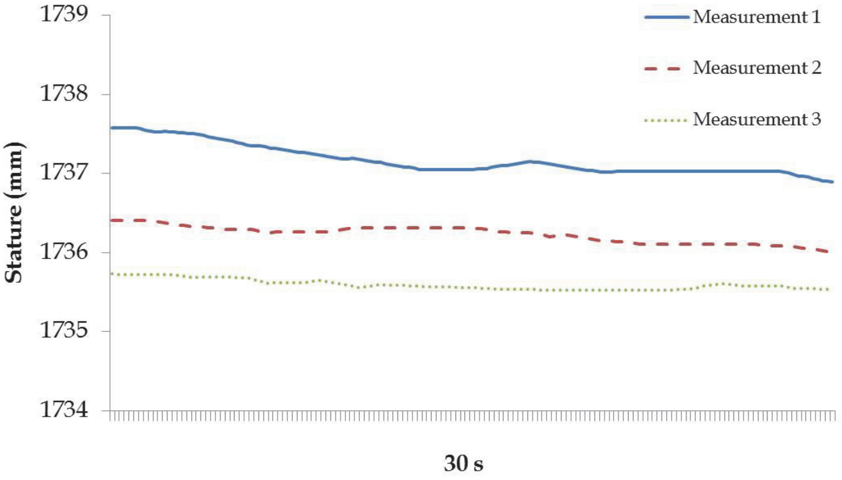

FIGURE 5 Stadiometer values for one participant; three bouts of 30 s are shown.

4.5.6 Electromyography

Textile surface EMG. In Study III, EMG shorts were used to assess quadriceps and hamstring muscle activity during work hours. The shorts were made of knitted fabric similar to elastic clothes, into which textile EMG electrodes were embedded in order to measure EMG from the skin surface (Myontec Ltd, Kuopio, Finland). Electrodes were positioned in a bipolar configuration over the muscle bellies of the left and right quadriceps and hamstring muscles. Raw signals were pre-processed and stored in a small waist-mounted module (Finni et al. 2007). These EMG shorts have been tested previously for validity, repeatability and feasibility, and a detailed description of the recording devices has been reported (Finni et al. 2007). Adequate repeatability and consistency of EMG signals, both day-to-day and within-day, have been shown in the laboratory and reported in previous studies during normal daily life (Tikkanen et al. 2013; Pesola et al. 2015).

The EMG signals from quadriceps and hamstring muscles were normalized channel by channel to EMG values measured during submaximal walking. Averaged EMG data were used from 10 consecutive step cycles during overground walking along a 30 m walkway measured at individually preferred speed (4.1 ± 0.4 km/h). In order to reflect the overall inactivity and activity periods, normalized data were averaged to produce mean thigh muscle EMG. The inactivity threshold was set individually at 90% of the mean EMG amplitude measured during standing for 10 s, in accordance with previous studies (Tikkanen et al. 2013; Pesola et al. 2015). The threshold for light and moderate-to-vigorous intensity was defined individually as the mean EMG value during normal walking. Mean EMG amplitudes from the reference tests and thresholds for different activity levels are shown in Figure 6.

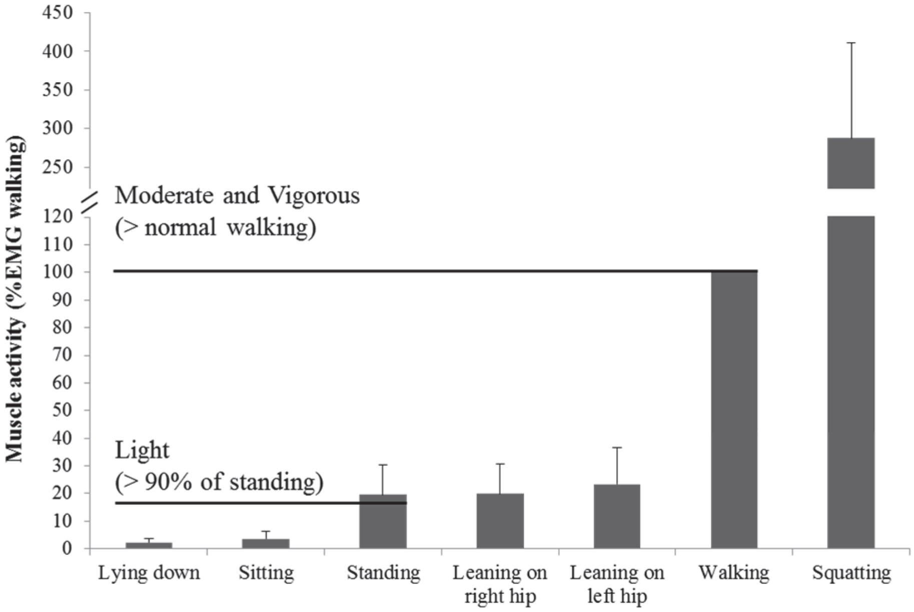

FIGURE 6 Mean EMG amplitudes from the reference tests and thresholds for different activity levels (Mean ± SD). Inactivity was defined as EMG amplitude below 90% of standing EMG and moderate-to-vigorous activity was defined as EMG amplitude above preferred walking speed (4.1 ± 0.4 km/h). These thresholds were determined for each participant individually. Average normalized muscle activity values from lying down, sitting, standing and squatting with body weight were 2.2 ± 1.5%, 3.6 ± 2.6%, 19.5 ± 10.7% and 287.1 ± 123.2% of walking EMG, respectively.

Occasional artifacts (e.g. toilet visits) were manually removed from all channels. If an EMG artifact was longer than 30 minutes, the particular channel was removed from the analysis. In total, 2.5% of recording time was visually considered to be artifact and removed from 78 channels of 24 participants' data. Signals were corrected for possible baseline drift using a moving 5 minute window (Tikkanen et al. 2013). The normalized, averaged, artifact-free EMG data were further processed using a custom-made Matlab script (MATLAB, MathWorks, Massachusetts). Based on the thresholds, signals were analyzed for total muscle inactivity duration (min), total muscle activity duration (min), light and moderate-to-vigorous muscle activity duration (min), duration of the five longest continuous inactivity periods (min), and number of activity bursts throughout the workday, as described previously (Tikkanen et al. 2013; Pesola et al. 2015).

Typical surface EMG. Typical surface EMG was used in Study IV to assess the activity of back and lower limb muscles throughout the measurements. Standard electrode placement and skin preparation procedures were used (Hermens et al. 2000). Bipolar electrodes (Ag/AgC1, Ambu White Sensor, 4500M, USA) were attached unilaterally on the right side over the following muscles: thoracic erector spinae (TES), lumbar erector spinae (LES), lumbar multifidus (LM), biceps femoris (BF), vastus lateralis (VL), tibialis anterior (TA), gastrocnemius medialis (GM) and soleus (SOL), all with an inter-electrode distance of 20 mm. EMG amplitude was normalized channel by channel and expressed as a percentage of that during walking at 5 km/h on a treadmill (%walk). The signals were collected using ME6000 Biomonitor, and root mean square values from the raw EMG data were computed with Megawin software (Mega Electronics Ltd, Kuopio, Finland). In order to reflect the overall muscle activity level, normalized data from different muscles were averaged to produce mean overall muscle activity. In addition, mean back muscle activity of TES, LES and LM, mean thigh muscle activity of BF and VL, and mean leg muscle activity of TA, GM and SOL were calculated.

4.5.7 Indirect calorimetry and heart rate

In Study IV, participants breathed through a facial mask equipped with ventilation sensors and gas sampling tubes (Figure 7). Ventilation, oxygen consumption (VO_2) and carbon dioxide production (VCO_2) were measured breath by breath with a Jaeger Oxycon Pro and LabManager 3.0 software (Viasys Healthcare Gmbh, Hoechberg, Germany). The measurement system was calibrated before each measurement and standardized for barometric pressure, temperature and humidity. Outputs of ventilation, breathing frequency, VO_2, VCO_2, VO_2/kg, respiratory exchange ratio (RER) and absolute metabolic equivalent were collected and averaged over 30 s intervals for data analysis. Energy expenditure (EE) and the percentage of fat and carbohydrate usage for energy production were calculated using respiratory quotient values, with corresponding caloric equivalent values (without protein) and oxygen uptake (McArdle, Katch & Katch 2010, 186-188). For the preparatory phase, a moving average was analyzed over 15 minute periods. The lowest values were taken to represent a steady state, where the mean resting energy expenditure was 0.9 ± 0.1 kcal/min, and ratios of fat and carbohydrate usage were 60.0 ± 10.8%EE and 40.0 ± 10.8%EE, respectively. During sitting and standing work the periods where the mask was removed were discarded, and the mean values of both 2 h conditions were calculated for the main variables.

FIGURE 7 Participants performed two hours desk work either in sitting (a) or standing (b) postures after a glucose loading.

Heart rate (HR) was measured using a heart rate belt (Polar Electro Oy, Finland) with a Polar RS800CXtm wrist computer. HR was recorded every 5 s for the duration of the measurement and averaged over the 2 h measurement period.

4.5.8 Venous blood samples

In Study IV, venous blood samples were collected and analyzed using standardized clinical procedures for serum lipids and glycerol, plasma glucose (Konelab 20 Xti, Thermo Fisher Scientifi Oy, Vantaa, Finland), and serum insulin and cortisol (Immulite 2000 Xpi, Siemens Healthcare Diagnostics., United Kingdom). The intra-assay coefficients of variation were 2.4% for triglycerides, 1.7% for glycerol, 2.8% for fat free acids (FFA), 7.8% for cortisol, 1.7% for glucose, and 4.2% for insulin.

From fasting blood (0 min), total cholesterol, high- (HDL-C) and low-density-lipoprotein cholesterol (LDL-C), triglycerides, glycerol, FFA, cortisol, glucose and insulin were analyzed. After glucose loading, the blood samples were analyzed for triglycerides, glycerol, FFA, cortisol, glucose and insulin at several time points (30, 60 and 120 min). The few missing samples (n = 1 at 30 min and n = 1 at 60 min) were interpolated using the best fit of a second degree polynomial through the other sample points available from the same individual. The total area under the curve (tAUC) and the net incremental area under the curve (iAUC) of a 120 minute period were calculated for glucose, insulin, triglycerides, glycerol, FFA and cortisol using a trapezoidal approximation of area under the curve, where tAUC was calculated from the zero level and iAUC from the fasting level.

4.6 Statistical analyses

Standard measures such as mean, standard deviation (SD), percentage and range were used for descriptive evaluation of the data unless otherwise indicated. Tests of normality (Shapiro-Wilk) were applied. Statistical analyses were conducted using IBM SPSS for Windows 22.0 (SPSS Inc., Chicago, IL, USA). A probability level of $p < 0.05$ (two-tailed) was considered statistically significant.

For day-to-day variability of occupational sitting time, coefficients of variation (CV) were calculated. Spearman's rho (r_s) with 95% confidence interval (CI) using Fisher transformation and Bland-Altman method with 95% limits of agreement (±1.96 SD) (Bland & Altman 1986) were used (I). The strength of correlation was interpreted as weak (< 0.30), low (0.30 − 0.49), moderate (0.50 − 0.69), strong (0.70 − 0.89) or very strong (≥ 0.90) (Pett 1997). Repeated measures analysis of variance (ANOVA) was used to assess the effects of the 6-month intervention (II). When ANOVA revealed significant effects, least significant difference post-hoc multiple comparison was used to localize the difference. Differences between groups were tested with independent t-tests (normally distributed data) or Mann-Whitney U (non-normally distributed data) for continuous variables, and chi-square test or chi-square test with Fisher's exact test for categorical variables (I, II, III). Paired t-tests (normal data) or Wilcoxon signed rank test (non-normal data) were used to assess differences in baseline assessment variables and the condition effects within participants (IV). In addition, Spearman's correlation coefficient was used to assess the strength of correlations: 1) between changes in sitting time and standing time, and between changes in sitting time and perceived musculoskeletal comfort (II); 2) between muscle activity and potential parameters including metabolic responses and energy expenditure (IV).

5 RESULTS

The main results of this thesis are presented in this section. For more details the original articles should be consulted.

5.1 Daily occupational sitting time (Study I)

Valid accelerometer data for at least three work days were obtained from 68 participants (78% completed five work days). In total, data were analyzed from 322 days (FIN: 162 days and CHI: 160 days). The results of occupational sitting time between FIN and CHI group are presented in Table 3. The length of recorded work time averaged 455.4 ± 61.0 mins per work day in the total sample, and there was no difference between groups. No differences were found in long-term or averaged daily short-term recall of occupational sitting time between groups, however FIN group had ~7% less sitting time according to accelerometer data (p = 0.017). Furthermore, ~39% of Chinese participants reported that they removed the device on at least one work day due to work-rest schedules (e.g. noon nap) for an average of 101.5 ± 48.4 min (range 17 − 204 min) per day per person. None of the CHI group used a sit-stand workstation, whereas ~38% of participants in the FIN group did.

TABLE 3 Self-reported and objectively measured occupational sitting time in the FIN and CHI groups.

	Total (n=70)	FIN (n=34)	CHI (n=36)	p-values
Long-term recall (%)	79.0±13.5	76.2±14.7	81.8±11.8	0.120
Short-term recall (%)	79.3±14.3	77.3±16.4	81.2±12.0	0.309
Accelerometer measured (%)#	76.6±12.4	73.2±12.8	80.1±11.1	**0.017**
Recording time (minutes)#	455.4±61.0	447.3±54.7	463.5±66.6	0.280

Data are shown as Mean ± SD; # Missing n = 2 in CHI group. Significance level is indicated in bold.

The day-to-day variation was 9.4% ± 11.4% for short-term recall and 10.4% ± 8.4% for accelerometer measured occupational sitting time for the total sample. Figure 8 shows subject-specific differences between daily short-term recall and accelerometer measured occupational sitting time. FIN group exhibited higher day-to-day variation in both short-term recall (12.8% ± 14.1% vs. 6.3% ± 6.8%, p = 0.012) and accelerometer based sitting time (13.3% ± 10.0% vs. 7.6% ± 5.2%, p = 0.012) than CHI group. No absolute difference was found between long-term and averaged daily short-term recall occupational sitting time (p = 0.815).

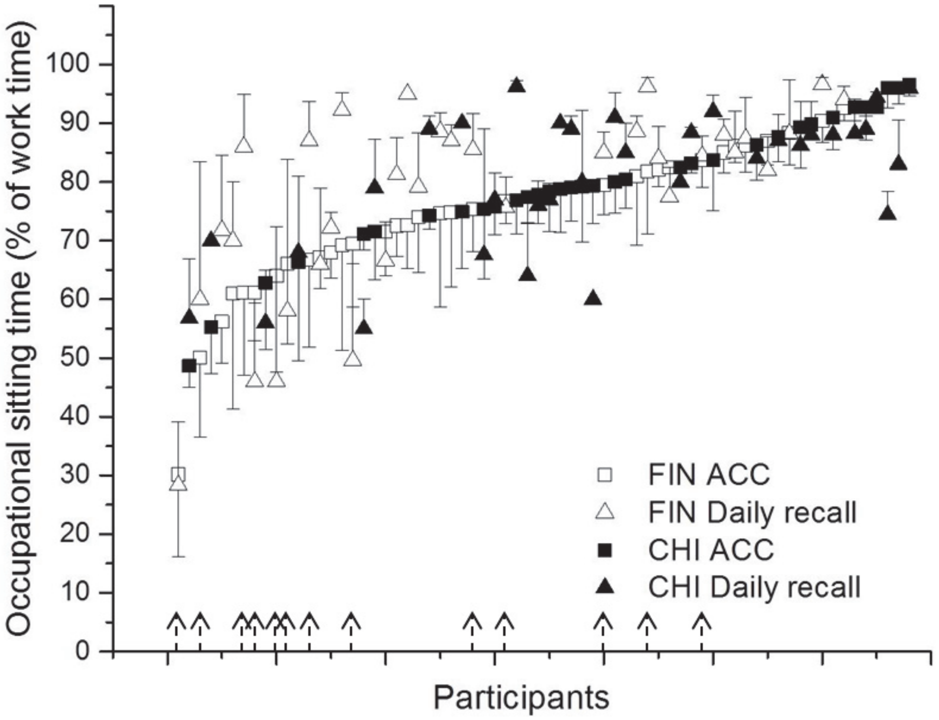

FIGURE 8 Differences between averaged daily short-term recall (triangles) and accelerometer measured occupational sitting time (squares) for each participant. Data are organized according to the amount of objectively measured sitting time so that participants who sat the most are on the right side and those who sat the least are on the left. Standard deviations denote day-to-day variation (3 − 5 workdays) in occupational sitting time. Dashed arrows indicate participants who used adjustable sit-stand workstations. □ Finnish group, accelerometer data; Δ Finnish group, daily recall; ■ Chinese group, accelerometer data; ▲ Chinese group, daily recall.

5.2 Validity of self-reported sitting time at work (Study I)

The questionnaire for long term recall and accelerometer measured sitting time at work correlated in the total study sample (r_s = 0.532, 95%CI = 0.336 – 0.684, p < 0.001), as well as in FIN group (r_s = 0.450, 95%CI = 0.132 – 0.684, p = 0.008) and CHI group (r_s = 0.515, 95%CI = 0.214 – 0.727, p = 0.002). Similarly, short-term recall and accelerometer measured sitting time for each work day correlated in the total study sample (r_s = 0.533, 95%CI = 0.449 – 0.607, p < 0.001), in FIN group (r_s = 0.600, 95%CI = 0.491 – 0.691, p < 0.001), and in CHI group (r_s = 0.459, 95%CI = 0.326 – 0.574, p < 0.001).

Figure 9 and Figure 10 show Bland-Altman plots for long-term and daily short-term recall, and accelerometer measured occupational sitting time for the total study sample separated by groups, respectively. The mean difference between long-term and averaged accelerometer measured results was 2.4% (95%CI = -0.5% – 5.3%, p = 0.091) for the total sample, 3.0% for FIN group (95%CI = -1.6% – 7.5%, p = 0.180) and 1.8% for CHI group (95%CI = -2.1% – 5.6%, p = 0.293). The agreement level was generally within the -21.2% to 25.9% range (±1.96 SD). Similarly, the mean difference between each short-term recall and the corresponding daily accelerometer measured value was 2.2% (95%CI = 0.7% – 3.6%, p = 0.005) for the total sample, 4.0% for FIN group (95%CI = 1.8% – 6.2%, p < 0.001) and 0.3% for CHI group (95%CI = -1.7% – 2.2%, p = 0.807). Agreement levels were generally within the -24.2% to 28.5% range (±1.96 SD). There were no correlations between the difference in self-reported vs. accelerometer measured sitting time and average occupational sitting time except for the FIN group where positive correlation between short-term self-reported vs. accelerometer measured sitting time and average occupational sitting time (r_s = 0.203, p = 0.010).

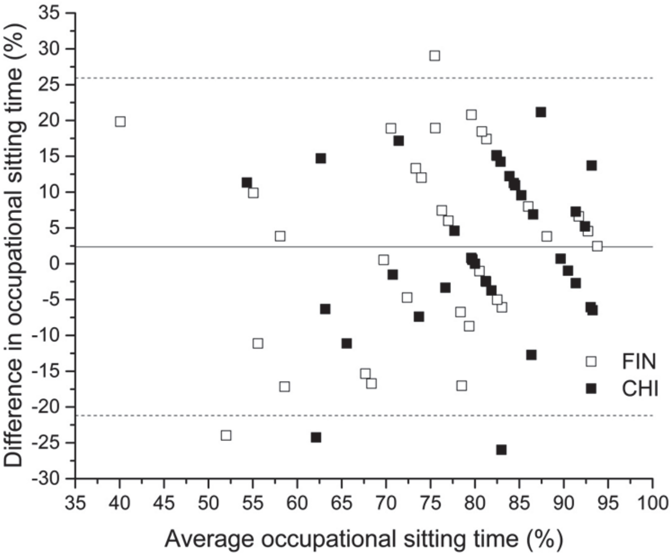

FIGURE 9 Bland–Altman plot of absolute agreement of occupational sitting time for all participants' data separated by groups. The y axis shows the difference between questionnaire for long-term recall and accelerometer measured occupational sitting time as a percentage of work time. The x axis is the average of them (%). The solid line represents the mean and the dashed lines represent the 95% limits of agreement (±1.96 SD). □ Finnish group; ■ Chinese group.

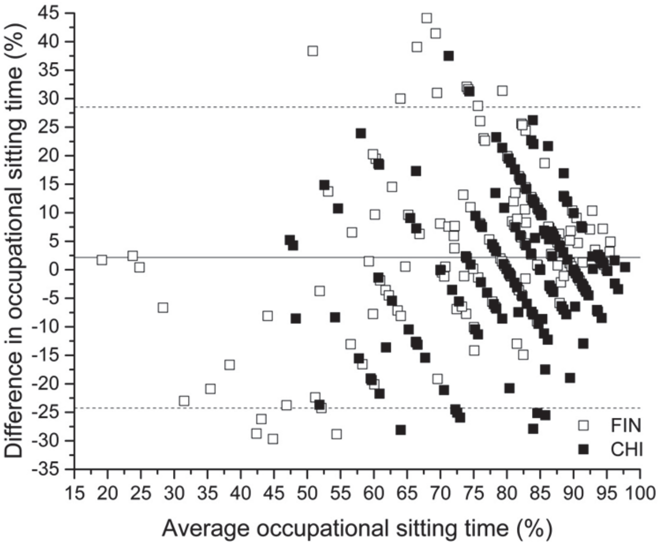

FIGURE 10 Bland–Altman plot of absolute agreement of occupational sitting time for all participants' data separated by groups. The y axis shows the difference between daily short-term recall and accelerometer measured occupational sitting time as a percentage of work time on each day. The x axis is the average of them (%). The solid line represents the mean and the dashed lines represent the 95% limits of agreement (±1.96 SD). □ Finnish group; ■ Chinese group.

5.3 Intervention effectiveness (Study II)

5.3.1 Changes in occupational sedentary behavior

Table 4 shows changes in sitting time for the intervention and control groups six months after sit-stand workstations were installed. At baseline, no significant differences were observed between groups. When comparing the intervention and control groups, repeated measures ANOVA revealed a group*time interaction in work time spent sitting (-6.7 ± 17.2% vs. 5.0 ± 14.6%, p = 0.019), work time spent standing (6.5 ± 15.8% vs. -3.6 ± 11.6%, p = 0.021), and computer work time spent standing (11.6 ± 16.6% vs. -0.5 ± 2.2%, p = 0.002), but no significant effect for computer sitting time (-11.0 ± 19.2% vs. -0.7 ± 26.5%, p = 0.144) or total leisure sitting time (-0.1 ± 1.0 h vs. 0.1 ± 0.6 h, p = 0.591). Pairwise comparisons showed that sitting time at work decreased by 6.7% (p = 0.048) and standing time during computer work increased by 11.6% (p < 0.001) in the intervention group, both of which were significantly different from the control group at 6 months (p = 0.007 and p < 0.001, respectively). Furthermore, in the intervention group, standing time during the whole work day increased (p = 0.003) and sitting time as a proportion of computer work time decreased (p = 0.026). Reduction in sitting time was significantly associated with an increase in standing time ($r_s = -0.719$, p < 0.001).

TABLE 4 Sitting time in intervention and control groups. Values correspond to the mean (± SD) percentage of work time spent sitting and standing, the percentage of computer work time spent sitting and standing, and average leisure sitting time in hours.

	Intervention group		Control group		Group*time
	Baseline	6 months	Baseline	6 months	p-values[a]
Sitting time (%)	75.5±15.9	68.9±16.2*	76.0±19.9	81.0±11.9#	**0.019**
Standing time (%)	14.2±9.0	20.7±14.9*	17.5±19.8	13.9±13.0	**0.021**
Computer sitting time (%)	89.2±15.0	78.2±17.9*	86.7±19.2	86.0±20.1	0.144
Computer standing time (%)	2.8±8.7	14.4±16.0*	0.5±2.2	0.0±0.0#	**0.002**
Leisure sitting time (hours)	3.1±0.8	3.0±0.7	2.6±0.9	2.6±0.9	0.591

[a] Repeated measures ANOVA for the group* time interaction effect. Significance levels are indicated in bold.

Significant difference between groups at 6 months.

* Significant difference within-group between baseline and 6 months.

5.3.2 Changes in musculoskeletal comfort and work ability

When comparing the intervention and control groups, repeated measures ANOVA revealed a group*time interaction in perceived musculoskeletal comfort in the neck and shoulders (-0.3 ± 0.9 vs. 0.3 ± 0.9, p = 0.028), as well as work ability (0.3 ± 0.6 vs. -0.4 ± 1.0, p = 0.022) (Table 5). Pairwise comparisons showed that perceived discomfort values in the intervention group were significantly lower in the neck and shoulders compared to the control group at 6 months (2.7

± 0.9 vs. 3.3 ± 0.9, p = 0.024). From baseline to follow up, no significant changes were observed in the control group, whereas a significant decrease in discomfort values was observed in the lower limbs in the intervention group (3.2 ± 0.8 to 2.7 ± 0.8, p = 0.020). Correlation analysis showed that reduction in sitting time was significantly associated with increased back comfort (r_s = 0.344, p = 0.024). Other correlations were not significant.

TABLE 5 Musculoskeletal comfort and work ability in intervention and control groups. Perceived musculoskeletal comfort (Mean ± SD) for different body parts was rated from 1 (very comfortable) to 5 (very uncomfortable). Perceived work ability at its best was rated from 0 (completely unable to work) to 10 (work ability at its best).

	Intervention group		Control group		Group*time
	Baseline	6 months	Baseline	6 months	p-values[a]
Musculoskeletal comfort					
Neck and shoulders	3.0±0.7	2.7±0.9	3.0±1.0	3.3±0.9[#]	**0.028**
Upper limbs	2.8±0.6	2.7±0.9	3.0±1.0	3.1±0.8	0.663
Back	3.0±0.6	2.7±0.8	3.0±1.0	3.1±0.9	0.348
Lower limbs	3.2±0.8	2.7±0.8*	2.9±0.8	2.9±0.9	0.153
Work ability	8.4±1.2	8.7±0.9	8.5±0.9	8.2±1.0	**0.022**

[a] Repeated measures ANOVA for the group* time interaction effect. Significance levels are indicated in bold.

[#] Significant difference between groups at 6 months.

[*] Significant difference within-group between baseline and 6 months.

5.3.3 Daily usage of the sit-stand function

At 6 months, the majority of intervention workers rated sit-stand workstation adjustability as either very good (54.2%) or good (29.2%). In addition, 75.0% of participants were satisfied with the sit-stand workstation. The daily usage level of the standing function was 41.7%, which included 12.5% who used it 'Many times a day' and 29.2% who used the function 'Once a day'. A large proportion of participants adjusted the sit-stand workstation 'Once a week' (16.7%) or 'Once a month or more seldom' (37.5%), and one participant reported never adjusting workstation height. Unlike the infrequent users group (n=14), daily users (n=10) were all female, and the number of females was significantly higher in the daily users group (p = 0.019).

When comparing daily users and infrequent users, repeated measures ANOVA revealed a group*time interaction in work time spent standing (16.5 ± 16.0% vs. -1.2 ± 11.0%, p = 0.005), computer work time spent sitting (-24.4 ± 21.7% vs. -2.4 ± 11.4%, p = 0.004) and standing (31.3 ± 10.3% vs. 0.3 ± 3.7%, p < 0.001), but no significant effect for work sitting time (-13.5 ± 15.6% vs. -1.8 ± 17.2%, p = 0.102) or total leisure sitting time (0.3 ± 0.5h vs. -0.3 ± 1.2h, p = 0.247) (Table 6). Pairwise comparisons were localized to the group of daily users, whose sitting time at work decreased by 13.5% (p = 0.017), and standing time increased by 16.5% (p = 0.001), which was significantly different from the control group at 6 months (p = 0.002). Similarly, as a proportion of computer work time, sitting decreased by 24.4% ($p < 0.001$) and standing increased by 31.3% ($p < 0.001$) in the daily user group, which was significantly different from the infrequent user group at 6 months ($p = 0.043$ and $p < 0.001$, respectively).

TABLE 6 Sitting time in daily users and infrequent users of the intervention group. Values correspond to the percentage of work time spent sitting and standing, the percentage of computer work time spent sitting and standing, and average leisure sitting time in hours (Mean ± SD).

	Daily users		Infrequent users		Group*time
	Baseline	6 months	Baseline	6 months	p-values[a]
Sitting time (%)	77.5±9.8	64.0±8.8*	74.1±19.4	72.4±20.0	0.102
Standing time (%)	14.5±10.1	31.0±10.2*	14.0±8.4	12.9±13.2#	**0.005**
Computer sitting time (%)	93.3±13.2	68.9±13.9*	86.6±15.9	84.1±18.0#	**0.004**
Computer standing time (%)	0.0±0.0	31.3±10.3*	4.4±10.7	4.7±9.0#	**0.000**
Leisure sitting time (hours)	2.7±0.5	3.0±0.6	3.3±0.9	3.0±0.8	0.247

[a] Repeated measures ANOVA for the group* time interaction effect. Significance levels are indicated in bold.

Significant difference between groups at 6 months.

* Significant difference within-group between baseline and 6 months.

No significant group*time interactions were observed in perceived musculoskeletal comfort or work ability when comparing the daily and infrequent users (Table 7). However, from baseline to follow up, daily users showed a significant decrease in discomfort values in the lower limbs (3.3 ± 0.9 to 2.6 ± 0.5, $p = 0.020$) and improved perceived work ability (8.0 ± 1.5 to 8.6 ± 1.1, $p = 0.009$).

TABLE 7 Musculoskeletal comfort and work ability in daily users and infrequent users of the intervention group. Perceived musculoskeletal comfort (Mean ± SD) for different body parts was rated from 1 (very comfortable) to 5 (very uncomfortable). Perceived work ability at its best was rated from 0 (completely unable to work) to 10 (work ability at its best).

	Daily users		Infrequent users		Group*time
	Baseline	6 months	Baseline	6 months	p-values[a]
Musculoskeletal comfort					
Neck and shoulders	3.1±0.6	2.6±1.0	2.9±0.8	2.7±0.8	0.280
Upper limbs	3.0±0.7	2.7±0.9	2.6±0.5	2.7±0.9	0.353
Back	3.0±0.7	2.8±0.8	2.9±0.5	2.7±0.8	0.986
Lower limbs	3.3±0.9	2.6±0.5*	3.1±0.7	2.9±0.9	0.168
Work ability	8.0±1.5	8.6±1.1*	8.6±0.8	8.7±0.7	0.066

[a] Repeated measures ANOVA for the group* time interaction effect.

* Significant difference within-group between baseline and 6 months.

5.4 Comparing the use of a sit–stand workstation versus a sit workstation (Study III)

5.4.1 Self-reported differences between Sit-Stand group and Sit group

Compared with the Sit group, participants from the Sit-Stand group self-reported less sitting time (62.0 ± 13.0% vs. 83.6 ± 12.0%, $p = 0.001$) and computer sitting time (68.5 ± 22.1% vs. 87.1 ± 17.7%, $p = 0.028$) during the workday, as well as more standing time (36.5 ± 21.9% vs. 18.2 ± 21.8%, $p = 0.031$) and computer standing time (23.7 ± 18.0% vs. 3.0 ± 10.7%, $p < 0.001$). Average daily leisure time sitting was 3.5 ± 1.2 h and did not differ between groups. There was no significant difference in perceived work ability between groups (8.7 ± 1.1 and 8.8 ± 0.9, respectively).

5.4.2 Muscle activity patterns and spinal shrinkage

Muscle activity patterns and spinal shrinkage data for both groups are presented in Table 8. Averaged EMG recording time of all participants was 403.9 ± 47.0 minutes and did not significantly differ between groups. Compared with the Sit group, the Sit-Stand group exhibited less muscle inactivity time (66.2 ± 17.1% vs. 80.9 ± 6.4%, $p = 0.014$) and more light muscle activity time (26.1 ± 12.3% vs. 14.9 ± 6.3%, $p = 0.019$) at work. Figure 11 shows an example of muscle activity patterns during one 6 h work day from one participant in each group. There were no significant differences in moderate-to-vigorous muscle activity time, total number of bursts or the sum of the 5 longest muscle inactivity periods between groups. Furthermore, both groups exhibited spinal shrinkage but there was no significant difference between groups (Table 8).

TABLE 8 Workday EMG-derived muscle activity and spinal shrinkage in the two study groups and mean of all participants. Values are Mean ± SD or n(%).

Characteristics	Sit-Stand (n=10)	Sit (n=14)	All (n=24)	p-values[a]
EMG-derived muscle activity[b]				
Recording time (min)	420.1±65.9	392.3±23.5	403.9±47.0	0.770
Inactivity time (%)	66.2±17.1	80.9±6.4	74.8±13.9	**0.014**
Activity time (%)	33.8±17.1	19.1±6.4	25.2±13.9	**0.014**
Light activity time (%)	26.1±12.3	14.9±6.3	19.6±10.6	**0.019**
Moderate-to-vigorous activity time (%)	7.7±7.4	4.2±2.1	5.7±5.2	0.349
No. of bursts	601.2±97.5	563.4±238.6	579.1±190.4	0.600
Sum of 5 longest inactivity periods (min)	41.6±17.6	60.8±37.4	52.8±31.7	0.178
Spinal shrinkage (mm)[c]	5.62±2.75	6.11±2.44	5.91±2.53	0.653

[a] Bolded p-values indicate a significant difference between groups.

[b] Muscle inactivity time (time spent with < 90% of $\text{EMG}_{\text{standing}}$), muscle light activity time (90% $\text{EMG}_{\text{standing}}$ – < $\text{EMG}_{\text{walking}}$), muscle moderate-to-vigorous activity time (≥ $\text{EMG}_{\text{walking}}$).

[c] Spinal shrinkage between the beginning and end of the workday.

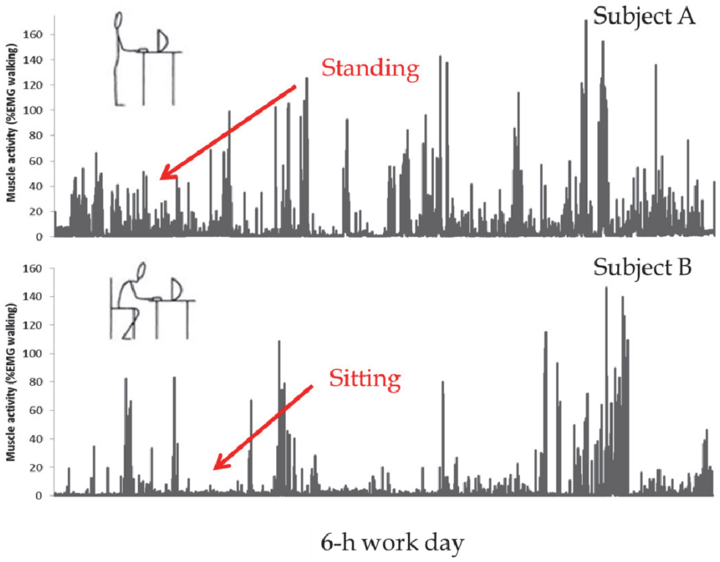

FIGURE 11 Normalized muscle activity from two participants who were from Sit-Stand group and Sit group, respectively. The marked areas of standing or sitting were based on their daily activity logs that indicated work routine and position.

5.5 Acute postural effects after glucose loading (Study IV)

5.5.1 Baseline assessments

Participants' age ranged between 40 – 64 years. Two participants stopped the measurements after the first hour in standing work because of feeling faint and unwell, leaving a total of 16 participants who completed both conditions. From the two participants with full data during sitting, but with incomplete data during standing, their first hour of data regarding mean energy expenditure, muscle activity and HR was analyzed. There were no differences in baseline assessments (anthropometric, dietary, and physical activity measures) or fasting biochemical values measured at 0 min between measurement days (Table 9), nor were there significant differences in resting energy expenditure or normalized EMG activity during both preparatory phases.

Twelve participants were post-menopausal and six were peri-menopausal. For peri-menopausal females, the menstrual cycle phase was not determined but the measurements were not done during menstruation. Independent t-tests were performed to test the tAUC, iAUC and fasting values of blood parameters under sitting and standing conditions between post- and peri-menopausal females. There were no significant differences in tAUC glucose between post- (955.3 ± 184.7 mmol/L·min) and peri-menopausal (897.3 ± 159.4 mmol/L·min) females (p = 0.522), as well as iAUC glucose (293.3 ± 176.2 mmol/L·min vs.

265.3 ± 138.4 mmol/L·min, p = 0.739) during sitting. The same was found during standing for tAUC (1013.8 ± 204.6 mmol/L·min vs. 928.3 ± 138.2 mmol/L·min, p = 0.382) and iAUC (341.8 ± 174.9 mmol/L·min vs. 288.3 ± 138.5 mmol/L·min, p = 0.534). For fasting glucose, the sitting condition yielded values of 5.5 ± 0.4 mmol/l vs. 5.3 ± 0.4 mmol/l (p = 0.205), and the corresponding results for standing were 5.6 ± 0.5 mmol/l vs. 5.3 ± 0.3 mmol/l (p = 0.250).

TABLE 9 Baseline assessments in fasting condition (0 min) on the two experimental days.

Variables (n=18)	Sit	Stand	p-values
Body mass (kg)	63.4 ± 7.7	63.4 ± 7.8	0.96
Physical activity (min/day)[a]			
Recording time	884.4 ± 81.4	879.2 ± 91.7	0.60
Sedentary	579.8 ± 111.7	569.2 ± 106.3	0.62
Light intensity	269.1 ± 75.6	272.6 ± 108.4	0.87
Moderate-to-vigorous	36.6 ± 27.8	38.2 ± 25.0	0.76
Sleep time (min/day)	480.5 ± 50.4	467.3 ± 48.5	0.33
Dietary intake			
EE (kcal/day)	1786.6 ± 331.5	1802.6 ± 411.5	0.82
Fat (g/day)	70.7 ± 23.0	68.7 ± 23.1	0.58
Protein (g/day)	80.4 ± 19.4	75.9 ± 26.8	0.31
Carbohydrate (g/day)	190.3 ± 54.7	202.5 ± 50.7	0.43
Fasting condition			
Total cholesterol (mmol/l)	4.98 ± 0.92	4.89 ± 0.87	0.36
HDL-C (mmol/l)	1.95 ± 0.45	1.94 ± 0.45	0.57
LDL-C (mmol/l)	2.85 ± 0.8	2.77 ± 0.7	0.27
Triglycerides (mmol/l)	0.95 ± 0.25	0.90 ± 0.35	0.08
Glycerol (mmol/l)	72.6 ± 43.1	65.8 ± 22.5	0.51
FFA (umol/l)	591.8 ± 306.4	535.1 ± 174.8	0.52
Cortisol (nmol/l)	368.4 ± 145.9	348.0 ± 143.6	0.61
Glucose (mmol/l)	5.4 ± 0.4	5.5 ± 0.4	0.42
Insulin (pmol/l)	26.7 ± 16.0	25.7 ± 14.7	0.67
HR (bpm)	67.4 ± 10.6	65.7 ± 8.8	0.16

[a] Missing n = 2

5.5.2 Muscle activity, energy expenditure and metabolic markers

The effects of condition on EMG activity are presented in Table 10. The muscle groups were categorized and averaged by region, where back muscles included TES, LES and LM, thigh muscles included BF and VL, and leg muscles included TA, GM and SOL. During continued standing the overall muscle activity levels of the back, thigh and leg muscles combined was 49.4% greater than during sitting (26 ± 9% vs. 19 ± 6%, $p = 0.006$). This difference resulted from 173.6% greater activity in thigh muscles (17 ± 8 % vs. 7 ± 2%, $p < 0.001$) and 160.5% greater activity in leg muscles (16 ± 6% vs. 7 ± 3%, $p < 0.001$), but no significant differences in the activity of back muscles (39 ± 17% vs. 43 ± 18%, $p > 0.05$). Detailed results from different muscle groups are presented in Figure 12.

TABLE 10 Muscle activity, energy expenditure, heart rate and metabolic biomarkers during sitting and standing.

Variables (n=18)	Sit	Stand	p-values
EMG activity (%walk)			
Overall	19.1 ± 5.9	26.4 ± 9.4	**0.006**
Back	39.0 ± 16.6	43.0 ± 18.4	0.446
Thigh	6.9 ± 2.1	17.2 ± 8.4	**0.000**
Leg	7.0 ± 2.5	15.9 ± 6.1	**0.000**
Energy expenditure[a]			
Ventilation (L/min)	8.5 ± 1.3	9.5 ± 1.8	**0.002**
Breathing frequency (L/min)	15.3 ± 2.2	16.3 ± 2.7	**0.037**
VO_2 (ml/min)	226.4 ± 28.9	248.3 ± 35.4	**0.001**
VCO_2 (ml/min)	199.2 ± 25.5	212.1 ± 33.3	**0.031**
VO_2/kg (ml/min·kg^{-1})	3.6 ± 0.5	4.0 ± 0.6	**0.001**
RER	0.879 ± 0.021	0.853 ± 0.026	**0.005**
MET	1.0 ± 0.2	1.1 ± 0.2	**0.001**
EE (kcal/min)	1.1 ± 0.1	1.2 ± 0.2	**0.002**
Fat (%EE)	39.4 ± 7.3	48.3 ± 9.1	**0.008**
Carbohydrate (%EE)	60.6 ± 7.3	51.7 ± 9.1	**0.008**
HR (bpm)	75.0 ± 12.6	83.8 ± 14.8	**0.000**
Metabolic markers[a]			
tAUC Glucose (mmol/L·min)	897.7 ± 139.4	981.7 ± 182.5	**0.026**
iAUC Glucose	246.7 ± 125.0	321.7 ± 159.6	**0.017**
tAUC Insulin[b] (pmol/L·min)	28512.2 ± 11812.0	30135.1 ± 16423.5	0.411
iAUC Insulin[b]	25006.6 ± 10297.5	26912.1 ± 15310.9	0.346
tAUC Triglycerides (mmol/L·min)	112.5 ± 32.8	112.4 ± 46.4	0.989
iAUC Triglycerides	0.9 ± 6.0	5.7 ± 12.4	0.103
tAUC Glycerol (mmol/L·min)	5676.7 ± 2188.9	6263.2 ± 1688.4	0.164
iAUC Glycerol	-2274.6 ± 2313.0	-1765.6 ± 2214.0	0.959
tAUC FFA(umol/L·min)	29925.7 ± 11444.1	36019.5 ± 11183.4	0.127
iAUC FFA	-37932.7 ± 28876.0	-27300.8 ± 21020.1	0.215
tAUC Cortisol[b] (nmol/L·min)	38539.5 ± 11369.3	42799.3 ± 21261.4	0.427
iAUC Cortisol[b]	-5524.5 ± 11621.0	-0.7 ± 11426.9	0.194

[*] Bold p-values indicate a significant difference between conditions.

[a] Missing n = 2

[b] Missing n = 3

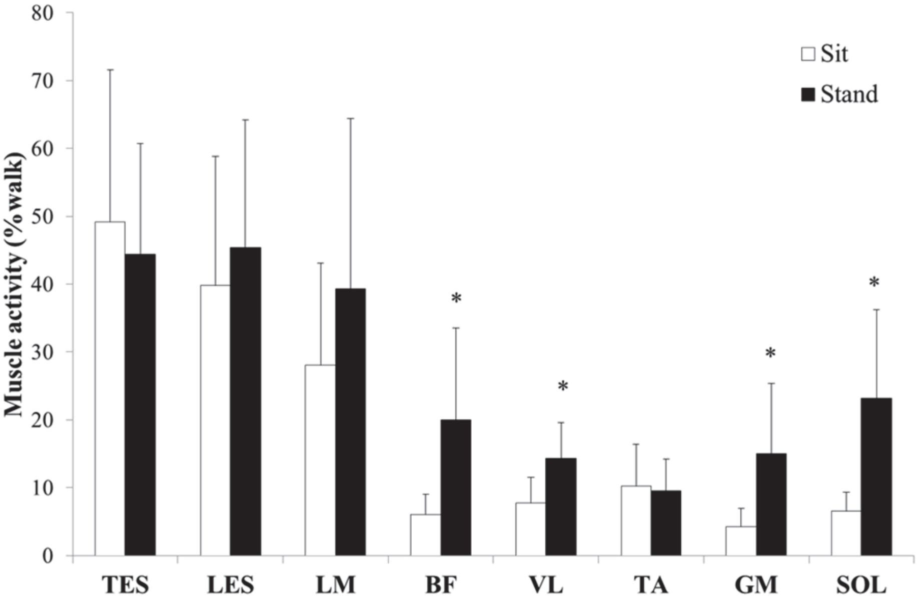

FIGURE 12 Muscle activity of thoracic erector spinae (TES), lumbar erector spinae (LES), lumbar multifidus (LM), biceps femoris (BF), vastus lateralis (VL), tibialis anterior (TA), gastrocnemius medialis (GM) and soleus (SOL) during sitting and standing at work (Gao et al. 2017, IV). * Significant difference based on paired t-tests ($p < 0.01$).

The results of energy expenditure and HR between conditions can be found in Table 10. Compared to sitting, during two hours of standing desk work the mean EE was 9.2% greater ($p = 0.002$) and the proportion of fat use increased from 39% to 48%EE ($p = 0.008$) while the proportion of carbohydrate use decreased from 61% to 52%EE ($p = 0.008$). Concomitant with energy expenditure, standing work resulted in 12.0% higher HR than sitting ($p < 0.001$). Energy expenditure positively correlated with mean thigh ($r_s = 0.392$, $p = 0.022$) and leg muscle activity ($r_s = 0.378$, $p = 0.028$).

Figure 13 and Table 10 show the metabolic responses to glucose loading in sitting and standing conditions. A significantly higher tAUC (9.8%, $p = 0.026$) and net iAUC of plasma glucose (42.3%, $p = 0.017$) were measured during standing than sitting. After glucose loading, the mean concentration of plasma glucose continued to rise until 60 min, reaching 9.3 ± 2.6 mmol/l during standing, whereas for seated work glucose peaked at 8.6 ± 1.2 mmol/l at the 30 min time point. For tAUC, net iAUCs and changes in 2-h concentration levels of serum insulin, triglycerides, glycerol, FFA and cortisol were not significantly different between conditions. There were no significant correlations between any of the metabolic responses (tAUC or iAUC) and muscle activity.

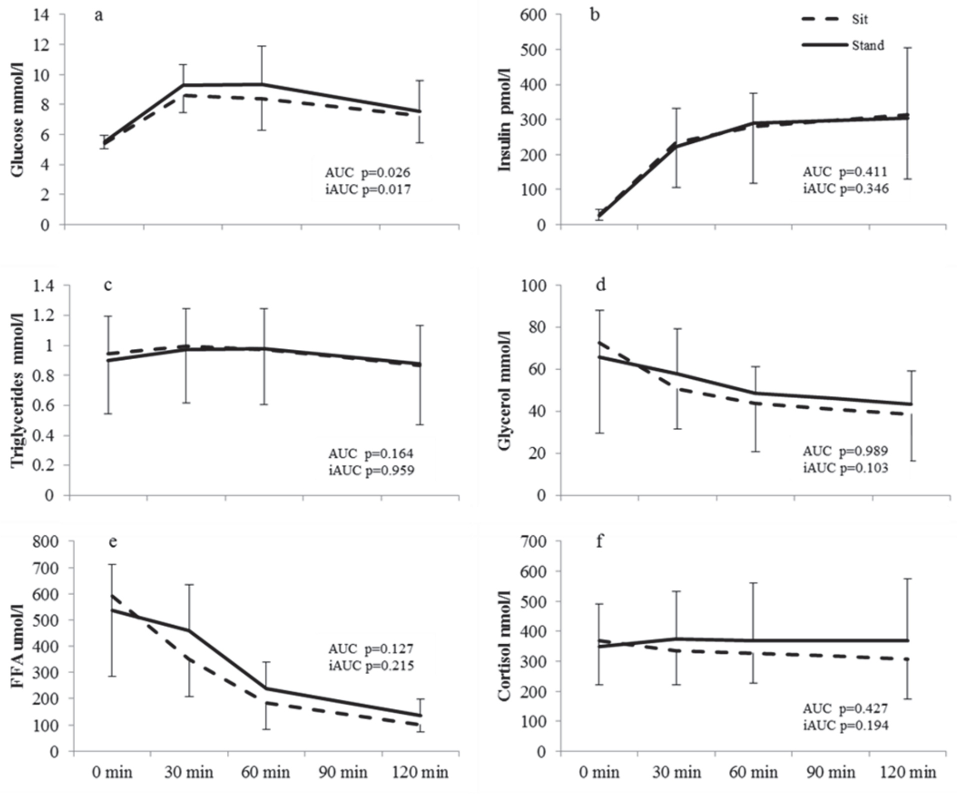

FIGURE 13 Responses (mean ± SD) of glucose (a), insulin (b), triglyceride (c), glycerol (d), FFA (e) and cortisol (f) to a standardized glucose loading (75 g) during sitting and standing at work for 120 minutes (Gao et al. 2017, IV).

6 DISCUSSION

Reducing sitting time has been proposed as a new workplace health priority. This multidisciplinary thesis was based on a sedentary behavior research framework, and together with postural considerations provides evidence for the benefits of working with sit-stand workstations. The purpose of this thesis was to examine whether and to what extent sit-stand workstations could reduce occupational sitting and improve health indexes in a real workplace. The thesis consisted of four studies including both field and laboratory settings with a range of methodological approaches. The main findings of this thesis were: both long-term and short-term self-reported instruments provide acceptable means of occupational sitting time in an office-based workplace, but their utility at the individual level is limited due to large variability (I); working with a sit-stand workstation reduced occupational sitting time and improved work-related health outcomes, such as musculoskeletal comfort, work ability, spinal loading and muscle activity patterns (II & III); the postural physiology study showed that compared with sitting, standing work increased energy expenditure and muscle activity after glucose loading in middle aged women. The results suggested that fuel switching occurs in favor of fat oxidation during standing despite extra carbohydrate availability (IV). The results of this thesis suggest that in the workplace, using sit-stand workstations can provide a promising strategy to reduce occupational sitting time and improve potential health outcomes.

6.1 Accuracy of self-reported occupational sitting time

While quantifying the time spent in different postures may help to elucidate the associations between occupational sitting time and health outcomes (Van Uffelen et al. 2010), it is important to develop and evaluate the accuracy of measures of sitting time at work. However, very few validity studies have examined subjective measures against accurate criterion measures that can distinguish between postures such as sitting or standing still and postural changes (Atkin et al. 2012).

In Study I, sitting time at work was quantified by separately identifying sitting and upright postures. The study examined the criterion validity and absolute agreement of two brief self-reported measures of occupational sitting time, assessed by long-term and short-term recall via an internet-administered questionnaire and daily recall, in a sample of Finnish and Chinese office-based workers. Criterion measures were compared with thigh-mounted accelerometer data, which were used to isolate sitting time. The findings suggest that both of the self-reported measures are acceptable (< 3% difference compared to accelerometry) for assessing the proportion of work time spent sitting at a group level, but not necessarily at an individual level. Although similar moderate correlations with objective measures were observed regardless of whether workers were asked about long- or short-term occupational sitting time, intra- and inter-individual variability of occupational sitting time was evident among Finnish and Chinese office workers.

Regarding the recall periods of the questionnaire, no difference was found between the last three months of occupational sitting time and the average of five work days (representing a typical work week), indicating that short-term recall adequately represented habitual occupational sedentary behaviors. Both long-term and short-term recall resulted in an average occupational sitting time of 79% during work hours. In addition, from the results of day-to-day variations in occupational sitting time, the overall range of CV% was less than 15% (from 6% to 13%) of short-term recall and accelerometer measured data from five work days. This is comparable with a previous validation study that reported differences in CV% between past day recall and measured sitting time based on postural allocations of 16% − 19% among adults (Matthews et al. 2013). In the present validation study (I), FIN group exhibited higher variations in daily occupational sitting time compared with CHI group. This may have been caused by several potential factors such as differences in sociocultural determinants, where work culture possibilities affect one's habitual occupational sedentary behavior (Owen et al. 2011). For example, participants in the FIN group were mostly university employees, and they may have had more flexible work schedules than those in CHI group, who were employed by companies with fixed work schedules. Importantly, some participants from FIN group used sit-stand workstations and it seems that they tended to have lower occupational sitting time, as shown in Study II and Study III, which likely also contributed to the greater variation.

Overall, the questionnaire for long-term recall and the daily short-term recall single-item question exhibited similar validity. The range of Spearman's rho was 0.336 – 0.684 in the total sample. Although the correlations found in Study I were low to moderate, they seem to be at least as strong as those for global sitting time measured with the International Physical Activity Questionnaire or Global Physical Activity Questionnaire in the general population (r_s = 0.07 – 0.61) (Cleland et al. 2014; Craig et al. 2003; Rosenberg et al. 2008). The results are also comparable to those of other studies that have examined the criterion validity of office-based sedentary time with accelerometry (r_s = 0.27 – 0.65) (Chau et al. 2012; Clark et al. 2011). Furthermore, the brief single-item question about occupational sitting time was self-administered at the end of each work day. Shorter-term recall has been suggested to improve self-report accuracy (Matthews et al. 2012b). Similar short- and long-term results were found in the total sample, although the difference between short-term recall and accelerometer measured occupational sitting time was greater in FIN group (mean difference 4%; equal to 18 minutes vs. 0.3% in CHI). This may have been caused by large day-to-day individual variability in occupational sitting time, which was larger in FIN than in CHI.

Long-term and short-term recall occupational sitting time estimates were both close to the accelerometer measured proportion of sitting time at work (mean differences were 2.4% and 2.2% respectively, equal to 11 minutes). This level of accuracy is comparable with results from the majority of validation studies assessing occupational sitting time, which reported mean differences from 2 min/d to 27 min/d (Clark et al. 2011; Chau et al. 2012; Chau et al. 2011), suggesting that the present method is suitable for surveillance purposes in large populations where it is desirable to estimate occupational sitting time at a group level. However, the limits of agreement were wide, whereby over- or underestimation generally varied between -24% – 28% (±1.96 SD), which is equal to more than 100 minutes. Thus, these measures may be less useful in studies that require a high level of accuracy at the individual level, e.g. smaller scale intervention studies. In these cases, self-report measures may be more appropriate as complementary information to objective measures. Overall, the brief single-item question about occupational sitting time may be sufficient to rank office-based workers on the basis of sitting time in large-scale workplace population studies.

6.2 Effects of using a sit-stand workstation on occupational sitting in a real workplace

In general, the installation of sit–stand workstations into an ecologically valid setting encourages office workers to adjust work postures, leading to a reduction in sitting time which is reallocated mostly to standing at work. Working at sit–stand workstations improved perceived musculoskeletal comfort, especially in the neck and shoulders, as well as work ability. There was also a positive correlation between reduced sitting time and improved musculoskeletal comfort in the back. The majority of intervention participants rated sit–stand workstation adjustability as good and satisfied with the workstation, although less than half of them, who were exclusively female, used the sit–stand function on a daily basis. Thus, the findings suggest that modifying the work environment by installation of sit-stand workstations alone is not enough to induce behavioral changes, and that adequate prompting may be required to increase their daily usage level. Furthermore, when compared with office workers who used traditional sit workstations, those using sit–stand workstations exhibited less muscle inactivity time and more light muscle activity time, without negative effects on spinal shrinkage.

Effects on sitting time. When the sitting questionnaire was used in the intervention study (II), we found that working at sit–stand workstations was beneficial for reducing sedentary time in comparison with traditional sit workstations. In the 6-month intervention period, office workers who used the sit–stand workstation significantly decreased the proportion of their work time spent sitting by 6.7%, equal to 30 min/8 h work time, which was highly associated with standing time. These potential behavior changes may bring health benefits in the long term (Hamilton, Hamilton & Zderic 2007). The intervention group also showed an increase in the proportion of work time and computer work time spent standing by 6.5% and 11.6%, respectively. These results support those of earlier studies, which found that sit–stand workstations can substantially reduce office workers' sitting time by 5 – 26% (Chau et al. 2014b; Dutta et al. 2014; Pronk et al. 2012; Grunseit et al. 2013), which is replaced by standing (Alkhajah et al. 2012; Healy et al. 2013; Straker et al. 2013).

Effects on musculoskeletal comfort and work performance. Aside from sitting time, mean perceived musculoskeletal comfort was generally maintained (upper limbs, back and lower limbs) or even improved (neck and shoulders) after working at a sit–stand workstation for 6 months. This improvement is consistent with a previous study, which showed that sit–stand workstations can reduce musculoskeletal discomfort across most upper body regions (Hedge & Ray 2004). It is interesting to note that a reduction in sitting time was positively correlated with perceived back comfort in office workers. Similarly, Pronk et al. (2012) suggested that alternating between sitting and standing postures at work may benefit musculoskeletal comfort. Regarding work performance, mean perceived work ability was higher in those who used the sit–stand workstation than those who used the traditional sit workstation. This is also in accordance with an earlier study, whereby individuals who worked both in sitting and standing postures reported significantly enhanced work productivity (Nevala & Choi 2013). A previous study also reported that typing performance does not differ between standing and sitting postures (Husemann et al. 2009). It should be noted that not all intervention studies have found positive effects on musculoskeletal health and work ability (Alkhajah et al. 2012; Ebara et al. 2008), which may be related to shorter intervention lengths compared to the present study.

Feasibility. The majority of users rated sit–stand workstation adjustability as good (83.3%), and 75.0% were satisfied with the workstation, which is rather high considering that the daily utilization rate was 41%. Unlike infrequent users, daily users of the sit–stand workstation were exclusively female. This may reflect a higher motivation of females to use the sit–stand function and a greater willingness to adapt to a new work environment. This group may also have been motivated by anticipated health benefits, willingness to experiment, and external prompting (Grunseit et al. 2013). The results showed effective changes in occupational sedentary behaviour, perceived musculoskeletal comfort in the lower limb and work ability in daily users, suggesting that daily prompting to use the sit–stand function should be encouraged. Support for this statement comes from the finding that percentage utilization was higher in a group who received instruction compared to those who did not (Wilks, Mortimer & Nylén 2006). Some studies have focused on a workplace setting within which the relevant contextual factors were controlled (organization, individual and environment). The results suggested that multi-component interventions targeting workplace sitting may achieve more substantial reductions in office workers' sitting time than the provision of sit–stand workstations alone (Healy et al. 2013; Neuhaus et al. 2014b). Collectively, these findings suggest that implementation of sit–stand workstations alone is not sufficient, and highlight the need for effective guidance (i.e. tailored counselling) to use the sit–stand function for reducing sedentary time, including adequate instruction and promotion of the potential health benefits.

Effects on muscle activity and inactivity time. In Study III, the activity patterns of quadriceps and hamstring muscles showed 15% less inactivity and 11% more light activity in workers using sit–stand workstations compared to users of traditional sit workstations. This is in line with Study II, which found that the introduction of sit–stand workstations was associated with reductions in sitting time of ~14% of work time for daily users, as also shown previously (Chau et al. 2014b; Dutta et al. 2014; Pronk et al. 2012; Alkhajah et al. 2012; Straker et al. 2013). Although energy expenditure when using a sit–stand workstation increases by a small amount compared with a traditional sit workstation (Tudor-Locke et al. 2013), less muscle inactivity, even by the small magnitude of 15%, may provide positive signals for metabolic health (Pesola et al. 2015). It has been reported that a difference of 2 h 18 min in daily muscle inactivity is beneficially associated with metabolic markers such as fasting HDL-C and triglycerides independent of moderate-to-vigorous muscle activity time (Pesola et al. 2015). While muscle inactivity time was reduced in the Sit–Stand group, there were no significant differences in moderate-to-vigorous muscle activity time between groups. This may reflect the sedentary nature of office work, whereby moderate-to-vigorous activity occupies only a fraction of daily work time, and lower intensity physical activity predominates (Clemes, O'Connell & Edwardson 2014). Interestingly, although the Sit–Stand group exhibited less total muscle inactivity time, neither the sum of the five longest inactivity periods nor the total number of bursts differed between groups. Similar results were also found in intervention studies (Alkhajah et al. 2012; Healy et al. 2013) and a cross-sectional study (Straker et al. 2013) that examined reductions in sitting time, but these studies did not detect changes in accumulated sitting bouts, stepping time or number of sit–stand transitions. Although there was no significant difference in the sum of the five longest inactivity periods, the almost 20-min difference between groups may have been sufficient to provide metabolic health benefits, but this needs to be confirmed in future studies. Because sitting periods accrued in bouts of 30 min or more are related to health risks, regular postural changes are recommended even for workers who use sit–stand workstations (Healy et al. 2012). Experimental studies have shown that frequent bouts of activity which reduce total sedentary time have a positive effect on metabolic variables (Dunstan et al. 2012; Duvivier et al. 2013), but it is still unclear whether the total or uninterrupted sitting time is important. Thus, in the present study the lack of difference in total number of muscle activity bursts may only imply that the pattern of postural transitions was similar between groups. Due to greater total duration of muscle activity, the use of a sit–stand workstation likely benefits metabolic outcomes even though it may not affect the number of activity bursts.

Effects on spinal loading. Spinal shrinkage is often quantified to reflect the effects of spinal loading, which can be assumed to have predictive value regarding health effects (Van Dieën & Oude Vrielink 1998; Igic, Ryser & Elfering 2013; Paul & Helander 1995). In Study III, the mean spinal shrinkage was 5.91 mm (0.35% of stature) after a typical office workday. This is comparable with results from another study that reported mean spinal shrinkage of 0.45% of stature at the end of a bout of standing work, with no significant differences between different work–rest schedules of standing and sitting: 60 min shift to 15 min break, 45 − 15, 30 − 15, and 30 − 30 (Van Dieën & Oude Vrielink 1998). A study focusing on work involving low physical activity reported shrinkage of the thoracolumbar spine of 4.75 or 6.95 mm, after 6.5 h of work in a prolonged sitting or standing posture, respectively. Corresponding values in the lumbar spine were 1.73 or 4.16 mm (Leivseth & Drerup 1997). However, in view of task specificity and large inter-individual variability in spinal shrinkage, comparisons across different groups and studies are difficult. Interestingly, there was no statistically significant difference in spinal shrinkage between groups. Although static standing has been reported to result in greater spinal shrinkage than static sitting (Van Deursen et al. 2005), in dynamic situations, where office workers change positions with higher job control (Igic, Ryser & Elfering 2013), it may be possible to mitigate increases in spinal shrinkage. In addition, using a sit–stand workstation may involve body movement which results in reduced spinal shrinkage or enhanced recovery of shrinkage (Van Dieën, De Looze & Hermans 2001). Importantly, the range of spinal shrinkage (1.55 – 10.55 mm) in both groups of the present work was below the highest permissible spinal shrinkage of 21 mm in order to prevent occupational low back pain (Ismaila & Charles-Owaba 2008). Thus, this study provides evidence from an occupational ergonomic perspective that habitual use of a sit–stand workstation does not cause negative effects on spinal shrinkage. However, it should be highlighted that excessive standing time at work may not be healthy (Igic, Ryser & Elfering 2013). The effect of prolonged standing on spinal health, over periods exceeding the habitual times measured in the present study, should be examined to be able to recommend safe limits for workday standing time to sit–stand workstation users.

6.3 Acute physiology: comparing sitting and standing at work

Study IV provides experimental evidence for the effects of two hour bouts of sitting and standing work on acute metabolic responses, energy expenditure and muscle activity after glucose loading in middle aged women. In line with the hypothesis, standing resulted in greater muscle activity, higher energy expenditure and fat oxidation when compared with sitting. In contrast to the hypothesis, standing elicited a higher glucose response after glucose loading than was observed during sitting. Together these results suggest fuel switching after glucose loading, whereby fat oxidation increased and carbohydrate usage decreased during standing compared to sitting (Figure 14).

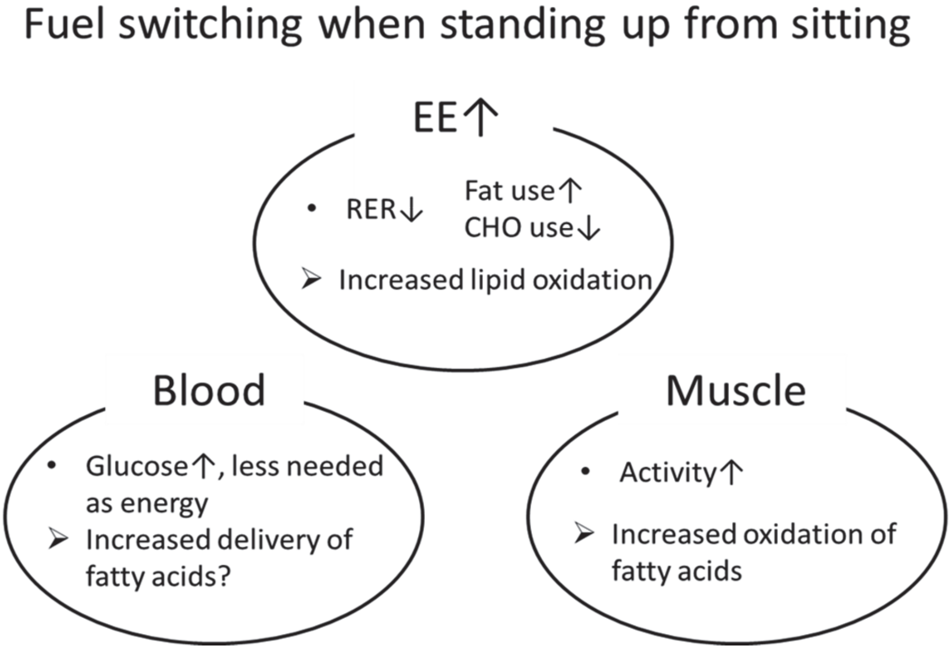

FIGURE 14 Fuel switching when standing up from sitting after glucose loading: fat oxidation was increased and carbohydrate (CHO) usage was reduced. This figure refers to the findings for energy expenditure (EE), muscle activity and blood samples (Gao et al. 2017, IV).

Previous studies using indirect calorimetry have reported that continuous motionless standing consumes 0.07 kcal/min more energy than sitting (Júdice et al. 2016). In the present study the energy expenditure increase from sitting to standing was roughly similar (0.10 kcal/min), suggesting that the participants were mainly standing still during the experiment, despite being allowed to sway and bend their legs. Lower extremity muscle activity was positively associated with energy expenditure, confirming that lower extremity muscle activity is an important factor in energy expenditure during standing. However, neither muscle activity nor energy expenditure were associated with metabolic changes, suggesting that factors other than lower extremity muscle activity or total energy expenditure may explain how individuals gain acute metabolic benefits when standing still instead of sitting.

In Study IV, an increase in fat oxidation and a decrease in carbohydrate oxidation were found in standing compared to sitting. This indicates a proportional increase in the use of fatty acids as an energy source and enhanced fatty acid oxidation to fuel muscle activity, which in turn supports the hypothesis that light-intensity physical activity like standing may alter the regulation of fat and carbohydrate usage (Spriet 2014). In the long term, increased fat oxidation may help in the clearance of intramuscular lipids and ectopic fat storage, with beneficial effects on the whole body, as well as muscle and liver insulin sensitivity, even in the absence of a negative energy balance or acute improvements in insulin sensitivity (Bergouignan et al. 2016; Bergouignan et al. 2013). Although in this study glucose loading caused no difference in insulin response or changes in triglyceride levels between conditions at 2 h, the results corroborate those of earlier studies which reported that postprandial insulinemic and lipaemia responses did not significantly change after alternating bouts of standing and sitting for 30 to 45 minutes (Miyashita et al. 2013; Thorp et al. 2014). Romijn et al. (1993) showed that during light intensity exercise, FFA release from adipose tissue is the main oxidative fuel used by working muscles, and lipolysis increases as a function of power output when changing from rest to physical activity (Romijn et al. 1993). It is also probable that increased muscle activity during standing increased FFA delivery into the muscle via increased blood flow (Spriet 2014). While a similar mobilization of FFA took place in both conditions, a slightly slower decline of FFA concentration can be found during standing than sitting (Henson et al. 2016), although this effect was nonsignificant in the present study. Thus, it was speculated that standing may attenuate insulin-induced lipolysis inhibition because glycerol and FFA both tended to decrease slower than during sitting. The second major source of fat is the release of FFA from triglycerides stored directly in the muscle, which increases during light to moderate intensity exercise (Spriet 2014). Therefore, it is concluded that in the conditions of the present study where there was maximal availability of glucose, the increased energy demand during standing promoted fuel switching by increasing fat oxidation (potentially due to increased delivery of FFA and/or increased oxidation of intramuscular FFA) and decreasing carbohydrate oxidation.

The elevated level of circulating plasma glucose found in standing suggests that glucose may not be needed as an extra energy source in standing. This apparently conflicts with previous results showing attenuated blood glucose excursion in standing (Buckley et al. 2014; Thorp et al. 2014). However, previous studies have used standardized standing breaks (Thorp et al. 2014) or standing while working in a real office environment (Buckley et al. 2014) as their exposure, both of which may elicit higher energy expenditure due to dynamic activity compared to predominantly motionless standing in the present study. Buckley et al. (2014) reported that the increase in energy expenditure of standing vs sitting while doing office work was 0.83 kcals/min, which is higher than in the present study (0.10 kcals/min). This suggests that frequent standing breaks or ambulation may be required to elevate energy expenditure above that of motionless standing in order to elicit changes in glucose tolerance. Furthermore, the high energy expenditure in Buckley’s study was estimated from HR rather than using indirect calorimetry, which may also explain the differences between Buckley's and the present findings. Many other factors may contribute to the apparent discrepancy regarding the glycemic response, including age, sex, BMI, metabolism and exercise status (Buckley et al. 2014; Thorp et al. 2014). For example, benefits of standing may be more evident in subjects with a higher BMI than those in the present study (Thorp et al. 2014), since higher muscle activity has been reported in overweight compared to normal weight subjects (Pesola et al. 2016). Another important difference to consider when comparing results is the time course of nutrient loading. In the present study the loading was done during the standing exposure, because the aim was to examine concurrent interaction between standing and nutrient loading, as occurs during daily life, where periods of energy intake and expenditure take place simultaneously. Some setups provide the nutrient loading after the physical activity exposure and do not allow direct comparison to the present findings because of a lack of concurrent interaction between diet and physical activity (Thorp et al. 2014; Duvivier et al. 2013). There is discrepancy in the literature regarding differences in experimental design that may be the cause of these inconsistent findings, e.g. intensity and frequency of breaks and duration of prolonged sitting (Thorp et al. 2014; Dunstan et al. 2012; Bailey & Locke 2015; Hansen et al. 2016; Henson et al. 2016). Importantly, distinct from the majority of experimental studies which have interrupted sitting with short periods of activities (Benatti & Ried-Larsen 2015), the current setup differentiates the independent effects of sitting and standing. It should be noted that although the increased glucose level may seem to have induced an adverse effect, the increased oxidation of lipids can benefit insulin sensitivity after an intervention or in the long term, and the resulting effect may be positive (Bergouignan et al. 2013; Dunstan et al. 2012). However, this should be confirmed in longitudinal studies.

6.4 Methodological considerations and limitations

6.4.1 Self-reported occupational sitting time

Although self-report measures may be associated with measurement errors, they still offer distinct information from objective measures to assess sedentary behavior. When objective measurements are impractical, accurate and reliable self-report measures are needed. Such measures can be implemented on a large scale with low cost and provide important information about domain- or behavior-specific sedentary time. However, regarding the workplace domain specifically, few studies have examined the validity of occupational sitting time, and even fewer have identified postural allocations and compared with objective criterion measures (Healy et al. 2011; Van Uffelen et al. 2010).

Previous ergonomics studies have identified individual work postures (e.g. sitting, standing etc.), and concluded that instruments were sufficiently accurate for studying those work postures in relation to health effects in epidemiological studies (Laperrière et al. 2005; Mortimer et al. 1999). Similarly, Reis et al. (2005) categorized the amount of time spent in specific occupational categories (Centers for Disease Control and Prevention 2001): "1) sitting or standing, 2) walking, and 3) heavy labor", where the Spearman correlation with sitting or standing was 0.37 against 7-d occupational physical activity records. Further examination of separated occupational sitting and standing is required, particularly for the assessment of occupational sitting time, as sit-stand workstations have been recently introduced in workplace settings (Van Nassau et al. 2015). Chau et al. (2012) assessed two brief instruments, which quantified the percentage of time spent in different activities at work. The results showed moderate correlations for measuring occupational sitting and standing time (r_s = 0.65 and 0.49, respectively), suggesting that it is a suitable method for measuring sitting and standing as discrete indicators (Chau et al. 2012). In addition, the questions were sufficiently valid and responsive to changes over time in the sit-stand transition when compared with stronger relevant criterion measures of different postures (Van Nassau et al. 2015). Thus accurate and reliable self-report measures should be developed and evaluated in the workplace (Castillo-Retamal & Hinckson 2011). Such measures should allow comparisons across different populations and be applicable in epidemiological research (Healy et al. 2011).

Along with the goal of improving self-reported occupational sitting time, in the present study (I), the validity of self-reported occupational sitting time with a questionnaire (long-term) and via daily recall (short-term) was examined in different sub-populations including Finnish and Chinese office-based workers. Although the present study used two brief instruments to assess occupational sitting time, both of them may be similarly susceptible to random and systematic reporting errors (Healy et al. 2011). Single item question had large limits of agreement, possibly because of fewer responses being required. Despite reducing measurement error issues, the present study also has some other limitations. This study used two cohort subgroups including participants from Finland and China. The study samples were small and may not be representative of the larger population. Participants were office-based workers, so these findings may not be representative of other occupations. Further examination of the utility of self-reported measures is recommended in different occupations with more varied patterns of sitting. While questionnaires containing several questions at a time may be associated with contamination, the two self-report measures used in this study were administered at different time points, which minimize this potential bias. In addition, few studies have examined the ability of self-report measures to detect behavior changes over time (Van Nassau et al. 2015; Gibbs et al. 2015). Although in the validation study (I) responsiveness to changes in occupational sitting was not assessed, an intervention study (II) was included where self-reported sitting time was examined with repeated measures. Results showed that self-reported occupational sitting time decreased by ~14% after 6-months of daily use of a sit-stand workstation. This difference is large compared to the mean difference of 2.2% − 2.4% between self-report and objective measures in the validation study (I), suggesting that self-report measures could be sensitive enough to detect longitudinal changes in sitting time at the population level. However, further studies are needed to test this hypothesis. Because the present study paid more attention to the workplace domain, I did not collect data using multiple domains or global measures of self-reported sitting time, which may have greater utility in epidemiological research on sedentary behavior (Atkin et al. 2012).

6.4.2 Postural allocation using accelerometry

In Study I, occupational sitting time was identified based on postural allocations from the raw thigh-mounted accelerometry data. Although it did not use standard devices, such as ActiPAL (Edwardson et al. 2016b), the raw data processing from thigh-mounted accelerometers (X6-1a, USA) was done so that the output corresponded to inclinometry results as explained in the text (4.5.4). Before selecting the threshold of 45 degrees, laboratory tests were done to confirm that the same threshold would work for different people. The threshold of 45 degrees was also used in another study to detect sitting posture using thigh-mounted accelerometry (inclination > 45 degrees) (Skotte et al. 2014). In pilot tests participants were asked to sit, stand and walk for known periods of time and thus confirmed the accuracy of the detection algorithm. The script used is an open source. However, further validation may be required to confirm the accuracy of the present devices for postural classification using raw accelerometry data. Furthermore, in the present study, total occupational sitting time was consistent with the validation of self-report measures, but the manner of sitting accumulation, which can also provide important additional information, such as the length of each sitting bout or the number of breaks during sitting time was not explored. Thus, as the data were date- and time-stamped, further work is needed to examine the potential value of this information, including both of sitting time and patterns in the workplace domain.

6.4.3 Long-term recordings of EMG during normal daily activity

Although accelerometry is often used to assess sitting time and sitting patterns, EMG could provide a good alternative by quantifying muscle activity during daily activities. Muscle activity can be evaluated noninvasively from the surface of the skin using EMG. Novel textile EMG shorts have been used for the long-term recording of muscle activity and inactivity during normal daily life (Tikkanen et al. 2013). When compared with traditional EMG, textile EMG shorts were found to be a valid and reliable tool for assessing muscle activity levels in field conditions (Finni et al. 2007). The signals from the textile electrodes recorded by EMG shorts are in good agreement with those from traditional bipolar electrodes (Finni et al. 2007).

Several methodological issues have been discussed in detail in two recent PhD theses, including threshold setting and the method used to normalize data, which affect EMG intensity and duration (Pesola 2016; Tikkanen 2014). Based on the postural hypothesis, Study III was consistent with some studies that used 90% of the amplitude of $EMG_{standing}$ as the threshold to separate muscle inactivity from activity (Tikkanen et al. 2013; Finni et al. 2014; Pesola et al. 2014; Pesola et al. 2015). Accordingly, there is clinically significant meaning behind this threshold, and a recent study reported that muscle inactivity is adversely associated with some cardio-metabolic biomarkers (Pesola et al. 2015). However, another recent study suggested that a threshold of 60% of $EMG_{standing}$ was a stronger predictor of sitting muscle inactivity time when compared with different thresholds, including 90% of $EMG_{standing}$ (Pesola et al. 2016). Considering the high heterogeneity of muscle activity during sitting (Pesola et al. 2016), multiple comparisons with several thresholds is required, because of the sensitivity of the threshold chosen (Klein et al. 2010). Moreover, instead of a treadmill test, in Study III overground walking was used for data normalization, and thus to determine the threshold for separating muscle light activity and moderate-to-vigorous activity (Pesola et al. 2016; Tikkanen et al. 2013). There is evidence to show that muscle activity patterns differ between overground and treadmill walking, for example hamstrings and vastus medialis muscle activity are higher in certain gait phases during overground walking (Lee & Hidler 2008). It seems that using overground walking is considered to more closely replicate normal daily activity.

Compared with traditional bipolar electrodes, EMG shorts with embedded textile electrodes have a larger surface area, and measure from global muscle groups rather than individual muscles. Although some superficial muscles (e.g. quadriceps and hamstrings) can be assessed with EMG shorts during daily activity, other major postural muscles cannot. It seems that postural muscles including soleus and gastrocnemius are important contributors to metabolic profiles during ambulation and upright activities (Hamilton, Hamilton & Zderic 2007). This suggestion is supported by the results of Study IV, where larger muscle activity was found in soleus and gastrocnemius during standing compared to seated work. However, similar magnitudes of EMG activity were found in the biceps femoris and vastus lateralis, and gastrocnemius medialis and soleus during standing work, suggesting that the results of Study III are representative of lower limb muscle activity patterns during work time.

Some data were excluded from analysis due to artifacts, although this had a limited effect on the results due to channel averaging. Since EMG was recorded from the hamstrings and quadriceps of both limbs, the effect of exclusion of single EMG channels on global muscle activity is rather small, as the majority of daily activity is bilateral. For all but one participant, valid data were acquired from at least one channel from each muscle. One recent study reported similar mean relative ratios of EMG activity between the left and right lower limbs in various tests using EMG shorts, indicating symmetric muscle activity in the lower limbs (Bengs et al. 2017). Furthermore, because data were only collected with EMG shorts for one day, it is difficult to reliably conclude about habitual muscle activity patterns during work time. Although some studies suggested that activity levels are highly consistent across days for sedentary occupations (Pesola et al. 2015; Baranowski et al. 2008), further studies should consider day-to-day variability at an individual level.

6.4.4 Controlled laboratory setting

Study IV was conducted in the laboratory setting, where a controlled measurement environment was used in order to eliminate potential confounding factors. In order to simulate a normal office work environment as closely as possible, participants were first familiarized with the laboratory layout, and during the measurements were asked to perform their usual daily tasks, which included Internet browsing, emailing, word document editing, reading materials and other paper work. Furthermore, participants were asked to do the same task during both experimental days in order to have comparable conditions. There were no differences between conditions at the baseline assessment, suggesting that the changes observed were due to changes in posture as opposed to external factors. However, some between-subjects variance in dietary patterns and profiles of fat, protein and carbohydrate may have influenced the results. Future studies should standardize meals prior to measurement days to minimize possible dietary effects on responsiveness. Moreover, previous studies have provided a non-standardized lunch or a mixed test drink rather than a glucose drink during the experiment (Buckley et al. 2014; Thorp et al. 2014), which may induce different changes in postprandial blood glucose responses due to the higher intake of energy and other macronutrients. Previous evidence suggests that differences in nutritional composition can influence plasma glucose concentrations, whereby postprandial plasma glucose concentration was significantly higher in a group that consumed a glucose drink than a group that consumed a drink with glucose and protein (Roberts et al. 2013).

It is important to note that the acute effects observed after two hours of exposure to continuous sitting and standing may not be extrapolated to long-term exposures. The current setup also limited ambulatory activity due to the measurements of respiratory gases and EMG. Measuring unilateral muscle activity may have caused loss of some information about postural variations during the measurements. Furthermore, this study was designed to include single bouts of two hours continuous sitting/standing, with the goal of inducing explicit physiological changes under standardized conditions. It should be noted that a period of two hours continuous standing may not be suitable for all participants. It was not possible to measure full data from two participants during standing work, as they reported feeling faint and unwell after the first hour. This should be carefully considered in future studies, as ergonomic recommendations suggest that continuous standing should be limited to one hour, and include frequent adjustments of posture throughout the workday (Commissaris et al. 2006). Furthermore, before suggesting the potential effects of promoting standing instead of sitting, a number of health- and work-related outcomes should be considered such as lower limb discomfort and fatigue (Chester, Rys & Konz 2002), entire body tiredness, alertness and performance (Ebara et al. 2008), leg swelling and venous blood pooling (Lin, Chen & Cho 2012), and low back pain (McGill, Hughson & Parks 2000). Future studies should also aim to identify the positive and negative effects of sitting/standing during desk work, not only in a lab setting but also in an ecological environment.

6.5 Practical implications and future directions

As sedentary behavior is a global health issue, reducing sedentary time has been recommended as a new workplace health priority. Working with a sit-stand workstation provides a possible solution to replace sitting time with standing. Studies are required to examine the effectiveness of this approach on reductions in sedentary time and potential health impacts in order to translate sit-stand interventions into practice. This study provided knowledge about intervention-induced changes in occupational sitting and health indexes. It further provided insight into the effects of using sit-stand workstations on muscle activity and inactivity patterns among office workers, and their links to spinal loading exposure under work conditions. While understanding of the underlying physiological processes affecting health is required, this study added evidence concerning metabolic responses during sitting and standing at work.

Research about self-reported sedentary time has focused on total sitting time. However, domain- and behavior- specific questions may provide more specific information about the time spent sitting. When leisure time sedentary behavior and non-occupational sedentary time have been reported (Clark et al. 2009), the workplace has been identified as a key setting. Thus, further study is required to evaluate the accuracy and reliability of self-reported occupational sitting time. Only a few previous studies have examined the validity of measures of occupational sitting time, and even fewer have identified postural allocations by comparing with objective criterion measures (Healy et al. 2011; Van Uffelen et al. 2010). Study I was initiated to examine the validity of self-reported occupational sitting time, and although in recent years new studies have emerged (Van Nassau et al. 2015; Chau et al. 2012), the current study includes several unique contributions. The amount of sitting time was quantified as a proportion of worktime. This may be a useful instrument in large population based studies, which are limited by space constraints for questionnaire items (Chau et al. 2012). Furthermore, when a standardized approach to measure sedentary behavior is required (Healy et al. 2011), the use of continuous variables may make it possible to directly compare various studies regarding the proportion of work time spent sitting (Chau et al. 2012). However, further examination of the units used to report sedentary and active time, for absolute and relative variables, is required to enable appropriate comparisons. In addition, there is limited research about intra- and inter-individual variability of sedentary behavior (Edwardson et al. 2016b). In the current study, subject-specific differences between subjective and objective sitting time were identified, as well as individual day-to-day variation of occupational sitting time. These results may improve understanding of how office workers individually accumulate their daily total sitting time at work. They may also bring new insight into workplace interventions targeting intra- and inter-individual variability of sedentary behavior at work. Furthermore, an important contribution of this study is the comparison between self-report instruments and accelerometer measures of sitting and upright postures (sitting and activity time) in the workplace; these simple self-report measures could feasibly be used in large population studies, which may ultimately help to establish associations between postural allocations and occupational health outcomes (Van Uffelen et al. 2010; Castillo-Retamal & Hinckson 2011).

Given the potential health benefits of reducing sedentary time, the effectiveness of working with a sit-stand workstation to reduce prolonged sedentary exposure is promising. Sit-stand workstations also provide musculoskeletal benefits with no impact, or even a positive impact on work performance. However, regarding the daily usage level of the sit-stand function in the real-world, where there is no form of external prompting, it seems based on the results of Study II that implementation of sit–stand workstations alone is not sufficient, and that effective guidance (i.e. tailored counselling) is also required to improve their usability. One recent study reported that the introduction of a sit-stand desk equipped with a semiautomatic system for prompting the workers to change the desk position led to higher usage of the sit-stand function than that obtained only with a standard sit-stand desk. The consistency of usage patterns between workers, and day-to-day consistency within workers across a period of time were also highlighted (Barbieri et al. 2017). Although in the current study the precise time allocation between sitting and standing was not examined, future studies are needed to determine ergonomics guiding standards for optimal usage ratios and postural variations in order to eliminate the possible negative impacts of prolonged sitting and prolonged standing (Callaghan et al. 2015). Furthermore, it should be noted that as the findings from Study II were heavily reliant on questionnaire responses, recall bias may have influenced the results. The results may reflect habitual patterns of sedentary behavior rather than actual time in the workplace, and could be influenced by the environment (Wallmann-Sperlich et al. 2014). Although the questionnaire regarding sitting was validated by comparison to thigh-mounted accelerometry in Study I, with a small sample size, caution must be applied, as the findings might not be transferable to epidemiological settings, and may be somewhat confounded by the use of a convenience sample. Future studies should include objective measurements such as thigh-mounted accelerometry to accurately capture sitting time. Furthermore, it needs to be emphasized that the findings were made in participants that rated their health rather or very good. Therefore, the findings may be even more marked in a population of workers with poorer self-rated health.

Beyond simply reporting differences in sitting time, Study III also assessed muscle activity and spinal shrinkage with objective measurements, and compared office workers who either worked with a sit-stand workstation or traditional sit workstation in a real workplace. Study III is one of very few that have measured muscle activity using EMG shorts with long-term recording, which have been reported to provide an accurate and detailed assessment of muscle activity patterns across the entire continuum of daily life (Tikkanen et al. 2013). Compared with analysis of activity outcomes from accelerometers and postural data (Chastin & Granat 2010), EMG as a direct measure of muscle activity provides further physiological insight into changes in muscle activity and inactivity time, and the associated cardio-metabolic impact when reducing sitting time (Tikkanen et al. 2014; Pesola et al. 2015). However, several considerations should be noted for future studies. This cross-sectional study (III) included data from only one workday, which could mask the effects of day-to-day variations and result in potential bias. To counteract this limitation, the participants were asked to choose a typical workday representative of their habitual daily work (Baranowski et al. 2008) for the day of the measurements. Although several studies have explored the optimal sit-stand ratio regarding health outcomes (Paul & Helander 1995; Van Dieën & Oude Vrielink 1998), in the current study no instructions were given regarding the sit-stand ratio but asked participants to behave as they would on a typical workday. Regarding some outcomes, the statistical power might have been too low to detect significant differences. For example, the difference in the sum of the 5 longest inactivity periods was almost 20 minutes, but it was not statistically significant between groups. For future studies, 17 participants in both groups would be required to achieve more than 90% power for the primary outcome of muscle inactivity time. Larger-scale randomized-controlled interventions with follow-up assessments are needed to investigate the potential causal long-term impact of using sit-stand workstations on various health outcomes.

With regards to the postural based hypothesis of sedentary behavior, Study IV highlighted the finding that the increased energy demand of standing was fulfilled by mobilizing fat stores. While intermittent muscle contractions may be one of the key mechanisms behind improving markers of metabolic health, the role of muscle activity has not been assessed in the majority of experimental studies (Benatti & Ried-Larsen 2015). Furthermore, most experimental studies have focused on short periods of interrupted sitting (Benatti & Ried-Larsen 2015), which may not produce significant reductions in sedentary time. Sit-stand workstations represent a potential intervention tool for replacing workplace sitting with standing. There is currently a need for acute experimental studies that differentiate the independent effects of sitting and standing, where the focus is on single bouts rather than interrupted sitting with short periods of activities. Although standing seems to have a positive effect on fuel switching based on the current findings, longer periods of observation may provide a better understanding of the longitudinal effects of standing.

7 MAIN FINDINGS AND CONCLUSIONS

The main findings and conclusions of this thesis can be summarized as follows:

1. A brief self-report about estimated long-term sitting time at work assessed via questionnaire, or short-term sitting time based on daily recall may be suitable for different population health surveys, prospective cohort studies, and other studies that rely on questionnaires. However, although both self-report instruments provide acceptable measures of occupational sitting time in an office-based workplace, their utility at the individual level is limited due to large variability.

2. Working at a sit-stand workstation can lead to a reduction in occupational sitting, as well as improved perceived musculoskeletal comfort and work ability in office workers. However, encouragement and proper guidelines of using sit-stand workstations may be required to promote daily usage of the sit–stand function. In general therefore, when aiming to reduce sitting time in an office setting, it seems that implementation of sit–stand workstations alone is not sufficient, and that tailored counselling is also needed.

3. When considering potential health impacts, office workers using sit–stand workstations had ~15% less muscle inactivity time and ~11% more light muscle activity time compared to office workers using sit workstations during one work day. A difference in muscle inactivity of this magnitude is mechanistically linked to acute, clinically significant cardiometabolic benefits (Pesola et al. 2015; Duvivier et al. 2013; Dunstan et al. 2012), and at the same time, using a sit–stand workstation does not seem to be associated with greater spinal shrinkage.

4. In support of the posture-based hypothesis of sedentary behavior, maintaining a standing posture at work increased muscle activity, energy expenditure and plasma glucose concentration compared to sitting follow-

ing a glucose loading. Standing seems to induce fuel switching in favor of fat oxidation for energy production, which may originate either from oxidation of local fat stores or from elsewhere via delivery in the bloodstream. Despite the acute increase in glucose concentration, especially in the current setup after glucose loading, increased fat use during standing might benefit metabolic flexibility and insulin sensitivity in the long term.

YHTEENVETO (FINNISH SUMMARY)

Korkeussäädettävien työpöytien mahdollisuudet vähentää istuma-aikaa ja vaikuttaa terveysmuuttujiin

Toimistotyöhön liittyy tyypillisesti paljon istumista. Suuri päivittäinen istumisaika tuo terveyshaittoja, joita voidaan pienentää fyysisellä aktiivisuudella. Työajalla istumisen vähentäminen onnistuu esimerkiksi korkeussäädettävän työpöydän avulla, joka mahdollistaa työn tekemisen joko istuen tai seisten. Säännöllisesti tehtynä seisomaan nousu katkaisee pitkiä istumisjaksoja ja mahdollisesti vähentää istumisen terveyshaittoja. Tämän väitöskirjan päätarkoituksena oli selvittää miten paljon korkeussäädettävät työpöydät voivat vähentää työperäistä istumista ja tutkia onko niiden käytöllä vaikutuksia eri terveysmuuttujiin.

Väitöskirjan ensimmäisessä osajulkaisussa kysyttiin istumisaikaa kahdella lyhyellä kysymyksellä, ja vastausten pätevyyttä verrattiin reiteen kiinnitetyn kiihtyvyysmittarin avulla tunnistettuihin asentoihin. Tulokset osoittivat että suomalaiset ja kiinalaiset toimistotyöntekijät istuivat keskimäärin 79 % työajasta kyselyyn perustuen ja 77 % työajasta objektiiviseen mittaukseen perustuen. Vaikka kyselyt keskimäärin antoivat hyvin lähelle saman tuloksen kuin objektiivinen mittaus, eivät kyselyt sovi yksilön istuma-ajan mittaamiseen suuren vaihtelun vuoksi (osajulkaisu I). Kun kyselyyn perustuen verrattiin normaalilla istumatyöpisteellä työskentelevien ja säädettävän työpisteen saaneiden työntekijöiden istuma-aikaa 6 kuukauden intervention aikana, havaittiin jälkimmäisellä ryhmällä työajan istumisen vähentyneen n. 7 %. Säädettävällä työpisteellä työskentelevien työntekijöiden työkyky ($p = 0.022$) ja selän ja hartioiden mukavuustuntemukset ($p = 0.028$) olivat istumatyöpisteellä työskenteleviä parempia. Korkeussäätöä käytti päivittäin 41 % tutkittavista, ja heidän työajalla tapahtuva istuminen väheni 14 % (osajulkaisu II).

Poikkileikkausasetelman perusteella korkeussäädettävää työpistettä käyttävillä tutkittavilla oli 11 % enemmän kevyttä lihasaktiivisuutta ja 15 % vähemmän reisilihasten passiivisuutta kuin istumatyöpistettä käyttävillä. Reisilihasten passiivisuuden on aiemmin havaittu olevan yhteydessä suurempaan veren triglyseridien määrään ja pienempään HDL kolesterolin määrään. Työpäivän aikainen kehon pituuden muutos, joka heijastaa selkärangan nikamavälilevyjen kokoonpuristumista, oli molemmilla ryhmillä yhtä suuri (osajulkaisu III). Istumisen ja seisomisen akuutteja vaikutuksia biomekaanisiin ja fysiologisiin muuttujiin tutkittiin kontrolloiduissa laboratorio-olosuhteissa. Kahden tunnin istumatyöskentelyyn verrattuna seisominen vaati enemmän jalkojen mutta ei selän lihasaktiivisuutta, ja kulutti 9 % enemmän energiaa ja 23 % enemmän rasvaa. Vaikka glukoosia oli saatavilla energiaksi tutkimuspäivän aamuna annetun glukoosijuoman vuoksi, seistessä rasvojen osuus energiankulutuksesta kasvoi, millä voi olla positiivisia aineenvaihdunnallisia terveysvaikutuksia (osajulkaisu IV).

Tämän väitöskirja osoittaa, että vaikka korkeussäädettävät työpisteet voivat vähentää työperäistä istumista, ilman neuvontaa mahdollisuutta työasennon vaihteluun käyttää vain vajaa puolet tutkittavista. Kuitenkin säännölliset seisomaan nousut lisäävät lihasten aktiivisuutta, energiankulutusta ja rasvan käyttöä energiaksi ja tuovat sen kautta terveyshyötyjä.

REFERENCES

Akihiko, S., Kakehashi, M., Tsuru, S. & Yoshinaga, F. 1996. Leg swelling during continuous standing and sitting work without restricting leg movement. Journal of Occupational Health 38 (4), 186-189.

Alkhajah, T. A., Reeves, M. M., Eakin, E. G., Winkler, E. A., Owen, N. & Healy, G. N. 2012. Sit–stand workstations: A pilot intervention to reduce office sitting time. American Journal of Preventive Medicine 43 (3), 298-303.

Andersen, J. H., Haahr, J. P. & Frost, P. 2007. Risk factors for more severe regional musculoskeletal symptoms: A two-year prospective study of a general working population. Arthritis & Rheumatism 56 (4), 1355-1364.

Atkin, A. J., Gorely, T., Clemes, S. A., Yates, T., Edwardson, C., Brage, S., Salmon, J., Marshall, S. J. & Biddle, S. J. 2012. Methods of measurement in epidemiology: Sedentary behaviour. International Journal of Epidemiology 41 (5), 1460-1471.

Bailey, D. P. & Locke, C. D. 2015. Breaking up prolonged sitting with light-intensity walking improves postprandial glycemia, but breaking up sitting with standing does not. Journal of Science and Medicine in Sport 18 (3), 294-298.

Bakker, E. W., Verhagen, A. P., van Trijffel, E., Lucas, C. & Koes, B. W. 2009. Spinal mechanical load as a risk factor for low back pain: A systematic review of prospective cohort studies. Spine 34 (8), E281-E293.

Balci, R. & Aghazadeh, F. 2004. Effects of exercise breaks on performance, muscular load, and perceived discomfort in data entry and cognitive tasks. Computers & Industrial Engineering 46 (3), 399-411.

Baranowski, T., Masse, L. C., Ragan, B. & Welk, G. 2008. How many days was that? We're still not sure, but we're asking the question better! Medicine and Science in Sports and Exercise 40 (7 Suppl), S544-S549.

Barbieri, D. F., Srinivasan, D., Mathiassen, S. E. & Oliveira, A. B. 2017. Comparison of sedentary behaviors in office workers using sit-stand tables with and without semiautomated position changes. Human factors , In press.

Barker, R. G. 1968. Ecological psychology. Stanford University Press Stanford, CA 7, 289-290.

Beebe-Dimmer, J. L., Pfeifer, J. R., Engle, J. S. & Schottenfeld, D. 2005. The epidemiology of chronic venous insufficiency and varicose veins. Annals of Epidemiology 15 (3), 175-184.

Beers, E. A., Roemmich, J. N., Epstein, L. H. & Horvath, P. J. 2008. Increasing passive energy expenditure during clerical work. European Journal of Applied Physiology 103 (3), 353-360.

Benatti, F. B. & Ried-Larsen, M. 2015. The effects of breaking up prolonged sitting time: A review of experimental studies. Medicine and Science in Sports and Exercise 47 (10), 2053-2061.

Bengs, D., Jeglinsky, I., Surakka, J., Hellsten, T., Ring, J. & Kettunen, J. 2017. Reliability of Measuring Lower-Limb Muscle EMG Activity Ratio in

Activities of Daily Living With Electrodes Embedded in the Clothing. Journal of Sport Rehabilitation , In press.

Bennie, J. A., Pedisic, Z., Timperio, A., Crawford, D., Dunstan, D., Bauman, A., van Uffelen, J. & Salmon, J. 2015. Total and domain-specific sitting time among employees in desk-based work settings in Australia. Australian and New Zealand Journal of Public Health 39 (3), 237-242.

Bergouignan, A., Latouche, C., Heywood, S., Grace, M. S., Reddy-Luthmoodoo, M., Natoli, A. K., Owen, N., Dunstan, D. W. & Kingwell, B. A. 2016. Frequent interruptions of sedentary time modulates contraction- and insulin-stimulated glucose uptake pathways in muscle: Ancillary analysis from randomized clinical trials. Scientific Reports 6, 32044.

Bergouignan, A., Momken, I., Lefai, E., Antoun, E., Schoeller, D. A., Platat, C., Chery, I., Zahariev, A., Vidal, H., Gabert, L., Normand, S., Freyssenet, D., Laville, M., Simon, C. & Blanc, S. 2013. Activity energy expenditure is a major determinant of dietary fat oxidation and trafficking, but the deleterious effect of detraining is more marked than the beneficial effect of training at current recommendations. American Journal of Clinical Nutrition 98 (3), 648-658.

Bergouignan, A., Rudwill, F., Simon, C. & Blanc, S. 2011. Physical inactivity as the culprit of metabolic inflexibility: Evidence from bed-rest studies. Journal of Applied Physiology 111 (4), 1201-1210.

Bernard, B. P. 1997. Musculoskeletal disorders and workplace factors: A critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back. U.S. Department of Health And Human Services (NIOSH) Publication No. 97B141.

Bey, L. & Hamilton, M. T. 2003. Suppression of skeletal muscle lipoprotein lipase activity during physical inactivity: a molecular reason to maintain daily low-intensity activity. The Journal of Physiology 551 (2), 673-682.

Beynon, C. & Reilly, T. 2001. Spinal shrinkage during a seated break and standing break during simulated nursing tasks. Applied Ergonomics 32 (6), 617-622.

Biswas, A., Oh, P. I., Faulkner, G. E., Bajaj, R. R., Silver, M. A., Mitchell, M. S. & Alter, D. A. 2015. Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults: A systematic review and meta-analysis. Annals of Internal Medicine 162 (2), 123-132.

Bland, J. M. & Altman, D. 1986. Statistical methods for assessing agreement between two methods of clinical measurement. The Lancet 327 (8476), 307-310.

Blankenship, J. M., Granados, K. & Braun, B. 2014. Effects of subtracting sitting versus adding exercise on glycemic control and variability in sedentary office workers. Applied Physiology, Nutrition, and Metabolism 39 (11), 1286-1293.

Booth, F. W., Roberts, C. K. & Laye, M. J. 2012. Lack of exercise is a major cause of chronic diseases. Comprehensive Physiology 2 (2), 1143-1211.

Bosch, T., De Looze, M. & Van Dieën, J. 2007. Development of fatigue and discomfort in the upper trapezius muscle during light manual work. Ergonomics 50 (2), 161-177.

Buckley, J. P., Mellor, D. D., Morris, M. & Joseph, F. 2014. Standing-based office work shows encouraging signs of attenuating post-prandial glycaemic excursion. Occupational and Environmental Medicine 71 (2), 109-111.

Callaghan, J. P., De Carvalho, D., Gallagher, K., Karakolis, T. & Nelson-Wong, E. 2015. Is standing the solution to sedentary office work? Ergonomics in Design 23 (3), 20-24.

Castillo-Retamal, M. & Hinckson, E. A. 2011. Measuring physical activity and sedentary behaviour at work: A review. Work: A Journal of Prevention, Assessment and Rehabilitation 40 (4), 345-357.

Centers for Disease Control and Prevention 2001. Behavioral risk factor surveillance system survey questionnaire. Atlanta, Georgia: US Department of Health and Human Services, Centers for Disease Control and Prevention , 22-23.

Chastin, S. F., Egerton, T., Leask, C. & Stamatakis, E. 2015. Meta-analysis of the relationship between breaks in sedentary behavior and cardiometabolic health. Obesity 23 (9), 1800-1810.

Chastin, S. & Granat, M. 2010. Methods for objective measure, quantification and analysis of sedentary behaviour and inactivity. Gait & Posture 31 (1), 82-86.

Chau, J. Y., Daley, M., Srinivasan, A., Dunn, S., Bauman, A. E. & van der Ploeg, Hidde P 2014a. Desk-based workers' perspectives on using sit-stand workstations: A qualitative analysis of the Stand@ Work study. BMC Public Health 14, 752.

Chau, J. Y., der Ploeg, Hidde P van, van Uffelen, J. G., Wong, J., Riphagen, I., Healy, G. N., Gilson, N. D., Dunstan, D. W., Bauman, A. E. & Owen, N. 2010. Are workplace interventions to reduce sitting effective? A systematic review. Preventive medicine 51 (5), 352-356.

Chau, J. Y., Grunseit, A. C., Chey, T., Stamatakis, E., Brown, W. J., Matthews, C. E., Bauman, A. E. & van der Ploeg, Hidde P 2013. Daily sitting time and all-cause mortality: A meta-analysis. PLoS ONE 8 (11), e80000.

Chau, J. Y., Daley, M., Dunn, S., Srinivasan, A., Do, A., Bauman, A. E. & Van Der Ploeg, H. P. 2014b. The effectiveness of sit-stand workstations for changing office workers' sitting time: Results from the Stand@Work randomized controlled trial pilot. The International Journal of Behavioral Nutrition and Physical Activity 11, 127.

Chau, J. Y., van der Ploeg, H. P., Dunn, S., Kurko, J. & Bauman, a. E. 2011. A tool for measuring workers' sitting time by domain: the Workforce Sitting Questionnaire. British Journal of Sports Medicine 45 (15), 1216-1222.

Chau, J. Y., Van Der Ploeg Hidde P., Dunn, S., Kurko, J. & Bauman, A. E. 2012. Validity of the occupational sitting and physical activity questionnaire. Medicine and Science in Sports and Exercise 44 (1), 118-125.

Chen, K. Y. & Bassett, D. R. 2005. The technology of accelerometry-based activity monitors: Current and future. Medicine and Science in Sports and Exercise 37 (11), S490-S500.

Chester, M. R., Rys, M. J. & Konz, S. A. 2002. Leg swelling, comfort and fatigue when sitting, standing, and sit/standing. International Journal of Industrial Ergonomics 29 (5), 289-296.

Chu, A. H. Y., Ng, S. H. X., Tan, C. S., Win, A. M., Koh, D. & Müller-Riemenschneider, F. 2016. A systematic review and meta-analysis of workplace intervention strategies to reduce sedentary time in white-collar workers. Obesity Reviews 17 (5), 467-481.

Clark, B. K., Sugiyama, T., Healy, G. N., Salmon, J., Dunstan, D. W. & Owen, N. 2009. Validity and reliability of measures of television viewing time and other non-occupational sedentary behaviour of adults: A review. Obesity Reviews 10 (1), 7-16.

Clark, B. K., Thorp, A. A., A.H. Winkler Elisabeth, Gardiner, P. A., Healy, G. N., Owen, N. & Dunstan, D. W. 2011. Validity of self-reported measures of workplace sitting time and breaks in sitting time. Medicine and Science in Sports and Exercise 43 (10), 1907-1912.

Claus, A., Hides, J., Moseley, G. L. & Hodges, P. 2008. Sitting versus standing: Does the intradiscal pressure cause disc degeneration or low back pain? Journal of Electromyography and Kinesiology 18 (4), 550-558.

Cleland, C. L., Hunter, R. F., Kee, F., Cupples, M. E., Sallis, J. F. & Tully, M. A. 2014. Validity of the Global Physical Activity Questionnaire (GPAQ) in assessing levels and change in moderate-vigorous physical activity and sedentary behaviour. BMC Public Health 14, 1255.

Clemes, S. A., O'Connell, S. E. & Edwardson, C. L. 2014. Office workers' objectively measured sedentary behavior and physical activity during and outside working hours. Journal of Occupational and Environmental Medicine 56 (3), 298-303.

Clemes, S. A., Patel, R., Mahon, C. & Griffiths, P. L. 2014. Sitting time and step counts in office workers. Occupational Medicine 64 (3), 188-192.

Coenen, P., Kingma, I., Boot, C. R., Twisk, J. W., Bongers, P. M. & van Dieën, J. H. 2013. Cumulative low back load at work as a risk factor of low back pain: A prospective cohort study. Journal of Occupational Rehabilitation 23 (1), 11-18.

Commissaris, D., Douwes, M., Schoenmaker, N. & de Korte, E. 2006. Recommendations for sufficient physical activity at work. Proc. Congress (IEA 2006).

Conn, V. S., Hafdahl, A. R., Cooper, P. S., Brown, L. M. & Lusk, S. L. 2009. Meta-analysis of workplace physical activity interventions. American Journal of Preventive Medicine 37 (4), 330-339.

Corlett, E. 2006. Background to sitting at work: Research-based requirements for the design of work seats. Ergonomics 49 (14), 1538-1546.

Corlett, E., Eklund, J., Reilly, T. & Troup, J. 1987. Assessment of workload from measurements of stature. Applied Ergonomics 18 (1), 65-71.

Cox, R. H., Guth, J., Siekemeyer, L., Kellems, B., Brehm, S. B. & Ohlinger, C. M. 2011. Metabolic cost and speech quality while using an active workstation. Journal of Physical Activity and Health 8 (3), 332-339.

Craig, C. L., Marshall, A. L., Sjöström, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., Pratt, M., Ekelund, U., Yngve, A., Sallis, J. F. & Oja, P. 2003. International physical activity questionnaire: 12-country reliability and validity. Medicine and Science in Sports and Exercise 35 (8), 1381-1395.

Da Costa, B. R. & Vieira, E. R. 2010. Risk factors for work-related musculoskeletal disorders: A systematic review of recent longitudinal studies. American Journal of Industrial Medicine 53 (3), 285-323.

De Cocker, K., Duncan, M. J., Short, C., van Uffelen, J. G. & Vandelanotte, C. 2014. Understanding occupational sitting: Prevalence, correlates and moderating effects in Australian employees. Preventive Medicine 67, 288-294.

DeFronzo, R., Jacot, E. & Jequier, E. 1981. The effect of insulin on the disposal of intravenous glucose: results from indirect calorimetry and hepatic and femoral venous catheterization. Diabetes 30 (12), 1000-1007.

Drury, C., Hsiao, Y., Joseph, C., Joshi, S., Lapp, J. & Pennathur, P. 2008. Posture and performance: sitting vs. standing for security screening. Ergonomics 51 (3), 290-307.

Dunstan, D. W., Kingwell, B. A., Larsen, R., Healy, G. N., Cerin, E., Hamilton, M. T., Shaw, J. E., Bertovic, D. A., Zimmet, P. Z. & Salmon, J. 2012. Breaking up prolonged sitting reduces postprandial glucose and insulin responses. Diabetes Care 35 (5), 976-983.

Dunstan, D. W., Zimmet, P. Z., Welborn, T. A., de Courten, M. P., Cameron, A. J., Sicree, R. A., Dwyer, T., Colagiuri, S., Jolley, D., Knuiman, M., Atkins, R. & Shaw, J. E. 2002. The Rising prevalence of diabetes and impaired glucose tolerance: the Australian diabetes, obesity and lifestyle study. Diabetes Care 25 (5), 829-834.

Dutta, N., Koepp, G. A., Stovitz, S. D., Levine, J. A. & Pereira, M. A. 2014. Using sit-stand workstations to decrease sedentary time in office workers: A randomized crossover trial. International Journal of Environmental Research and Public Health 11 (7), 6653-6665.

Duvivier, B. M., Schaper, N. C., Bremers, M. A., van Crombrugge, G., Menheere, P. P., Kars, M. & Savelberg, H. H. 2013. Minimal intensity physical activity (standing and walking) of longer duration improves insulin action and plasma lipids more than shorter periods of moderate to vigorous exercise (cycling) in sedentary subjects when energy expenditure is comparable. PloS one 8 (2), e55542.

Ebara, T., Kubo, T., Inoue, T., Murasaki, G., Takeyama, H., Sato, T., Suzumura, H., Niwa, S., Takanishi, T. & Tachi, N. 2008. Effects of adjustable sit-stand VDT workstations on workers' musculoskeletal discomfort, alertness and performance. Industrial Health 46 (5), 497-505.

Edwardson, C. L., Rowlands, A. V., Bunnewell, S., Sanders, J., Esliger, D. W., Gorely, T., O'Connell, S., Davies, M., Khunti, K. & Yates, T. 2016a. Accuracy of posture allocation algorithms for thigh- and waist-worn accelerometers. Medicine and Science in Sports and Exercise 48 (6), 1085-1090.

Edwardson, C. L., Winkler, E. A. H., Bodicoat, D. H., Yates, T., Davies, M. J., Dunstan, D. W. & Healy, G. N. 2016b. Considerations when using the activPAL monitor in field based research with adult populations. Journal of Sport and Health Science , In press.

Ekelund, U., Steene-Johannessen, J., Brown, W. J., Fagerland, M. W., Owen, N., Powell, K. E., Bauman, A., Lee, I., Series, L. P. A. & Lancet Sedentary Behaviour Working Group 2016. Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonised meta-analysis of data from more than 1 million men and women. The Lancet 388 (10051), 1302-1310.

Eklund, J. A. & Corlett, E. N. 1984. Shrinkage as a measure of the effect of load on the spine. Spine 9 (2), 189-194.

Ellegast, R. P., Kraft, K., Groenesteijn, L., Krause, F., Berger, H. & Vink, P. 2012. Comparison of four specific dynamic office chairs with a conventional office chair: Impact upon muscle activation, physical activity and posture. Applied Ergonomics 43 (2), 296-307.

Finni, T., Haakana, P., Pesola, A. & Pullinen, T. 2014. Exercise for fitness does not decrease the muscular inactivity time during normal daily life. Scandinavian Journal of Medicine & Science in Sports 24 (1), 211-219.

Finni, T., Hu, M., Kettunen, P., Vilavuo, T. & Cheng, S. 2007. Measurement of EMG activity with textile electrodes embedded into clothing. Physiological Measurement 28 (11), 1405-1419.

Fishman, E. I., Steeves, J. A., Zipunnikov, V., Koster, A., Berrigan, D., Harris, T. A. & Murphy, R. 2016. Association between objectively measured physical activity and mortality in NHANES. Medicine and Science in Sports and Exercise 48 (7), 1303-1311.

Fitts, R. H., Riley, D. R. & Widrick, J. J. 2000. Physiology of a microgravity environment invited review: Microgravity and skeletal muscle. Journal of Applied Physiology 89 (2), 823-839.

Freedson, P. S., Melanson, E. & Sirard, J. 1998. Calibration of the Computer Science and Applications, Inc. accelerometer. Medicine and Science in Sports and Exercise 30 (5), 777-781.

Gallagher, K. M., Campbell, T. & Callaghan, J. P. 2014. The influence of a seated break on prolonged standing induced low back pain development. Ergonomics 57 (4), 555-562.

Gardner, B., Smith, L., Lorencatto, F., Hamer, M. & Biddle, S. J. 2016. How to reduce sitting time? A review of behaviour change strategies used in sedentary behaviour reduction interventions among adults. Health Psychology Review 10 (1), 89-112.

Gibbs, B. B., Hergenroeder, A. L., Katzmarzyk, P. T., Lee, I. M. & Jakicic, J. M. 2015. Definition, measurement, and health risks associated with sedentary behavior. Medicine and Science in Sports and Exercise 47 (6), 1295-1300.

Gilson, N. D., Suppini, A., Ryde, G. C., Brown, H. E. & Brown, W. J. 2012. Does the use of standing 'hot' desks change sedentary work time in an open plan office? Preventive Medicine 54 (1), 65-67.

Godfrey, A., Conway, R., Meagher, D. & ÓLaighin, G. 2008. Direct measurement of human movement by accelerometry. Medical Engineering & Physics 30 (10), 1364-1386.

Gonzalez, H. E. & Manns, A. 1996. Forward head posture: Its structural and functional influence on the stomatognathic system, a conceptual study. The Journal of Craniomandibular & Sleep Practice 14 (1), 71-80.

Grant, P. M., Ryan, C. G., Tigbe, W. W. & Granat, M. H. 2006. The validation of a novel activity monitor in the measurement of posture and motion during everyday activities. British Journal of Sports Medicine 40 (12), 992-997.

Green, R. A. & Briggs, C. A. 1989. Effect of overuse injury and the importance of training on the use of adjustable workstations by keyboard operators. Journal of Occupational and Environmental Medicine 31 (6), 557-562.

Grondin, D. E., Triano, J. J., Tran, S. & Soave, D. 2013. The effect of a lumbar support pillow on lumbar posture and comfort during a prolonged seated task. Chiropractic & Manual Therapies 21 (1), 21.

Grunseit, A. C., Chau, J. Y., Van der Ploeg, Hidde Pieter & Bauman, A. 2013. “Thinking on your feet”: A qualitative evaluation of sit-stand desks in an Australian workplace. BMC public health 13 (1), 1-10.

Hägg, G. 1991. Static work loads and occupational myalgia—a new explanation model. Electromyographical Kinesiology 9, 141-144.

Hamilton, M. T., Hamilton, D. G. & Zderic, T. W. 2007. Role of low energy expenditure and sitting in obesity, metabolic syndrome, type 2 diabetes, and cardiovascular disease. Diabetes 56 (11), 2655-2667.

Hamilton, M. T., Hamilton, D. G. & Zderic, T. W. 2004. Exercise physiology versus inactivity physiology: An essential concept for understanding lipoprotein lipase regulation. Exercise and Sport Sciences Reviews 32 (4), 161-166.

Hamilton, M. T., Healy, G. N., Dunstan, D. W., Zderic, T. W. & Owen, N. 2008. Too little exercise and too much sitting: Inactivity physiology and the need for new recommendations on sedentary behavior. Current Cardiovascular Risk Reports 2 (4), 292-298.

Hansen, R. K., Andersen, J. B., Vinther, A. S., Pielmeier, U. & Larsen, R. G. 2016. Breaking up prolonged sitting does not alter postprandial glycemia in young, normal-weight men and women. International Journal of Sports Medicine 37 (14), 1097-1102.

Harrison, D. D., Harrison, S. O., Croft, A. C., Harrison, D. E. & Troyanovich, S. J. 1999. Sitting biomechanics part I: Review of the literature. Journal of Manipulative and Physiological Therapeutics 22 (9), 594-609.

Hasegawa, T., Inoue, K., Tsutsue, O. & Kumashiro, M. 2001. Effects of a sit–stand schedule on a light repetitive task. International Journal of Industrial Ergonomics 28 (3), 219-224.

Haskell, W. L., Lee, I., Pate, R. R., Powell, K. E., Blair, S. N., Franklin, B. A., Macera, C. A., Heath, G. W., Thompson, P. D. & Bauman, A. 2007. Physical activity and public health: Updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. Circulation 116 (9), 1081-1093.

Healey, E., Fowler, N., Burden, A. & McEwan, I. M. 2005. Repeatability of stature measurements in individuals with and without chronic low-back pain. Ergonomics 48 (11-14), 1613-1622.

Healy, G. N., Dunstan, D. W., Salmon, J., Cerin, E., Shaw, J. E., Zimmet, P. Z. & Owen, N. 2008. Breaks in sedentary time beneficial associations with metabolic risk. Diabetes Care 31 (4), 661-666.

Healy, G., Lawler, S., Thorp, A., Neuhaus, M., Robson, E., Owen, N. & Dunstan, D. 2012. Reducing prolonged sitting in the workplace (An evidence review: full report). Victorian Health Promotion Foundation .

Healy, G. N., Winkler, E. A., Owen, N., Anuradha, S. & Dunstan, D. W. 2015. Replacing sitting time with standing or stepping: Associations with cardio-metabolic risk biomarkers. European Heart Journal 36 (39), 2643-2649.

Healy, G. N., Clark, B. K., Winkler, E. A. H., Gardiner, P. A., Brown, W. J. & Matthews, C. E. 2011. Measurement of adults' sedentary time in population-based studies. American Journal of Preventive Medicine 41 (2), 216-227.

Healy, G. N., Eakin, E. G., LaMontagne, A. D., Owen, N., Winkler, E. A. H., Wiesner, G., Gunning, L., Neuhaus, M., Lawler, S., Fjeldsoe, B. S. & Dunstan, D. W. 2013. Reducing sitting time in office workers: Short-term efficacy of a multicomponent intervention. Preventive Medicine 57 (1), 43-48.

Hedge, A. & Ray, E. J. 2004. Effects of an electronic height-adjustable worksurface on computer worker musculoskeletal discomfort and productivity. Proceedings of the Human Factors and Ergonomics Society Annual Meeting. SAGE Publications Sage CA: Los Angeles, CA, 1091.

Helander, M. & Quance, L. 1990. Effect of work—rest schedules on spinal shrinkage in the sedentary worker. Applied Ergonomics 21 (4), 279-284.

Henneman, E., Somjen, G. & Carpenter, D. O. 1965. Functional significance of cell size in spinal motoneurons. J neurophysiol 28 (3), 560-580.

Henson, J., Davies, M. J., Bodicoat, D. H., Edwardson, C. L., Gill, J. M. R., Stensel, D. J., Tolfrey, K., Dunstan, D. W., Khunti, K. & Yates, T. 2016. Breaking up prolonged sitting With standing or walking attenuates the postprandial metabolic response in postmenopausal women: A randomized acute study. Diabetes Care 39 (1), 130-138.

Hermens, H. J., Freriks, B., Disselhorst-Klug, C. & Rau, G. 2000. Development of recommendations for SEMG sensors and sensor placement procedures. Journal of Electromyography and Kinesiology 10 (5), 361-374.

Husemann, B., Von Mach, C. Y., Borsotto, D., Zepf, K. I. & Scharnbacher, J. 2009. Comparisons of musculoskeletal complaints and data entry between a sitting and a sit-stand workstation paradigm. Human Factors: The Journal of the Human Factors and Ergonomics Society 51 (3), 310-320.

Igic, I., Ryser, S. & Elfering, A. 2013. Does work stress make you shorter? An ambulatory field study of daily work stressors, job control, and spinal shrinkage. Journal of Occupational Health Psychology 18 (4), 469-480.

Ismaila, S. & Charles-Owaba, O. 2008. Determination of the highest permissible spinal shrinkage. Australian Journal of Basic and Applied Sciences 2 (4), 872-875.

Jawien, A. 2003. The influence of environmental factors in chronic venous insufficiency. Angiology 54 (1 Suppl), S19-S31.

Júdice, P. B., Hamilton, M. T., Sardinha, L. B., Zderic, T. W. & Silva, A. M. 2016. What is the metabolic and energy cost of sitting, standing and sit/stand transitions? European Journal of Applied Physiology 116 (2), 263-273.

Karakolis, T. & Callaghan, J. P. 2014. The impact of sit–stand office workstations on worker discomfort and productivity: A review. Applied Ergonomics 45 (3), 799-806.

Katzmarzyk, P. T. 2014. Standing and mortality in a prospective cohort of Canadian adults. Medicine and Science in Sports and Exercise 46 (5), 940-946.

Keadle, S. K., Conroy, D. E., Buman, M. P., Dunstan, D. W. & Matthews, C. E. 2017. Targeting reductions in sitting time to increase physical activity and improve health. Medicine and Science in Sports and Exercise , In press.

Kerr, M. S., Frank, J. W., Shannon, H. S., Norman, R. W., Wells, R. P., Neumann, W. P., Bombardier, C. & Ontario Universities Back Pain Study Group 2001. Biomechanical and psychosocial risk factors for low back pain at work. American Journal of Public Health 91 (7), 1069-1075.

Kilbom, A., Persson, J. & Jonsson, B. 1986. Risk factors for work-related disorders of the neck and shoulder-with special emphasis on working postures and movements. The Ergonomics of Working Postures 1, 44-53.

Klein, C. S., Peterson, L. B., Ferrell, S. & Thomas, C. K. 2010. Sensitivity of 24-h EMG duration and intensity in the human vastus lateralis muscle to threshold changes. Journal of Applied Physiology 108 (3), 655-661.

Koohsari, M. J., Sugiyama, T., Sahlqvist, S., Mavoa, S., Hadgraft, N. & Owen, N. 2015. Neighborhood environmental attributes and adults' sedentary behaviors: Review and research agenda. Preventive Medicine 77, 141-149.

Kozey-Keadle, S., Libertine, A., Lyden, K., Staudenmayer, J. & Freedson, P. S. 2011. Validation of wearable monitors for assessing sedentary behavior. Medicine and Science in Sports and Exercise 43 (8), 1561-1567.

Kumar, S. 1990. Cumulative load as a risk factor for back pain. Spine 15 (12), 1311-1316.

Kwon, B. K., Roffey, D. M., Bishop, P. B., Dagenais, S. & Wai, E. K. 2011. Systematic review: Occupational physical activity and low back pain. Occupational Medicine 61 (8), 541-548.

Laperrière, E., Messing, K., Couture, V. & Stock, S. 2005. Validation of questions on working posture among those who stand during most of the work day. International Journal of Industrial Ergonomics 35 (4), 371-378.

Larsson, B., Søgaard, K. & Rosendal, L. 2007. Work related neck–shoulder pain: A review on magnitude, risk factors, biochemical characteristics, clinical picture and preventive interventions. Best Practice & Research Clinical Rheumatology 21 (3), 447-463.

Lee, J., Kuk, J. L. & Ardern, C. I. 2016. The relationship between changes in sitting time and mortality in post-menopausal US women. Journal of Public Health 38 (2), 270-278.

Lee, S. J. & Hidler, J. 2008. Biomechanics of overground vs. treadmill walking in healthy individuals. Journal of Applied Physiology 104 (3), 747-755.

Leivseth, G. & Drerup, B. 1997. Spinal shrinkage during work in a sitting posture compared to work in a standing posture. Clinical Biomechanics 12 (7), 409-418.

Levine, J. A. & Miller, J. M. 2007. The energy expenditure of using a "walk-and-work" desk for office workers with obesity. British Journal of Sports Medicine 41 (9), 558-561.

Levine, J. A., McCrady, S. K., Lanningham-Foster, L. M., Kane, P. H., Foster, R. C. & Manohar, C. U. 2008. The role of free-living daily walking in human weight gain and obesity. Diabetes 57 (3), 548-554.

Lin, Y., Chen, C. & Cho, M. 2012. Effectiveness of leg movement in reducing leg swelling and discomfort in lower extremities. Applied Ergonomics 43 (6), 1033-1037.

Lyden, K., Kozey Keadle, S. L., Staudenmayer, J. W. & Freedson, P. S. 2012. Validity of two wearable monitors to estimate breaks from sedentary time. Medicine and Science in Sports and Exercise 44 (11), 2243-2252.

MacEwen, B. T., MacDonald, D. J. & Burr, J. F. 2015. A systematic review of standing and treadmill desks in the workplace. Preventive Medicine 70, 50-58.

Madeleine, P. 2010. On functional motor adaptations: from the quantification of motor strategies to the prevention of musculoskeletal disorders in the neck-shoulder region. Acta Physiologica 199, 1-46.

Magnusson, M. & Pope, M. 1998. A review of the biomechanics and epidemiology of working postures (it isn't always vibration which is to blame!). Journal of Sound and Vibration 215 (4), 965-976.

Manchikanti, L. 2000. Epidemiology of low back pain. Pain Physician 3 (2), 167-192.

Mansoubi, M., Pearson, N., Clemes, S. A., Biddle, S. J., Bodicoat, D. H., Tolfrey, K., Edwardson, C. L. & Yates, T. 2015. Energy expenditure during common sitting and standing tasks: Examining the 1.5 MET definition of sedentary behaviour. BMC Public Health 15 (1), 516.

Marshall, S. J. & Ramirez, E. 2011. Reducing sedentary behavior: A new paradigm in physical activity promotion. American Journal of Lifestyle Medicine 5 (6), 518-530.

Marshall, P. W. M., Patel, H. & Callaghan, J. P. 2011. Gluteus medius strength, endurance, and co-activation in the development of low back pain during prolonged standing. Human Movement Science 30 (1), 63-73.

Martin, A., Fitzsimons, C., Jepson, R., Saunders, D. H., van der Ploeg, H. P., Teixeira, P. J., Gray, C. M., Mutrie, N. & EuroFIT consortium 2015. Interventions with potential to reduce sedentary time in adults: Systematic review and meta-analysis. British Journal of Sports Medicine 49 (16), 1056-1063.

Matthews, C. E., Chen, K. Y., Freedson, P. S., Buchowski, M. S., Beech, B. M., Pate, R. R. & Troiano, R. P. 2008. Amount of time spent in sedentary behaviors in the United States, 2003-2004. American Journal of Epidemiology 167 (7), 875-881.

Matthews, C. E., Hagstromer, M., Pober, D. M. & Bowles, H. R. 2012a. Best practices for using physical activity monitors in population-based research. Medicine and Science in Sports and Exercise 44 (1 Suppl), S68-S76.

Matthews, C. E., Keadle, S. K., Troiano, R. P., Kahle, L., Koster, A., Brychta, R., Van Domelen, D., Caserotti, P., Chen, K. Y., Harris, T. B. & Berrigan, D. 2016. Accelerometer-measured dose-response for physical activity, sedentary time, and mortality in US adults. The American Journal of Clinical Nutrition 104 (5), 1424-1432.

Matthews, C. E., Moore, S. C., Sampson, J., Blair, A., Xiao, Q., Keadle, S. K., Hollenbeck, A. & Park, Y. 2015. Mortality benefits for replacing sitting time with different physical activities. Medicine and Science in Sports and Exercise 47 (9), 1833-1840.

Matthews, C. E., Keadle, S. K., Sampson, J., Lyden, K., Bowles, H. R., Moore, S. C., Libertine, A., Freedson, P. S. & Fowke, J. H. 2013. Validation of a previous-day recall measure of active and sedentary behaviors. Medicine and Science in Sports and Exercise 45 (8), 1629-1638.

Matthews, C. E., Moore, S. C., George, S. M., Sampson, J. & Bowles, H. R. 2012b. Improving self-reports of active and sedentary behaviors in large epidemiologic studies. Exercise and Sport Sciences Reviews 40 (3), 118-126.

McAlpine, D. A., Manohar, C. U., McCrady, S. K., Hensrud, D. & Levine, J. A. 2007. An office-place stepping device to promote workplace physical activity. British Journal of Sports Medicine 41 (12), 903-907.

McArdle, W. D., Katch, F. I. & Katch, V. L. 2010. Exercise Physiology: Nutrition, Energy, and Human Performance. Lippincott Williams & Wilkins.

McGill, S. M., Hughson, R. L. & Parks, K. 2000. Lumbar erector spinae oxygenation during prolonged contractions: Implications for prolonged work. Ergonomics 43 (4), 486-493.

Mekary, R. A., Lucas, M., Pan, A., Okereke, O. I., Willett, W. C., Hu, F. B. & Ding, E. L. 2013. Isotemporal substitution analysis for physical activity, television watching, and risk of depression. American Journal of Epidemiology 178 (3), 474-483.

Miyashita, M., Park, J. H., Takahashi, M., Suzuki, K., Stensel, D. & Nakamura, Y. 2013. Postprandial lipaemia: Effects of sitting, standing and walking in healthy normolipidaemic humans. International Journal of Sports Medicine 34 (1), 21-27.

Mortimer, M., Hjelm, E. W., Wiktorin, C., Pernold, G., Lbom, Å & Vingård, E. 1999. Validity of self-reported duration of work postures obtained by interview. Applied Ergonomics 30 (6), 477-486.

Nelson-Wong, E. & Callaghan, J. P. 2010. Is muscle co-activation a predisposing factor for low back pain development during standing? A multifactorial approach for early identification of at-risk individuals. Journal of Electromyography and Kinesiology 20 (2), 256-263.

Neuhaus, M., Eakin, E., Straker, L., Owen, N., Dunstan, D., Reid, N. & Healy, G. 2014a. Reducing occupational sedentary time: A systematic review and meta-analysis of evidence on activity-permissive workstations. Obesity Reviews 15 (10), 822-838.

Neuhaus, M., Healy, G. N., Dunstan, D. W., Owen, N. & Eakin, E. G. 2014b. Workplace Sitting and Height-Adjustable Workstations: A Randomized Controlled Trial. American Journal of Preventive Medicine 46 (1), 30-40.

Nevala, N. & Choi, D. 2013. Ergonomic comparison of a sit-stand workstation with a traditional workstation in visual display unit work. The Ergonomics Open Journal 6 (1), 22-27.

Noddeland, H. & Winkel, J. 1988. Effects of leg activity and ambient barometric pressure on foot swelling and lower-limb skin temperature during 8 h of sitting. European Journal of Applied Physiology and Occupational Physiology 57 (4), 409-414.

Norton, K., Norton, L. & Sadgrove, D. 2010. Position statement on physical activity and exercise intensity terminology. Journal of Science and Medicine in Sport 13 (5), 496-502.

Owen, N. 2012. Sedentary behavior: Understanding and influencing adults' prolonged sitting time. Preventive Medicine 55 (6), 535-539.

Owen, N., Healy, G. N., Matthews, C. E. & Dunstan, D. W. 2010. Too much sitting: The population-health science of sedentary behavior. Exercise and Sport Sciences Reviews 38 (3), 105-113.

Owen, N., Sugiyama, T., Eakin, E. E., Gardiner, P. A., Tremblay, M. S. & Sallis, J. F. 2011. Adults' sedentary behavior: Determinants and interventions. American Journal of Preventive Medicine 41 (2), 189-196.

Parry, S. & Straker, L. 2013. The contribution of office work to sedentary behaviour associated risk. BMC Public Health 13, 296.

Pate, R. R., O'Neill, J. R. & Lobelo, F. 2008. The evolving definition of "sedentary". Exercise and Sport Sciences Reviews 36 (4), 173-178.

Paul, R. D. & Helander, M. G. 1995. Effect of sit-stand schedule on spinal shrinkage in VDT operators. Proceedings of the Human Factors and Ergonomics Society Annual Meeting. SAGE Publications, 563.

Pesola, A. 2016. Reduced muscle inactivity, sedentary time and cardio-metabolic benefits: Effectiveness of a one-year family-based cluster randomized controlled trial. University of Jyväskylä. Studies in Sport, Physical Education and Health 252.

Pesola, A. J., Laukkanen, A., Haakana, P., Havu, M., Saakslahti, A., Sipila, S. & Finni, T. 2014. Muscle inactivity and activity patterns after sedentary time-targeted randomized controlled trial. Medicine and Science in Sports and Exercise 46 (11), 2122-2131.

Pesola, A. J., Laukkanen, A., Tikkanen, O., Sipila, S., Kainulainen, H. & Finni, T. 2015. Muscle inactivity is adversely associated with biomarkers in physically active adults. Medicine and Science in Sports and Exercise 47 (6), 1188-1196.

Pesola, A. J., Laukkanen, A., Tikkanen, O. & Finni, T. 2016. Heterogeneity of muscle activity during sedentary behavior. Applied Physiology, Nutrition, and Metabolism 41 (11), 1155-1162.

Pett, M. A. 1997. Nonparametric statistics for health care research: Statistics for small samples and unusual distributions.

Pope, M. H., Goh, K. L. & Magnusson, M. L. 2002. Spine ergonomics. Annual Review of Biomedical Engineering 4 (1), 49-68.

Powell, K. E., Paluch, A. E. & Blair, S. N. 2011. Physical activity for health: What kind? How much? How intense? On top of what? Annual Review of Public Health 32, 349-365.

Price, D. D., McGrath, P. A., Rafii, A. & Buckingham, B. 1983. The validation of visual analogue scales as ratio scale measures for chronic and experimental pain. Pain 17 (1), 45-56.

Prince, S., Saunders, T., Gresty, K. & Reid, R. 2014. A comparison of the effectiveness of physical activity and sedentary behaviour interventions in reducing sedentary time in adults: A systematic review and meta-analysis of controlled trials. Obesity Reviews 15 (11), 905-919.

Pronk, N. P., Katz, A. S., Lowry, M. & Payfer, J. R. 2012. Reducing occupational sitting time and improving worker health: The Take-a-Stand Project, 2011. Preventing Chronic Disease 9, E154.

Proper, K. I., Singh, A. S., Van Mechelen, W. & Chinapaw, M. J. 2011. Sedentary behaviors and health outcomes among adults: A systematic review of prospective studies. American Journal of Preventive Medicine 40 (2), 174-182.

Reis, J. P., Dubose, K. D., Ainsworth, B. E., Macera, C. A. & Yore, M. M. 2005. Reliability and validity of the occupational physical activity questionnaire. Medicine and Science in Sports and Exercise 37 (12), 2075-2083.

Rezende, L. F. M., Sá, T. H., Mielke, G. I., Viscondi, J. Y. K., Rey-López, J. P. & Garcia, L. M. T. 2016. All-cause mortality attributable to sitting time:

Analysis of 54 countries worldwide. American Journal of Preventive Medicine 51 (2), 253-263.

Roberts, S., Desbrow, B., Grant, G., Anoopkumar-Dukie, S. & Leveritt, M. 2013. Glycemic response to carbohydrate and the effects of exercise and protein. Nutrition 29 (6), 881-885.

Robertson, M. M., Ciriello, V. M. & Garabet, A. M. 2013. Office ergonomics training and a sit-stand workstation: Effects on musculoskeletal and visual symptoms and performance of office workers. Applied Ergonomics 44 (1), 73-85.

Rodacki, Cíntia de Lourd Nahhas, Fowler, N. E., Rodacki, A. L. & Birch, K. 2001. Repeatability of measurement in determining stature in sitting and standing postures. Ergonomics 44 (12), 1076-1085.

Roelen, C. A., Schreuder, K. J., Koopmans, P. C. & Groothoff, J. W. 2008. Perceived job demands relate to self-reported health complaints. Occupational Medicine 58 (1), 58-63.

Romijn, J. A., Coyle, E. F., Sidossis, L. S., Gastaldelli, A., Horowitz, J. F., Endert, E. & Wolfe, R. R. 1993. Regulation of endogenous fat and carbohydrate metabolism in relation to exercise intensity and duration. American Journal of Physiology - Endocrinology and Metabolism 265 (3), E380-E391.

Rosenberg, D. E., Bull, F. C., Marshall, A. L., Sallis, J. F. & Bauman, A. E. 2008. Assessment of sedentary behavior with the International Physical Activity Questionnaire. Journal of Physical Activity and Health 5 (1 Suppl), S30-S44.

Rosenberg, D. E., Norman, G. J., Wagner, N., Patrick, K., Calfas, K. J. & Sallis, J. F. 2010. Reliability and validity of the Sedentary Behavior Questionnaire (SBQ) for adults. Journal of Physical Activity and Health 7 (6), 697-705.

Ross, R. & Jackson, A. 1990. Exercise concepts, calculations, and computer applications. Caramel, IN: Benchmark Press .

Rowlands, A. V., Olds, T. S., Hillsdon, M., Pulsford, R., Hurst, T. L., Eston, R. G., Gomersall, S. R., Johnston, K. & Langford, J. 2014. Assessing sedentary behavior with the GENEActiv: Introducing the sedentary sphere. Medicine and Science in Sports and Exercise 46 (6), 1235-1247.

Saarni, L. A., Rimpelä, A. H., Nummi, T. H., Kaukiainen, A., Salminen, J. J. & Nygård, C. 2009. Do ergonomically designed school workstations decrease musculoskeletal symptoms in children? A 26-month prospective follow-up study. Applied Ergonomics 40 (3), 491-499.

Sakamoto, K. & Holman, G. D. 2008. Emerging role for AS160/TBC1D4 and TBC1D1 in the regulation of GLUT4 traffic. American Journal of Physiology - Endocrinology and Metabolism 295 (1), E29-E37.

Salami, O. I., Charles-Owaba, O. E., Oguntola, J. A. & Akanbi, O. G. 2010. Estimating load on the spine using spinal shrinkage. Leonardo Journal of Sciences (16), 117-124.

Samani, A., Holtermann, A., Søgaard, K. & Madeleine, P. 2010. Active biofeedback changes the spatial distribution of upper trapezius muscle activity during computer work. European Journal of Applied Physiology 110 (2), 415-423.

Samani, A., Holtermann, A., Søgaard, K. & Madeleine, P. 2009. Active pauses induce more variable electromyographic pattern of the trapezius muscle activity during computer work. Journal of Electromyography and Kinesiology 19 (6), e430-e437.

Saunders, T. J., Larouche, R., Colley, R. C. & Tremblay, M. S. 2012. Acute sedentary behaviour and markers of cardiometabolic risk: A systematic review of intervention studies. Journal of Nutrition and Metabolism .

Schuna, J. M., Johnson, W. D. & Tudor-Locke, C. 2013. Adult self-reported and objectively monitored physical activity and sedentary behavior: NHANES 2005–2006. International Journal of Behavioral Nutrition and Physical Activity 10 (1), 126.

Sedentary Behaviour Research Network 2012. Letter to the editor: Standardized use of the terms sedentary and sedentary behaviours. Applied Physiology, Nutrition, and Metabolism 37 (3), 540-542.

Shrestha, N., Kukkonen-Harjula, K. T., Verbeek, J. H., Ijaz, S., Hermans, V. & Bhaumik, S. 2016. Workplace interventions for reducing sitting at work. Cochrane Database of Systematic Reviews 3.

Shvartz, E., Gaume, J., White, R., Reibold, R. & Glassford, E. 1980. Effect of the circutone seat on hemodynamic, subjective and thermal responses during prolonged sitting. Proceedings of the Human Factors Society Annual Meeting. SAGE Publications Sage CA: Los Angeles, CA, 639.

Sjøgaard, G., Lundberg, U. & Kadefors, R. 2000. The role of muscle activity and mental load in the development of pain and degenerative processes at the muscle cell level during computer work. European Journal of Applied Physiology 83 (2), 99-105.

Sjöström, M., Oja, P., Hagströmer, M., Smith, B. & Bauman, A. 2006. Health-enhancing physical activity across European Union countries: The Eurobarometer study. Journal of Public Health 14 (5), 291-300.

Skotte, J., Korshøj, M., Kristiansen, J., Hanisch, C. & Holtermann, A. 2014. Detection of physical activity types using triaxial accelerometers. Journal of Physical Activity and Health 11 (1), 76-84.

Sorensen, C. J., Norton, B. J., Callaghan, J. P., Hwang, C. & Van Dillen, L. R. 2015. Is lumbar lordosis related to low back pain development during prolonged standing? Manual Therapy 20 (4), 553-557.

Speck, R. M. & Schmitz, K. H. 2011. Energy expenditure comparison: A pilot study of standing instead of sitting at work for obesity prevention. Preventive Medicine 52 (3), 283-284.

Spriet, L. L. 2014. New insights into the interaction of carbohydrate and fat metabolism during exercise. Sports Medicine 44 (1 Suppl), 87-96.

Spyropoulos, P., Papathanasiou, G., Georgoudis, G., Chronopoulos, E., Koutis, H. & Koumoutsou, F. 2007. Prevalence of low back pain in Greek public office workers. Pain Physician 10 (5), 651-660.

Srinivasan, D., Mathiassen, S. E., 2012. Motor variability in occupational health and performance. Clinical Biomechanics 27 (10), 979-993.

Stamatakis, E., Rogers, K., Ding, D., Berrigan, D., Chau, J., Hamer, M. & Bauman, A. 2015. All-cause mortality effects of replacing sedentary time with physical activity and sleeping using an isotemporal substitution model: A prospective study of 201,129 mid-aged and older adults. International Journal of Behavioral Nutrition and Physical Activity 12 (1), 121.

Steeves, J. A., Bowles, H. R., McClain, J. J., Dodd, K. W., Brychta, R. J., Wang, J. & Chen, K. Y. 2015. Ability of thigh-worn actigraph and activPAL monitors to classify posture and motion. Medicine and Science in Sports and Exercise 47 (5), 952-959.

Straker, L., Abbott, R. A., Heiden, M., Mathiassen, S. E. & Toomingas, A. 2013. Sit–stand desks in call centres: Associations of use and ergonomics awareness with sedentary behavior. Applied Ergonomics 44 (4), 517-522.

Straker, L., Levine, J. & Campbell, A. 2009. The effects of walking and cycling computer workstations on keyboard and mouse performance. Human Factors: The Journal of the Human Factors and Ergonomics Society 51 (6), 831-844.

Stranden, E. 2000. Dynamic leg volume changes when sitting in a locked and free floating tilt office chair. Ergonomics 43 (3), 421-433.

Sudoł-Szopińska, I., Bogdan, A., Szopiński, T., Panorska, A. K. & Kołodziejczak, M. 2011. Prevalence of chronic venous disorders among employees working in prolonged sitting and standing postures. International Journal of Occupational Safety and Ergonomics 17 (2), 165-173.

Tew, G. A., Posso, M. C., Arundel, C. E. & McDaid, C. M. 2015. Systematic review: Height-adjustable workstations to reduce sedentary behaviour in office-based workers. Occupational Medicine 65 (5), 357-366.

Thompson, W. G., Foster, R. C., Eide, D. S. & Levine, J. A. 2008. Feasibility of a walking workstation to increase daily walking. British Journal of Sports Medicine 42 (3), 225-228.

Thorn, S., Forsman, M., Zhang, Q. & Taoda, K. 2002. Low-threshold motor unit activity during a 1-h static contraction in the trapezius muscle. International Journal of Industrial Ergonomics 30 (4), 225-236.

Thorn, S., Søgaard, K., Kallenberg, L., Sandsjö, L., Sjøgaard, G., Hermens, H., Kadefors, R. & Forsman, M. 2007. Trapezius muscle rest time during standardised computer work–a comparison of female computer users with and without self-reported neck/shoulder complaints. Journal of Electromyography and Kinesiology 17 (4), 420-427.

Thorp, A. A., Kingwell, B. A., Sethi, P., Hammond, L., Owen, N. & Dunstan, D. W. 2014. Alternating bouts of sitting and standing attenuate postprandial glucose responses. Medicine and Science in Sports and Exercise 46 (11), 2053-2061.

Thyfault, J. P., Du, M., Kraus, W. E., Levine, J. A. & Booth, F. W. 2015. Physiology of sedentary behavior and its relationship to health outcomes. Medicine and Science in Sports and Exercise 47 (6), 1301-1305.

Thyfault, J. P. & Krogh-Madsen, R. 2011. Metabolic disruptions induced by reduced ambulatory activity in free-living humans. Journal of Applied Physiology 111 (4), 1218-1224.

Tikkanen, O. 2014. Physiological loading during normal daily life and exercise assessed with electromyography. University of Jyväskylä. Studies in Sport, Physical Education and Health 211.

Tikkanen, O., Haakana, P., Pesola, A. J., Häkkinen, K., Rantalainen, T., Havu, M., Pullinen, T. & Finni, T. 2013. Muscle activity and inactivity periods during normal daily life. PloS one 8 (1), e52228.

Tikkanen, O., Karkkainen, S., Haakana, P., Kallinen, M., Pullinen, T. & Finni, T. 2014. EMG, heart rate, and accelerometer as estimators of energy expenditure in locomotion. Medicine and Science in Sports and Exercise 46 (9), 1831-1839.

Tissot, F., Messing, K. & Stock, S. 2009. Studying the relationship between low back pain and working postures among those who stand and those who sit most of the working day. Ergonomics 52 (11), 1402-1418.

Todd, A. I., Bennett, A. I. & Christie, C. J. 2007. Physical implications of prolonged sitting in a confined posture-a literature review. Ergonomics SA 19 (2), 7-21.

Toomingas, A., Forsman, M., Mathiassen, S. E., Heiden, M. & Nilsson, T. 2012. Variation between seated and standing/walking postures among male and female call centre operators. BMC Public Health 12 (1), 154.

Trost, S. G., Mciver, K. L. & Pate, R. R. 2005. Conducting accelerometer-based activity assessments in field-based research. Medicine and science in sports and exercise 37 (11 Suppl), S531-S543.

Tudor-Locke, C., Schuna, J., Frensham, L. & Proenca, M. 2013. Changing the way we work: Elevating energy expenditure with workstation alternatives. International Journal of Obesity 38, 755-765.

Tuomi, K., Ilmarinen, J., Jahkola, A., Katajarinne, L. & Tulkki, A. 1998. An approved version of the Work Ability Index. Finnish Institute of Occupational Health .

Valachi, B. & Valachi, K. 2003. Mechanisms leading to musculoskeletal disorders in dentistry. The Journal of the American Dental Association 134 (10), 1344-1350.

Van der Ploeg, H. P., Chey, T., Ding, D., Chau, J. Y., Stamatakis, E. & Bauman, A. E. 2014. Standing time and all-cause mortality in a large cohort of Australian adults. Preventive Medicine 69, 187-191.

Van Deursen, L., Van Deursen, D., Snijders, C. & Wilke, H. 2005. Relationship between everyday activities and spinal shrinkage. Clinical Biomechanics 20 (5), 547-550.

Van Dieën, J. H. & Toussaint, H. M. 1993. Spinal shrinkage as a parameter of functional load. Spine 18 (11), 1504-1514.

Van Dieën, J., De Looze, M. & Hermans, V. 2001. Effects of dynamic office chairs on trunk kinematics, trunk extensor EMG and spinal shrinkage. Ergonomics 44 (7), 739-750.

Van Dieën, J. H. & Oude Vrielink, H. H. E. 1998. Evaluation of work-rest schedules with respect to the effects of postural workload in standing work. Ergonomics 41 (12), 1832-1844.

Van Nassau, F., Chau, J. Y., Lakerveld, J., Bauman, A. E. & van der Ploeg, H. P. 2015. Validity and responsiveness of four measures of occupational sitting and standing. The International Journal of Behavioral Nutrition and Physical Activity 12 (1), 144.

Van Uffelen, J. G., Wong, J., Chau, J. Y., van der Ploeg, Hidde P, Riphagen, I., Gilson, N. D., Burton, N. W., Healy, G. N., Thorp, A. A. & Clark, B. K. 2010. Occupational sitting and health risks: A systematic review. American Journal of Preventive Medicine 39 (4), 379-388.

Vieira, E. & Kumar, S. 2004. Working postures: A literature review. Journal of Occupational Rehabilitation 14 (2), 143-159.

Vink, P., Konijn, I., Jongejan, B. & Berger, M. 2009. Varying the office work posture between standing, half-standing and sitting results in less discomfort. Ergonomics and Health Aspects of Work with Computers. Springer, 115.

Wahlström, J. 2005. Ergonomics, musculoskeletal disorders and computer work. Occupational Medicine 55 (3), 168-176.

Wallmann-Sperlich, B., Bucksch, J., Schneider, S. & Froboese, I. 2014. Socio-demographic, behavioural and cognitive correlates of work-related sitting time in German men and women. BMC Public Health 14 (1), 1259.

Weon, J., Oh, J., Cynn, H., Kim, Y., Kwon, O. & Yi, C. 2010. Influence of forward head posture on scapular upward rotators during isometric shoulder flexion. Journal of Bodywork and Movement Therapies 14 (4), 367-374.

Wilks, S., Mortimer, M. & Nylén, P. 2006. The introduction of sit–stand worktables; aspects of attitudes, compliance and satisfaction. Applied Ergonomics 37 (3), 359-365.

ORIGINAL PAPERS

I

VALIDITY OF LONG-TERM AND SHORT-TERM RECALL OF OCCUPATIONAL SITTING TIME IN FINNISH AND CHINESE OFFICE WORKERS

by

Gao Y, Cronin NJ, Nevala N & Finni T, 2017

Journal of Sport and Health Science, In Press, doi: 10.1016/j.jshs.2017.06.003

HOSTED BY
ELSEVIER
Available online at www.sciencedirect.com
ScienceDirect
Journal of Sport and Health Science xx (2017) 1–8

www.jshs.org.cn

Original article

Validity of long-term and short-term recall of occupational sitting time in Finnish and Chinese office workers

Ying Gao [a,*], Neil J. Cronin [a], Nina Nevala [b], Taija Finni [a]

[a] *Neuromuscular Research Center, Faculty of Sport and Health Sciences, University of Jyväskylä, Jyväskylä FI-40014, Finland*
[b] *Finnish Institute of Occupational Health, Helsinki FI-00250, Finland*

Received 24 August 2016; revised 10 November 2016; accepted 15 May 2017
Available online

Abstract

Background: As sedentary behavior is a global health issue, there is a need for methods of self-reported sitting assessment. The accuracy and reliability of these methods should also be tested in various populations and different cultural contexts. This study examined the validity of long-term and short-term recall of occupational sitting time in Finnish and Chinese subgroups.

Methods: Two cohort groups of office-based workers (58.6% female, age range 22–67 years) participated: a Finnish group (FIN, $n = 34$) and a Chinese group (CHI, $n = 36$). Long-term (past 3-month sitting) and short-term (daily sitting assessed on 5 consecutive days) single-item measures were used to assess self-reported occupational sitting time. Values from each participant were compared to objectively measured occupational sitting time assessed via thigh-mounted accelerometers, with Spearman's rho (ρ) used to assess validity and the Bland-Altman method used to evaluate agreement. Coefficients of variation depicted day-to-day variability of time spent on sitting at work.

Results: In the total study sample, the results showed that both long-term and short-term recall correlated with accelerometer-derived sitting time ($\rho = 0.532$, 95% confidence intervals (CI): 0.336 to 0.684, $p < 0.001$; $\rho = 0.533$, 95% CI: 0.449 to 0.607, $p < 0.001$, respectively). Compared to objectively measured sitting time, self-reported occupational sitting time was 2.4% (95% CI: −0.5% to 5.3%, $p = 0.091$) and 2.2% (95% CI: 0.7% to 3.6%, $p = 0.005$) greater for long-term and short-term recall, respectively. The agreement level was within the range −21.2% to 25.9% for long-term recall, and −24.2% to 28.5% for short-term recall. During a 5-day work week, day-to-day variation of sitting time was 9.4% ± 11.4% according to short-term recall and 10.4% ± 8.4% according to accelerometry-derived occupational sitting time.

Conclusion: Overall, both long-term and short-term self-reported instruments provide acceptable measures of occupational sitting time in an office-based workplace, but their utility at the individual level is limited due to large variability.

Keywords: Accelerometry; Daily recall; Office workers; Questionnaire; Self-report; Sitting time; Validity

1. Introduction

A large amount of time spent in sedentary behaviors is associated with several deleterious health outcomes including all-cause mortality; cardiovascular disease incidence or mortality; cancer incidence or mortality; and type 2 diabetes in adults.[1] Sedentary behavior is usually defined as any waking behavior in sitting or reclining posture with low energy expenditure (≤1.5 metabolic equivalents.[2] On average, adults spend over half of their waking hours sedentary and their sedentary time accrues across multiple domains.[3,4] In particular, occupational sitting is a major contributor to total daily sitting time among office-based workers.[5–7] As objective measurements are often impractical, there is a need to develop and evaluate the accuracy and reliability of self-report measures of occupational sitting.[8] Such measures should allow comparisons across different populations and cultures and be applicable in epidemiologic research.[9]

Questionnaires are the most common self-report method for assessing sedentary time.[10–12] Unfortunately, the majority of questionnaires exhibit a weak or low correlation between sedentary time and the criterion measure (range of correlation coefficients from 0.16 to 0.44).[9] When compared with questionnaires assessing recall over the past week or longer, shorter-term recall has been suggested to reduce reporting errors in estimates of usual levels of behavior.[13] However, studies are

---

Peer review under responsibility of Shanghai University of Sport.

* Corresponding author.
E-mail address: yigao@jyu.fi (Y. Gao)

http://dx.doi.org/10.1016/j.jshs.2017.06.003

Please cite this article in press as: Ying Gao, Neil J. Cronin, Nina Nevala, Taija Finni, Validity of long-term and short-term recall of occupational sitting time in Finnish and Chinese office workers, Journal of Sport and Health Science (2017), doi: 10.1016/j.jshs.2017.06.003

required to evaluate and compare the differences over varying time frames of self-report assessment, such as long-term recall of habitual sedentary behavior *vs.* short-term recall on a daily basis.[9] In fact, short-term recall can bring new insights into individual day-to-day variation of occupational sitting time, which may facilitate workplace interventions targeting intra- and inter-individual variability of sedentary behavior at work.[13]

Previous ergonomics studies have identified individual work postures (e.g., sitting, standing, etc.), and concluded that instruments were sufficiently accurate for studying those work postures in relation to health effects in epidemiologic studies.[14,15] Similarly, Reis et al.[16] developed the Occupational Physical Activity Questionnaire to identify the amount of time spent in specific occupational categories:[17] "1) sitting or standing, 2) walking, and 3) heavy labor," where the Spearman correlation with sitting or standing was 0.37 against 7-day occupational physical activity (PA) records.[16] Further examination of separated occupational sitting and standing is required, particularly for the assessment of self-administered occupational sitting time, as sit-stand workstations have been recently introduced in workplace settings.[18] Chau et al.[19] assessed 2 brief instruments including an Occupation Sitting and Physical Activity Questionnaire (OSPAQ), which quantifies percentage time spent in different activities at work. The results showed moderate correlations for measuring occupational sitting and standing time (Spearman's rho (ρ) = 0.65 and 0.49, respectively), suggesting that it is a suitable method for measuring sitting and standing as discrete indicators.[19] In addition, the questions were sufficiently valid and responsive to changes over time in the sit-stand transition when compared with stronger relevant criterion measures of different postures.[20] However, their validation studies were mainly conducted in Australia, which may limit the generalizability of the results to different populations. The concepts and contextualization may vary in different cultural contexts, which could affect self-reported sedentary time.[21] Thus it is important to examine and compare methods of self-reported occupational sitting assessment in different countries.

Most studies have used hip- or waist-worn accelerometers as criterion measures based on body movement, where sedentary time is usually classified as accelerometer counts per minute less than 100.[9] However, this may result in misclassification of low intensity non-sedentary behaviors. As these devices do not detect body position, they cannot distinguish sitting time from standing.[22] Thus, the absolute difference between self-reported and accelerometer-measured values may have been under- or overestimated.[9] Recently, direct measures of postural aspects of sedentary behaviors have been developed. In particular, thigh-mounted accelerometry can identify distinct postures.[23–26] However, only a few recent validity studies have examined self-reported sitting time at work compared with thigh-mounted accelerometry as criterion measures.[20,27]

This study assessed the validity of 2 brief instruments for measuring occupational sitting time. We evaluated the criterion validity of long-term and short-term recall of occupational sitting time by comparing the results with thigh-mounted accelerometry in Finnish and Chinese office-based workers.

2. Methods

2.1. Recruitment, study sample, and procedures

This study was conducted between February and October 2013. Recruitment for the study took place in the cities of Jyväskylä, Finland and Hangzhou, China. Jyväskylä is located in central Finland with a population of 135,591 in 2015 (Population Register Center of Finland). Hangzhou is the capital and largest city of Zhejiang Province in Eastern China with a registered population of 9,018,000 in 2015 (www.zj.stats.gov.cn). Recruitment was achieved by advertising the study on webpages, placing flyers in public places, and individually by word-of-mouth. The study received ethics approval from the Ethics Committee of the University of Jyväskylä. No monetary incentive was offered to the participants.

A total of 131 individuals responded to an internet-administered questionnaire, of whom 70 agreed to attend an initial interview (participation response 53.4%) where they provided written informed consent to participate in the study, and all of them completed the study components including objective measurements. Participants in this study were office-based workers, over 18 years old, ambulatory, and non-pregnant. The sample of 70 contained 2 cohort groups: a Finnish group (FIN, $n = 34$) and a Chinese group (CHI, $n = 36$). In the FIN group, participants were mostly university employees (82% Finnish), and included researchers, teachers, administrative workers, assistants, professors, and technical workers. In the CHI group, participants (100% Chinese) had office-based occupations from different workplace settings, such as office workers, administrative workers, bankers, and IT workers.

The timeline of the procedures is shown in Fig. 1. All participants attended an initial interview where they were instructed to wear a triaxial accelerometer (X6-1a: Gulf Coast Data Concepts Inc., Waveland, MS, USA) secured to the mid-anterior thigh by using a flexible bandage (Pharmacare Sport, Oriola Oy, Espoo, Finland) for 5 consecutive workdays (by default a typical work week with 5 workdays), except when sick or not at work. Participants were individually given verbal and written instructions on how to position the accelerometer. They were asked to wear the device continuously from when they arrived at the workplace until the end of the workday. In addition, they were asked to keep a daily activity log where they recorded what time they came to and left the office, the exact time when they put on and took off the accelerometer, and other events. If they removed the device during work time, this

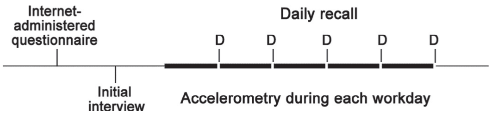

Fig. 1. Timeline of the procedures. The internet-administered questionnaire to assess long-term occupational sitting was administered before the initial interview, and the daily recall of occupational sitting time (D) was assessed at the end of each workday. Accelerometer data were obtained during each workday.

Please cite this article in press as: Ying Gao, Neil J. Cronin, Nina Nevala, Taija Finni, Validity of long-term and short-term recall of occupational sitting time in Finnish and Chinese office workers, Journal of Sport and Health Science (2017), doi: 10.1016/j.jshs.2017.06.003

information was also recorded in logs, accompanied by the reasons (e.g., noon nap in CHI group). They were further asked about the type of their workstation, and those who used a sit-stand workstation were asked to note the time when it was used to sit or stand at work. All the materials were translated to Finnish, English, or Chinese language and checked by native speakers. The questionnaire versions were pilot tested before the validity study.

2.2. *Demographic and physical characteristics*

The questionnaire was implemented electronically using SPSS Dimension mrInterview (Version 5.5 IBM Corp., Armonk, NY, USA), as used previously.[28] This system was based on the e-mail distribution of a link to the actual survey and completed via a web browser on the Internet. It included age, height, body mass, gender, education, overall health status, and PA level.[29] Body mass index (BMI) was calculated.

2.3. *Self-reported occupational sitting time*

Long-term recall was assessed using an internet-administered question: "How much of your entire workday, on average, did you sit during the last 3 months? (0–100% of worktime)." Short-term recall of occupational sitting time, which was assessed after each workday, involved a single-item question: "How much of your entire workday, on average, did you sit today? (as a percentage 0–100%)." The duration of work time was obtained from each individual's daily activity logs.

2.4. *Accelerometer-measured occupational sitting time*

Thigh-mounted accelerometer data, recorded during the same days as the assessment of short-term recall, were used to classify an individual's activity into sitting or activity (standing or walking), and to calculate these values as a percent of recorded work time. The initial utilities setting of the accelerometer was low gain (± 6 G) at a sampling frequency of 20 Hz with 16-bit resolution (sensitivity: 0.000183105 G), and the internal clock of the accelerometer was synchronized with a local online computer. All data analysis was performed using a custom-made script called OpenSALTO (https://github.com/mhavu/OpenSALTO), where data were transformed into a polar coordinate system. Inclination in the sagittal plane was low-pass filtered with 1-Hz cutoff. Sitting and upright positions (standing or walking) were discriminated on the basis of the angle of inclination of the thigh relative to gravity. A threshold of 45° from horizontal was set for the transition from sedentary to upright posture or the reverse, as done previously.[26] The analysis was set to detect a given posture with a minimum 5-s duration. This method is highly valid for classifying body postures to measure sitting time in adults by comparison with direct observation (mean difference of 0.19%, limits of agreement: −0.68% to 1.06%), both in the laboratory[30] and in the free-living setting,[31,32] and was confirmed in pilot tests to work accurately with the device used in the present study. All results were exported to Microsoft Excel 2010 (Microsoft, Redmond, WA, USA) with date- and time-stamped information, where non-wear time was discarded based on individually reported non-wear episodes in their logs. Data were considered valid if participants wore the accelerometer for at least 3 workdays during working hours, which is considered to be sufficient to determine habitual PA among adults.[33] Accelerometer data were compared on a day-to-day basis with short-term recall results so that 3-5 comparisons were performed for each participant, while the questionnaire for long-term recall was compared to the accelerometer data averaged over the measurement days.

2.5. *Statistics*

Statistical analyses were conducted using IBM SPSS for Windows Version 22.0 (IBM Corp., Armonk, NY, USA). A probability level of $p < 0.05$ (two-tailed) was considered statistically significant. Values are presented as means ± SD or % (*n*) unless otherwise indicated. Differences in participant characteristics between groups were tested using an independent t test (normal data) or Mann-Whitney U test (non-normal data) for continuous variables, and χ^2 test or χ^2 test with Fisher's exact test for categorical variables. For day-to-day variability, coefficients of variation (CV) were calculated for short-term recall and thigh-mounted accelerometer-measured occupational sitting time. The absolute difference between the long-term recall results was compared to the averaged daily short-term recall occupational sitting time using Wilcoxon signed-rank test. For validity, Spearman's rho (ρ) was calculated for self-reported (long-term and short-term) and accelerometer-measured occupational sitting time in the total study sample and the 2 cohort groups. The 95% confidence intervals (CI) for the correlations were calculated using Fisher transformation. The strength of correlation as indicated by Spearman's rho (ρ) was interpreted as weak (<0.30), low (0.30–0.49), moderate (0.50–0.69), strong (0.70–0.89), or very strong (≥0.90).[34] Agreement between self-reported and accelerometer-measured occupational sitting time was calculated for the total sample with 2 cohort groups using the Bland-Altman method.[35] Plots were presented with mean difference and 95% limits of agreement (±1.96 SD).

3. Results

Participant characteristics and occupational sitting time are presented in Table 1. Participants were 58.6% female, aged 22-67 years, and had a BMI of 17.1-30.1 kg/m^2. All reported their education to be above college level, thus education level was further classified as college or university level and higher education level, which included academic degree and academic postgraduate qualifications. Compared with FIN group, CHI group was younger ($p < 0.001$) and shorter ($p = 0.043$), and had lower weight ($p < 0.001$), BMI ($p = 0.001$), education level ($p < 0.001$), self-rated health ($p < 0.001$), and fewer met PA guidelines ($p < 0.001$).[29]

Valid accelerometer data for at least 3 workdays were obtained from 68 participants (78% completed 5 workdays). In total, data were analyzed from 322 days (FIN: 162 days; CHI: 160 days). The length of recorded work time averaged 455.4 ± 61.0 mins per workday in the total sample, and there was no difference between groups. No differences were found

Please cite this article in press as: Ying Gao, Neil J. Cronin, Nina Nevala, Taija Finni, Validity of long-term and short-term recall of occupational sitting time in Finnish and Chinese office workers, Journal of Sport and Health Science (2017), doi: 10.1016/j.jshs.2017.06.003

Table 1
Participant characteristics and occupational sitting time.

	Total ($n = 70$)	FIN ($n = 34$)	CHI ($n = 36$)	p values
Age (year)	33.1 ± 10.7	39.6 ± 11.5	26.9 ± 4.6	<0.001
Height (cm)	168.3 ± 8.5	170.5 ± 8.6	166.3 ± 7.9	0.043
Body mass (kg)	63.3 ± 12.5	68.2 ± 10.8	58.6 ± 12.4	<0.001
BMI (kg/m^2)	22.2 ± 3.0	23.4 ± 2.5	21.0 ± 3.0	0.001
Proportion of females	58.6 (41)	58.8 (20)	58.3 (21)	0.967
Education				<0.001
College or university level	38.6 (27)	5.9 (2)	69.4 (25)	
Academic graduate level	61.4 (43)	94.1 (32)	30.6 (11)	
Self-rated health				<0.001
Very good or rather good	62.9 (44)	88.2 (30)	38.9 (14)	
Average, rather poor, or very poor	37.1 (26)	11.8 (4)	61.1 (22)	
Use of sit-stand workstation	18.6 (13)	38.2 (13)	0.0 (0)	<0.001
PA level *	21.4 (15)	41.2 (14)	2.8 (1)	<0.001
Occupational sitting time				
Long-term recall (%)	79.0 ± 13.5	76.2 ± 14.7	81.8 ± 11.8	0.120
Short-term recall (%)	79.3 ± 14.3	77.3 ± 16.4	81.2 ± 12.0	0.309
Accelerometer measured (%) #	76.6 ± 12.4	73.2 ± 12.8	80.1 ± 11.1	0.017
Recording time (min) #	455.4 ± 61.0	447.3 ± 54.7	463.5 ± 66.6	0.280

Note: Data are shown as mean ± SD or % (*n*).
* Meeting the updated physical activity and health recommendations.[29]
\# Missing $n = 2$ in CHI group.
Abbreviations: BMI = body mass index; PA = physical activity.

in long-term or averaged daily short-term recall of occupational sitting time between groups, however FIN group had ~7% less sitting time according to accelerometer data ($p = 0.017$). Furthermore, ~ 39% of Chinese participants reported that they removed the device on at least 1 workday due to work-rest schedules (e.g., noon nap during work time) for an average of 101.5 ± 48.4 min (range 17-204 min) per day per person. None of the CHI group used a sit-stand workstation, whereas ~39% of participants in the FIN group did.

The day-to-day variation was 9.4% ± 11.4% for short-term recall and 10.4% ± 8.4% for accelerometer-measured occupational sitting time for the total sample. Fig. 2 shows subject-specific differences between daily short-term recall and accelerometer-measured occupational sitting time. FIN group exhibited higher day-to-day variation in both short-term recall (12.8% ± 14.1% *vs*. 6.3% ± 6.8%, $p = 0.012$) and accelerometer-based sitting time (13.3% ± 10.0% *vs.* 7.6 ± 5.2%, $p = 0.012$) than CHI group. No absolute difference was found between long-term and averaged daily short-term recall occupational sitting time ($p = 0.815$).

Long-term recall and accelerometer-measured sitting time at work correlated in the total study sample ($\rho = 0.532$, 95% CI: 0.336–0.684, $p < 0.001$), as well as in FIN group ($\rho = 0.450$, 95% CI: 0.132–0.684, $p = 0.008$) and CHI group ($\rho = 0.515$, 95% CI: 0.214–0.727, $p = 0.002$). Similarly, short-term recall and accelerometer-measured sitting time for each work day correlated in the total study sample ($\rho = 0.533$, 95% CI: 0.449–0.607, $p < 0.001$), in FIN group ($\rho = 0.600$, 95% CI: 0.491–0.691, $p < 0.001$), and in CHI group ($\rho = 0.459$, 95% CI: 0.326–0.574, $p < 0.001$).

Fig. 3 shows the Bland-Altman plots for long-term and daily short-term recall and accelerometer-measured occupational sitting time for the total study sample separated by groups. The mean difference between long-term recall and averaged accelerometer-measured results was 2.4% (95% CI: 0.5% to 5.3%, $p = 0.091$) for the total sample, 3.0% for FIN group (95% CI: –1.6% to 7.5%, $p = 0.180$), and 1.8% for CHI group (95% CI: –2.1% to 5.6%, $p = 0.293$). The agreement level was generally within the –21.2% to 25.9% range (±1.96 SD). Similarly, the mean difference between each short-term recall and the corresponding daily accelerometer-measured value was 2.2% (95% CI: 0.7% to 3.6%, $p = 0.005$) for the total sample, 4.0% for FIN group (95% CI: 1.8% to 6.2%, $p < 0.001$), and 0.3% for

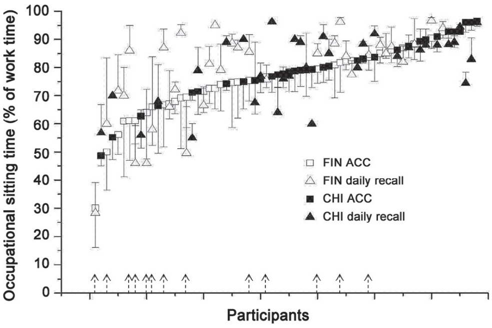

Fig. 2. Differences between averaged daily short-term recall (triangles) and accelerometer-measured occupational sitting time (squares) for each participant. Data are organized according to the amount of objectively measured sitting time so that participants who sat the most are on the right side and those who sat the least are on the left. Standard deviations denote day-to-day variation (3-5 workdays) in occupational sitting time. Dashed arrows indicate participants who used adjustable sit-stand workstations. ACC = accelerometer; CHI = Chinese group; FIN = Finnish group.

Please cite this article in press as: Ying Gao, Neil J. Cronin, Nina Nevala, Taija Finni, Validity of long-term and short-term recall of occupational sitting time in Finnish and Chinese office workers, Journal of Sport and Health Science (2017), doi: 10.1016/j.jshs.2017.06.003

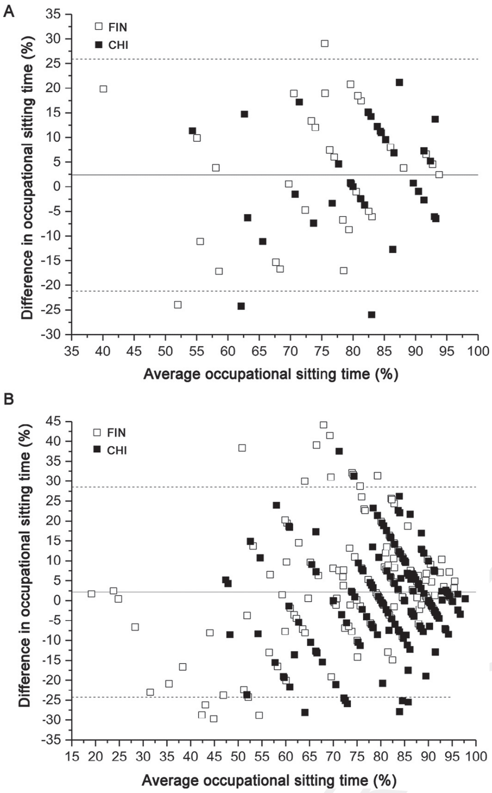

Fig. 3. Bland-Altman plot of absolute agreement of occupational sitting time for all participants' data separated by groups. The *y* axis shows the difference between long-term (A) and daily short-term (B) recall and accelerometer-measured occupational sitting time as a percentage of work time. The *x* axis is the average of them (%). The solid line represents the mean and the dashed lines represent the 95% limits of agreement (±1.96 SD). CHI = Chinese group; FIN = Finnish group.

CHI group (95% CI: −1.7% to 2.2%, $p = 0.807$). Agreement levels were generally within the −24.2% to 28.5% range (±1.96 SD).

4. Discussion

This study examined the criterion validity and absolute agreement of 2 brief self-reported measures of occupational sitting time, assessed by long-term and short-term recall, in a sample of Finnish and Chinese office-based workers. Criterion measures were compared with thigh-mounted accelerometer data, which were used to isolate sitting time. The findings suggest that both self-reported measures are acceptable (<3% difference compared to accelerometry) for assessing the proportion of work time spent sitting at a group level, but not necessarily at an individual level. Similar moderate correlations with objective measures were observed regardless of whether workers were asked about short- or long-term occupational sitting time.

Both long-term and short-term recall resulted in an average occupational sitting time of 79%, indicating that short-term recall adequately represented habitual occupational sedentary behavior. In addition, from the results of day-to-day variations in occupational sitting time, the overall range of CV% was less than 15% (6%-13%) of short-term recall and accelerometer-measured data from 5 workdays. This is comparable with a previous validation study that reported differences in CV% between past day recall and activPAL measured sedentary time of 16%-19% among adults.[36] In the present study, FIN group exhibited higher variations in daily occupational sitting time compared with CHI group. This may have been caused by several potential factors such as differences in sociocultural determinants, where work culture possibilities affect one's habitual occupational sedentary behavior.[4] For example, participants in the FIN group were mostly university employees, and they may have had more flexible work schedules than those in CHI group, who were employed by companies with fixed work schedules. Importantly, some participants from FIN group used sit-stand workstations and it seems that they tended to have lower occupational sitting time, which likely also contributed to the greater variation, as noted previously.[28]

The validity of detailed workplace-specific measures to assess occupational sitting time has been reported in some studies.[19,37] While quantifying the time spent in different postures may help to elucidate the associations between occupational sitting time and health outcomes,[38] few validity studies have examined subjective measures against accurate criterion measures that can distinguish between postures such as sitting or standing still.[20] Our study allowed us to separate sitting and upright postures to quantify sitting time at work. Overall, the long-term recall questionnaire and short-term recall single-item question exhibited similar validity. The range of Spearman's rho (ρ) was 0.336-0.684 in the total sample. Although the correlations found in our study were low to moderate, they seem to be at least as strong as those for global sitting time measured with the International Physical Activity Questionnaire or Global Physical Activity Questionnaire in the general population ($\rho = 0.07$–0.61).[10,11,39] Our results are also comparable to those of other studies that have examined the criterion validity of office-based sedentary time with accelerometry ($\rho = 0.27$-0.65).[19,37] Furthermore, we used a brief single-item question about occupational sitting time administered at the end of each work day. Shorter term recall has been suggested to improve self-report accuracy.[13] Although we found similar results of short- and long-term recall in the total sample, the difference between short-term recall and accelerometer-measured occupational sitting time was smaller in CHI group (mean difference 0.3%; equal to less than 2 min *vs.* 4.0% in FIN). This may have been caused by large day-to-day individual variability in occupational sitting time, which was larger in FIN than in CHI.

Long-term and short-term recall occupational sitting time estimates were both close to the accelerometer-measured

Please cite this article in press as: Ying Gao, Neil J. Cronin, Nina Nevala, Taija Finni, Validity of long-term and short-term recall of occupational sitting time in Finnish and Chinese office workers, Journal of Sport and Health Science (2017), doi: 10.1016/j.jshs.2017.06.003

proportion of sitting time at work (mean differences were 2.4% and 2.2% respectively, equal to 11 min). This level of accuracy is comparable with results from the majority of occupational validation studies, which reported mean differences from 2 min/day to 27 min/day,[19,37,40] suggesting that our method is suitable for surveillance purposes in large populations where it is desirable to estimate occupational sitting time at a group level. However, the limits of agreement were wide, whereby over- or underestimation generally varied between –24% and 28% (±1.96 SD), which is equal to more than 100 min. Thus, these measures may be less useful in studies that require a high level of accuracy at the individual level, such as smaller scale intervention studies. In these cases, self-report measures may be more appropriate as complementary information to objective measures. Overall, our brief single-item question about occupational sitting time may be sufficient to rank office-based workers on the basis of sitting time in large-scale workplace population studies.

In the current study, we quantified the amount of sitting time as a proportion of worktime. This may be a useful instrument in large population based studies, which are limited by space constraints for questionnaire items.[19] Furthermore, when a standardized approach to measure sedentary behavior is required,[9] the use of continuous variables may make it possible to directly compare various studies regarding the proportion of work time spent sitting.[19] However, further examination of the units used to report sedentary and active time, for absolute and relative variables, is required to enable appropriate comparisons. In addition, there is limited research about intra- and inter-individual variability of sedentary behavior.[22] In the current study, we identified subject-specific differences between subjective and objective sitting time, and individual day-to-day variation of occupational sitting time. These results may improve understanding of how office workers individually accumulate their daily total sitting time at work. Furthermore, an important contribution of this study is the comparison between self-report instruments and accelerometer measures of sitting and upright postures (sitting and activity time) in the workplace; these simple self-report measures could feasibly be used in large population studies, which may ultimately help to establish associations between postural allocations and occupational health outcomes.[38,41]

However, the current study also has some limitations. Although this study used 2 cohort groups, which included participants from Finland and China, the study samples were small and may not be representative of the larger population. Participants were office-based workers, so these findings may not be representative of other occupations. Further examination of the utility of self-reported measures is recommended in different occupations with more varied patterns of sitting. Although the current study used 2 brief instruments to assess occupational sitting time, both of them may have been susceptible to random and systematic reporting errors.[9] While questionnaires containing several questions at a time may be associated with contamination, the 2 self-report measures used in this study were administered at different time points, which minimizes this potential bias. In addition, few studies have examined the ability of self-report measures to detect behavior changes over time.[20] Although in the current study we did not assess responsiveness to changes in occupational sitting, in our previous study we found that self-reported occupational sitting time decreased by ~14% after 6 months of daily use of a sit-stand workstation.[28] This difference is large compared to the mean difference of 2.2%-2.4% between self-report and objective measures in the present study, suggesting that our self-report measures could be sensitive enough to detect longitudinal changes in sitting time at the population level. However, further studies are needed to test this hypothesis.

5. Conclusion

A brief questionnaire about estimated sitting time at work, based on either long-term or short-term recall, may be suitable for different population health surveys, prospective cohort studies, and other studies that rely on questionnaire items.

Acknowledgments

Ying Gao was supported by the China Scholarship Council (No.201206320092), China. We thank Marko Havu, M.Sc., for assistance with data analysis.

Authors' contributions

YG designed the study, translated the questionnaire, carried out data collection, performed analysis, and drafted the manuscript; NJC designed the study, conducted conceptual development of variables, and critically revised the manuscript; NN designed the study, translated the questionnaire, and critically revised the manuscript; TF designed the study, conducted conceptual development of variables, and critically revised the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

Appendix: 1

Internet-administered questionnaire regarding occupational sitting time during the last three months

English version

How much of your entire workday, on average, did you sit during the last 3 months? (0–100% of worktime)

______________ %

Finnish version

Kuinka paljon viimeisen 3 kk aikana olet keskimäärin istunut koko työajastasi? (% työajasta, 0–100)

______________ %

Chinese version

在过去的三个月，在你一天的工作时间中，平均，你坐着的时间？（请用占工作时间的百分比表示 0–100%)

______________ %

Please cite this article in press as: Ying Gao, Neil J. Cronin, Nina Nevala, Taija Finni, Validity of long-term and short-term recall of occupational sitting time in Finnish and Chinese office workers, Journal of Sport and Health Science (2017), doi: 10.1016/j.jshs.2017.06.003

Appendix: 2

Daily recall questionnaire regarding occupational sitting time at the end of the workday

English version

How much of your entire workday, on average, did you sit today? (as a percentage 0–100%)

______________ %

Finnish version

Kuinka monta prosenttia työajastasi käytit istumiseen tänään? (0–100%)

______________ %

Chinese version

今天一天的工作时间中, 平均, 你坐的时间? (请使用百分比0–100%)

______________ %

References

1. Biswas A, Oh PI, Faulkner GE, Bajaj RR, Silver MA, Mitchell MS, et al. Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults: a systematic review and meta-analysis. *Ann Intern Med* 2015;**162**:123–32.
2. Cart L. Letter to the editor: standardized use of the terms "sedentary" and "sedentary behaviours". *Appl Physiol Nutr Metab* 2012;**37**:540–2.
3. Matthews CE, Chen KY, Freedson PS, Buchowski MS, Beech BM, Pate RR, et al. Amount of time spent in sedentary behaviors in the United States, 2003–2004. *Am J Epidemiol* 2008;**167**:875–81.
4. Owen N, Sugiyama T, Eakin EE, Gardiner PA, Tremblay MS, Sallis JF. Adults' sedentary behavior determinants and interventions. *Am J Prev Med* 2011;**41**:189–96.
5. Bennie JA, Pedisic Z, Timperio A, Crawford D, Dunstan D, Bauman A, et al. Total and domain-specific sitting time among employees in desk-based work settings in Australia. *Aust N Z J Public Health* 2015;**39**:237–42.
6. Clemes SA, Patel R, Mahon C, Griffiths PL. Sitting time and step counts in office workers. *Occup Med (Lond)* 2014;**64**:188–92.
7. Parry S, Straker L. The contribution of office work to sedentary behaviour associated risk. *BMC Public Health* 2013;**13**:296. doi:10.1186/1471-2458-13-296
8. Marshall SJ, Ramirez E. Reducing sedentary behavior: a new paradigm in physical activity promotion. *Am J Lifestyle Med* 2011;**5**:518–30.
9. Healy GN, Clark BK, Winkler EAH, Gardiner PA, Brown WJ, Matthews CE. Measurement of adults' sedentary time in population-based studies. *Am J Prev Med* 2011;**41**:216–27.
10. Rosenberg DE, Bull FC, Marshall AL, Sallis JF, Bauman AE. Assessment of sedentary behavior with the International Physical Activity Questionnaire. *J Phys Act Health* 2008;**5**(Suppl. 1):S30–44.
11. Cleland CL, Hunter RF, Kee F, Cupples ME, Sallis JF, Tully MA. Validity of the Global Physical Activity Questionnaire (GPAQ) in assessing levels and change in moderate-vigorous physical activity and sedentary behaviour. *BMC Public Health* 2014;**14**:1–11.
12. Rosenberg DE, Norman GJ, Wagner N, Patrick K, Calfas KJ, Sallis JF. Reliability and validity of the Sedentary Behavior Questionnaire (SBQ) for adults. *J Phys Act Health* 2010;**7**:697–705.
13. Matthews CE, Moore SC, George SM, Sampson J, Bowles HR. Improving self-reports of active and sedentary behaviors in large epidemiologic studies. *Exerc Sport Sci Rev* 2012;**40**:118–26.
14. Laperrière E, Messing K, Couture V, Stock S. Validation of questions on working posture among those who stand during most of the work day. *Int J Ind Ergonom* 2005;**35**:371–8.
15. Mortimer M, Hjelm EW, Wiktorin C, Pernold G, Lbom Å, Vingård E. Validity of self-reported duration of work postures obtained by interview. *Appl Ergon* 1999;**30**:477–86.
16. Reis JP, Dubose KD, Ainsworth BE, Macera CA, Yore MM. Reliability and validity of the occupational physical activity questionnaire. *Med Sci Sports Exerc* 2005;**37**:2075–83.
17. Centers for Disease Control and Prevention. *Behavioral risk factor surveillance system survey questionnaire*. Atlanta, GA: US Department of Health and Human Services, Centers for Disease Control and Prevention; 2001.p.22–3.
18. Pronk NP, Katz AS, Lowry M, Payfer JR. Reducing occupational sitting time and improving worker health: the Take-a-Stand Project, 2011. *Prev Chronic Dis* 2012;**9**:E154. doi:10.5888.pcd9.110323
19. Chau JY, Van Der Ploeg HP, Dunn S, Kurko J, Bauman AE. Validity of the occupational sitting and physical activity questionnaire. *Med Sci Sports Exerc* 2012;**44**:118–25.
20. van Nassau F, Chau JY, Lakerveld J, Bauman AE, van der Ploeg HP. Validity and responsiveness of four measures of occupational sitting and standing. *Int J Behav Nutr Phys Act* 2015;**12**:144. doi:10.1186/s12966-015-0306-1
21. Curry WB, Duda JL, Thompson JL. Perceived and objectively measured physical activity and sedentary time among South Asian women in the UK. *Int J Environ Res Public Health* 2015;**12**:3152–73.
22. Edwardson CL, Winkler EAH, Bodicoat DH, Yates T, Davies MJ, Dunstan DW, et al. Considerations when using the activPAL monitor in field based research with adult populations. *J Sport Health Sci* 2016. doi:10.1016/j.jshs.2016.02.002
23. Edwardson CL, Rowlands AV, Bunnewell S, Sanders J, Esliger DW, Gorely T, et al. Accuracy of posture allocation algorithms for thigh- and waist-worn accelerometers. *Med Sci Sports Exerc* 2016;**48**:1085–90.
24. Rowlands AV, Olds TS, Hillsdon M, Pulsford R, Hurst TL, Eston RG, et al. Assessing sedentary behavior with the GENEActiv: introducing the sedentary sphere. *Med Sci Sports Exerc* 2014;**46**:1235–47.
25. Steeves JA, Bowles HR, McClain JJ, Dodd KW, Brychta RJ, Wang J, et al. Ability of thigh-worn actigraph and activPAL monitors to classify posture and motion. *Med Sci Sports Exerc* 2015;**47**:952–9.
26. Skotte J, Korshøj M, Kristiansen J, Hanisch C, Holtermann A. Detection of physical activity types using triaxial accelerometers. *J Phys Act Health* 2014;**11**:76–84.
27. Wijndaele K, De Bourdeaudhuij I, Godino JG, Lynch BM, Griffin SJ, Westgate K, et al. Reliability and validity of a domain-specific last 7-d sedentary time questionnaire. *Med Sci Sports Exerc* 2014;**46**:1248–60.
28. Gao Y, Nevala N, Cronin NJ, Finni T. Effects of environmental intervention on sedentary time, musculoskeletal comfort and work ability in office workers. *Eur J Sport Sci* 2016;**16**:747–54.
29. Haskell WL, Lee I, Pate RR, Powell KE, Blair SN, Franklin BA, et al. Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Circulation* 2007;**116**:1081–93.
30. Grant PM, Ryan CG, Tigbe WW, Granat MH. The validation of a novel activity monitor in the measurement of posture and motion during everyday activities. *Br J Sports Med* 2006;**40**:992–7.
31. Kozey-Keadle S, Libertine A, Lyden K, Staudenmayer J, Freedson PS. Validation of wearable monitors for assessing sedentary behavior. *Med Sci Sports Exerc* 2011;**43**:1561–7.
32. Lyden K, Kozey Keadle SL, Staudenmayer JW, Freedson PS. Validity of two wearable monitors to estimate breaks from sedentary time. *Med Sci Sports Exerc* 2012;**44**:2243–52.
33. Trost SG, McIver KL, Pate RR. Conducting accelerometer-based activity assessments in field-based research. *Med Sci Sports Exerc* 2005;**37**:531–43.
34. Pett MA. *Nonparametric statistics for health care research: Statistics for small samples and unusual distributions*. SAGE Publications; 1997.
35. Bland JM, Altman D. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986;**327**:307–10.

Please cite this article in press as: Ying Gao, Neil J. Cronin, Nina Nevala, Taija Finni, Validity of long-term and short-term recall of occupational sitting time in Finnish and Chinese office workers, Journal of Sport and Health Science (2017), doi: 10.1016/j.jshs.2017.06.003

36. Matthews CE, Keadle SK, Sampson J, Lyden K, Bowles HR, Moore SC, et al. Validation of a previous-day recall measure of active and sedentary behaviors. *Med Sci Sports Exerc* 2013;**45**:1629–38.

37. Clark BK1, Thorp AA, Winkler EA, Gardiner PA, Healy GN, Owen N, et al. Validity of self-reported measures of workplace sitting time and breaks in sitting time. *Med Sci Sports Exerc* 2011;**43**:1907–12.

38. Van Uffelen JG, Wong J, Chau JY, van der Ploeg HP, Riphagen I, Gilson ND,et al. Occupational sitting and health risks: a systematic review. *Am J Prev Med* 2010;**39**:379–88.

39. Craig CL, Marshall AL, Sjöström M, Bauman AE, Booth ML, Ainsworth BE, et al. International physical activity questionnaire: 12-country reliability and validity. *Med Sci Sports Exerc* 2003;**35**: 1381–95.

40. Chau JY, van der Ploeg HP, Dunn S, Kurko J, Bauman AE. A tool for measuring workers' sitting time by domain: the Workforce Sitting Questionnaire. *Br J Sports Med* 2011;**45**:1216–22.

41. Castillo-Retamal M, Hinckson EA. Measuring physical activity and sedentary behaviour at work: a review. *Work* 2011;**40**:345–57.

Please cite this article in press as: Ying Gao, Neil J. Cronin, Nina Nevala, Taija Finni, Validity of long-term and short-term recall of occupational sitting time in Finnish and Chinese office workers, Journal of Sport and Health Science (2017), doi: 10.1016/j.jshs.2017.06.003

II

EFFECTS OF ENVIRONMENTAL INTERVENTION ON SEDENTARY TIME, MUSCULOSKELETAL COMFORT AND WORK ABILITY IN OFFICE WORKERS

by

Gao Y, Nevala N, Cronin NJ & Finni T, 2016

European Journal of Sport Science 16 (6), 747−754

III

MUSCLE ACTIVITY PATTERNS AND SPINAL SHRINKAGE IN OFFICE WORKERS USING A SIT−STAND WORKSTATION VERSUS A SIT WORKSTATION

by

Gao Y, Cronin NJ, Pesola AJ & Finni T, 2016

Ergonomics 59 (10), 1267−1274

http://urn.fi/URN:NBN:fi:jyu-201611024549

IV

ACUTE METABOLIC RESPONSE, ENERGY EXPENDITURE, AND EMG ACTIVITY IN SITTING AND STANDING

by

Gao Y, Silvennoinen M, Pesola AJ, Kainulainen H, Cronin NJ & Finni T, 2017

Medicine & Science in Sports & Exercise 49 (9), 1927−1934

http://urn.fi/URN:NBN:fi:jyu-201708313629