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211

Olli Tikkanen

Physiological loading during normal daily life and exercise assessed with electromyography

JYVÄSKYLÄN YLIOPISTO

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ABSTRACT

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Finnish Summary

The aims of the present study were to validate shorts implemented with textile electromyography (EMG) electrodes to estimate energy expenditure (EE) and aerobic exercise capacity, to develop analysis methods for long-term EMG measurements, and to quantify EMG activity and inactivity of thigh muscles during normal daily life in adults and elderly. In total, 150 volunteers were measured in the laboratory for EMG, heart rate, accelerometry and ventilatory gases, and during normal daily life EMG was recorded.

The results demonstrated that EMG shorts can be used for EE estimations in a wide range of physical activity intensities in a heterogeneous subject group. On the other hand, an increase in EMG slope was detected during running which occurred near the second ventilatory threshold (V_{T2}) indicating that EMG can be used also to estimate aerobic exercise capacity. Furthermore, long-term recordings of EMG provided novel insights into daily inactivity and activity of main locomotor muscles. Daily measurements revealed that thigh muscles are inactive over 65 % of the measurement time and long continuous inactivity periods are common in normal daily life. On average, only a fraction (4%) of muscle's maximal voluntary strength capacity is used during normal daily life, and the muscles work at high intensities only for very short periods. In daily life older people have less activity bursts with higher intensity and are less time inactive, but have longer continuous inactivity periods than younger adults. Consequently, daily life was shown to be physically more demanding for the elderly due to lower maximum strength levels highlighting the importance of maintaining strength levels with aging.

EMG can provide an alternative for accelerometer when greater accuracy is needed and can provide distinct and valuable information of physical inactivity and activity, especially at low intensity levels of normal daily life. The muscle activity patterns reported in this study are significant for understanding intensity, amount and distribution of physical activity which is typical in healthy adults and elderly.

Keywords: Muscle activity, physical activity, electromyography, EMG shorts, EMG threshold, inactivity

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The data collection and analysis were very time consuming and effortful due to large participant group, prototype level technology and novel analysis methods utilized. Without great help from my wonderful colleagues Piia Haakana, MSc, Arto Pesola, MSc, Toivo Vilavuo, MSc, Pasi Kettunen, MSc, Gauthier Perez, MSc, Marco Petrin, MSc, Marja Katajavuori, MSc, Anna-Stina Kuula, MSc, Johanna Stenholm, MSc, and Sakari Mikkola, MSc, this project would have been an impossible task to accomplish. These people were invaluable in the measurements and data analysis. Even though data collection phase often demanded long days, we were able to get through the measurements in professional but at the same time good and enjoyable atmosphere without forgetting humor. Especially memorable were nice breakfasts together when schedules happened to allow for such a luxury. Special thank is more than deserved to Piia Haakana, MSc. Without her help this PhD would have never seen the daylight as she has been the mastermind orchestrating the data collection and analysis. I would like to thank also co-authors of the articles, Professor Sarianna Sipilä, PhD, Professor Mauri Kallinen, MD, Salme Kärkkäinen, PhD, Teemu Pullinen, PhD, Hu Min, PhD, Timo Rantalainen, PhD, and Marko Havu, MSc, for all their help in the data analysis and feedback on manuscripts. In addition, I would like to thank Ritva Taipale, PhD, and Neil Cronin, PhD, for proofreading of the articles. Furthermore, I wish to thank all the university staff and the research participants for giving their essential share for this study.

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Finally, completing a PhD is a time consuming process and involves setbacks and times of confusion. In this journey, as well as in many other projects of life, it is good to be guided by wisdom from a Chinese teacher and philosopher Confucius (551-479 BC):”*It does not matter how slowly you go as long as you do not stop”.*

This book is dedicated to my parents.

August 2014,
Olli Tikkanen

ORIGINAL PUBLICATIONS

The thesis is based on the following original publications, which will be referred to in the text by their Roman numerals.

I Tikkanen O, Kärkkäinen S, Haakana P, Kallinen M, Pullinen T, Finni T. 2014. EMG, heart rate and accelerometry as estimators of energy expenditure during locomotion. Medicine & Science in Sport & Exercise 46 (9): 1831-1839.

II Tikkanen O, Min H, Vilavuo T, Tolvanen P, Cheng S, Finni, T. 2012. Ventilatory threshold during incremental running can be estimated using EMG shorts. Physiological Measurement 33: 603-614.

III Tikkanen, O, Haakana P, Pesola AJ, 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. doi:10.1371/journal.pone.0052228.

IV Tikkanen O, Kuula A-S, Pesola AJ, Haakana P, Sipilä S, Finni T. Muscle activity during daily life in older people. Submitted for publication.

Additionally, some previously unpublished results are included in the thesis.

ABBREVIATIONS

ACC	Accelerometry
ACSM	American College of Sports Medicine
AEE	Physical activity-associated energy expenditure
aEMG	Average electromyography
aEMG (H)	aEMG of hamstrings
aEMG (Q)	aEMG of quadriceps
aEMG (Q+H)	aEMG of quadriceps and hamstrings combined
AIC	Akaike information criteria
AIC/n	Akaike information criteria divided by number of subjects
BMI	Body mass index
BMR	Basal metabolic rate
bpm	Beats per minute
EE	Energy expenditure
EMG	Electromyography
EMG_{MVC}	Maximum value of electromyography from MVC
EMG_T	Electromyographic threshold
Fat %	Fat percentage
HIT	High intensity interval training
HR	Heart rate
IPAQ	International Physical Activity Questionnaire
kcal	Kilocalories
MET	Metabolic equivalents
MVC	Maximal voluntary contraction
NEAT	Non-exercise activity thermogenesis
OBLA	Onset of blood lactate accumulation
R^2	Coefficient of determination
RMR	Resting metabolic rate
SD	Standard deviation
VO_2	Oxygen consumption
VO_{2max}	Maximal oxygen consumption
V_{T1}	First ventilatory threshold
V_{T2}	Second ventilatory threshold

CONTENTS

1 INTRODUCTION

The importance of physical activity in sustaining healthy life has gained increasing attention in academic research as well as in popular culture. Physical activity has been shown to have beneficial effects on cardiorespiratory fitness, blood pressure, lipid profiles, weight control as well as chronic conditions such as cardiovascular diseases, diabetes (Kesäniemi et al. 2001) and Parkinson's disease (Thacker et al. 2007). Also muscle function, specifically muscle strength, is important for maintaining health and well-being especially among middle-aged and older people (Rantanen 2003, Sillanpää et al. 2012). Muscle strength and endurance have been associated with general physical health benefits such as glucose tolerance, lower risk of musculoskeletal injuries, higher fat-free mass and resting metabolic rate (Kesäniemi et al. 2001).

There are also indications that sitting and inactivity per se are harmful for health even if person is physically active (Hamilton, Hamilton & Zderic 2007). Physical inactivity has been this far found to be related to several chronic diseases, such as cardiovascular diseases and type II diabetes (Booth, Roberts & Laye 2012). Since different levels of physical activity affect different physiological mechanisms that contribute to physical health, it has been argued that a person should obtain a portion of activity at each intensity to sustain health (Powell, Paluch & Blair 2011). However, the existing scientific literature has not been able to provide the exact pattern of optimal physical activity and the activity threshold that triggers the healthy signals is yet unknown (Hamilton, Hamilton & Zderic 2007). What has been reported is that daily muscle activity has positive effects on glucose uptake and insulin sensitivity and thus can prevent from type II diabetes (Krogh-Madsen et al. 2010).

Physical activity is defined as bodily movement that is produced by the contractile activity of skeletal muscle that substantially increases energy expenditure (Caspersen, Powell & Christenson 1985). While cardiovascular response is primarily related to the duration of muscular activity the improvements in strength require high intensity level activations (Häkkinen et al. 2000). Muscle strength and endurance can be improved by various kinds of exercises with a common denominator of muscular activity (Häkkinen et al. 2001, Sipilä et al. 1996, Sipilä et al. 2001).

Accurate and valid measurement methods and detailed information of physical activity are of great importance when exercise prescriptions are outlined. Objective and practical methods to measure physical activity include, for example, accelerometry and heart rate (HR) monitoring (Lagerros & Lagiou 2007). Accelerometers have been used widely to monitor physical inactivity as they can provide information of patterns of physical activity (Lagerros & Lagiou 2007). Many of the accelerometer equations work well in classifying moderate intensity activity but accuracy decrease at other intensities (Crouter, Churilla & Bassett 2006). In addition, accelerometers cannot detect static work or an increase of energy expenditure with ascent or when the load is increased (Haskell et al. 1993). HR measurements, in turn, are based on linear relationship between HR and energy expenditure within an individual throughout a large portion of the aerobic work range (Livingstone 1997), although there is almost no slope between HR and energy expenditure during light activity or inactivity (Rennie et al. 2001). In addition, several factors other than energy expenditure can affect HR including body position, ambient temperature, food intake, emotions, muscle groups used and type of muscle activity (Livingstone 1997).

There is clearly a need for more accurate measurement method, especially for low intensity activities, and electromyography could provide a good alternative. Muscular activity can be measured noninvasively from the surface of the skin using EMG (Maton 1976). While EMG allows accurate quantification of muscle activity (duration and magnitude) it has not been used to study physical activity during daily life. Until now, daily muscle activity has been mainly studied in animals (Alford et al. 1987, Fournier et al. 1983, Hodgson et al. 2001) while ambulatory EMG measurements in humans have focused on risk factors of muscular complaints and ergonomics (Ortengren et al. 1975, Thorn et al. 2007, Nordander et al. 2000, Mork & Westgaard 2005), antigravity effects (Edgerton et al. 2001) and to compare patients to healthy individuals (Jakobi, Edwards & Connelly 2008, Howe & Rafferty 2009). One reason for scarce utilization of EMG for long-term measurements in humans (Klein et al. 2010, Kern, Semmler & Enoka 2001) is the complicated measurement system that involves wires around the body, expensive devices, possible problems with movement artifacts and data storage.

The whole day field EMG measurements has become convenient due to the development of clothes with embedded textile electrodes (Finni et al. 2014, Finni et al. 2007, Scilingo et al. 2005). Using this novel methodology, the first aim of this study was to assess the validity of the EMG method to estimate energy expenditure during locomotion and especially at low physical activity intensities. Since it is clear that people spend more time performing sedentary and light activities than higher intensity activities (Crouter, Churilla & Bassett 2006), it is very important that also low-to-moderate intensity activities can be tracked accurately. It has been shown that in the normal physical activity level (PAL) range, the distribution of time spent on activities with low-to-moderate intensity activities determines the activity level of a person (Westerterp & Plasqui 2004). Further aims were to evaluate the possilitity to assess aerobic exercise capacity based on the recordings from EMG shorts and to quantify activity and inactivity of thigh muscles during normal daily life in adults and elderly.

2 REVIEW OF LITERATURE

2.1 Physical inactivity and activity

2.1.1 Definitions and classifications

Definitions. In health science literature, *physical inactivity* or *sedentary behaviour* may be defined as an activity expending very little energy (about 1.0–1.5 METs), such as lying down and sitting (Sedentary Behaviour Research Network 2012). Inactivity can be categorized into modifiable (e.g. television viewing and recreational computer use) and necessary (e.g. sleeping, sitting in occupational activities) sedentary behaviours. In research the focus is usually on modifiable sedentary activities when quantifying physical inactivity. Researchers commonly examine the average amount of time spent viewing television and playing computer games and sometimes even includes reading and napping. (Fitzgerald et al. 1997, Andersen et al. 1998, Fung et al. 2000, Gordon-Larsen, Adair & Popkin 2002, Hu 2003, Evenson & McGinn 2005, Vaz de Almeida et al. 1999, Utter et al. 2003). There is limited evidence regarding the validity and reliability of methods that can be used to accurately assess physical inactivity (Gordon-Larsen, McMurray & Popkin 2000).

Physical activity, in turn, is defined as bodily movement produced by the contraction of skeletal muscles that substantially increase energy expenditure over resting energy expenditure (Caspersen, Powell & Christenson 1985). Furthermore, physical activity comprising of planned, structured and repetitive bodily movement done to maintain or improve one or more components of physical fitness is referred as *exercise*. *Physical fitness*, on the other hand, is a set of characteristics or attributes that relates to the ability to perform physical activity. Another way to define physical fitness is the ability to complete daily tasks, perform physical activity and muscular work without too much effort and fatigue (Physical Activity Guidelines Advisory Committee 2008, McArdle, Katch & Katch 2001). Characteristics of physical fitness are commonly divided into health-related (e.g. cardiovascular fitness, muscle strength and flexibility), or skill-related (e.g. coordination, balance and reaction time) components (Caspersen, Powell & Christenson 1985).

Non-exercise activity thermogenesis (NEAT) is defined as energy expenditure of everything else except sleeping, eating and sports-like exercise (Levine 2002). NEAT can also divided into components based on volition, such that a spontaneous component includes actions like fidgeting, sitting, standing, and walking, and an obligatory component includes daily living, household and occupation activities (Levine, Schleusner & Jensen 2000). As mentioned, energy expenditure during sedentary behaviours is close to resting energy expenditure, but supporting the body mass while standing in combination with spontaneous fidgeting-like movements raises whole body energy expenditure 2.5-fold (Levine, Schleusner & Jensen 2000, Levine 2004). Cumulative effect of NEAT can be very high and can range from 300 to 2000 kcal per day (when comparing the average of the lowest and highest quartiles in total energy expenditure) (Hamilton, Hamilton & Zderic 2007).

Classifications. Physical activity intensity can be reported in *metabolic equivalents* (METs). One MET refers to energy expenditure at rest and is equivalent of VO_2 of 3.5 millilitres per kilogram of body weight per minute (McArdle & Katch 2005) and is roughly equivalent to 1 kilocalorie per kilogram body weight per hour ($kcal \cdot kg^{-1} \cdot hour^{-1}$) (Ainsworth et al. 1993). Table 1 shows the MET classification by leisure-time physical activity intensity. Physical activity is often expressed as time per week or can be weighted by an estimate of intensity and expressed as MET-time/week (MET-hours/week). This summary variable can be created by multiplying the MET value for each activity by the amount of time spent performing that activity during the week (Ainsworth et al. 2000).

Physical activity can be divided into light, moderate and vigorous intensity activities. *Light-intensity activity* includes activities such as standing, slow walking and self-care activities, requiring low energy expenditure (approximately 1.6–2.9 METs) (Ainsworth et al. 2000). *Moderate-intensity activity* is defined as activities with energy expenditure of 3-5.9 METs and *vigorous-intensity activity* over 6 METs (Ainsworth et al. 2000).

TABLE 1 MET classification by leisure-time physical activity intensity for young / middle-age subjects, modified from (McArdle & Katch 2005, American College of Sports Medicine 2010a).

Category	% of HR max	MET intensity	Example of activity
Rest	< 50	1-2	Sitting, arts and crafts
Light	50-63	2-4	Slow walking, sailing boat
Moderate	64-76	4-7	Brisk walking, badminton
Hard (vigorous)	77-94	7-10	Jogging, swimming
Maximal	> 95	>10	Running, competitive sports

HR=heart rate

Exercise intensity can also be determined in relation to ventilatory thresholds (Myers 2005). The first ventilatory threshold (V_{T1}) has been defined as the exercise intensity in which blood lactate level starts to raise from its baseline levels (Wasserman et al. 1973). A non-linear increase in oxygen consumption has also been noticed at the same point (Wasserman et al. 1973). The second ventilatory threshold (V_{T2}, also called as anaerobic threshold), in turn, is defined as the highest sustained exercise intensity in which oxygen uptake can account for the entire energy requirement (Svedahl & MacIntosh 2003). At the anaerobic threshold, the rate of lactate appearance in the blood is equal to the rate of its disappearance (Svedahl & MacIntosh 2003). Although the lack of oxygen in the tissues may facilitate lactic acid production, there is no evidence that lactic acid production above the anaerobic threshold is due to inadequate oxygen delivery (Svedahl & MacIntosh 2003). There are several reasons for quantifying the anaerobic threshold, including evaluation of training programs, assessment of pulmonary or cardiovascular health, and categorization of the intensity of exercise as mild, moderate, or intense (Myers 2005). Several tests have been developed to assess exercise intensity associated with the anaerobic threshold: lactate minimum test, lactate threshold, maximal lactate steady state, onset of blood lactate accumulation (OBLA), individual anaerobic threshold, and ventilatory threshold (Svedahl & MacIntosh 2003). Each method can be used to estimate exercise intensity associated with the anaerobic threshold, but also has consistent and predictable errors depending on the protocol and the criteria used to identify the threshold (Svedahl & MacIntosh 2003).

Blood lactate levels during exercise and associated ventilatory changes have useful and interesting applications in both sport science and in the clinical settings (Myers 2005). In athletes, the intensity of exercise that can be sustained prior to lactate accumulation is an accurate predictor of endurance performance (Myers & Ashley 1997). It has been shown that lactate accumulation occurs later (shifting to a higher percentage of VO_{2max}) after a period of endurance training (Myers & Ashley 1997). In patients undergoing surgery cardiopulmonary exercise testing is an important preoperative assessment tool to evaluate functional capacity and predict outcomes (Ridgway & Howell 2010). Low VO_{2max} or anaerobic threshold has been shown to be associated with an increased occurrence of perioperative complications in several surgical settings (Ridgway & Howell 2010). In addition, any delay in the accumulation of blood lactate attributed to an intervention (e.g. exercise training, drug, surgical) adds important information concerning the efficacy of the intervention (Myers & Ashley 1997).

2.1.2 Recommendations of physical activity

Recommendations for the normal population. Despite growing consensus on the importance of the relation between physical activity and health, the specific dose of physical activity for good health remains still unclear (Kesäniemi et al. 2001). Continued debate of physical activity dose (what type, how often, what intensity, how long etc.) has led to the promulgation of several different public health recommendations. The American College of Sports Medicine (ACSM) was an early leader with publication in 1975 entitled *Guidelines for Graded Exercise Testing and Exercise Prescription*, and its subsequent later editions. These recommendations had a major influence on the fields of rehabilitation and clinical medicine and exercise science (American College of Sports Medicine 1975, American College of Sports Medicine 1980, American College of Sports Medicine 1986, American College of Sports Medicine 1991, American College of Sports Medicine 1995, American College of Sports Medicine 2000). Specific exercise recommendations of the ACSM led to rather regimented thinking about exercise and led many people to think that exercise not meeting these criteria would be of limited or no value.

However, ACSM recommendations from 1990 can be considered as the beginning of a shift from "performance-related fitness" paradigm to one that has recommendations for both health and performance-related outcomes (American College of Sports Medicine 1990). Before this time exercise and physical activity were considered as synonyms and their main goal was to improve cardiorespiratory fitness. In 1990 recommendations stated for the first time that the quality and quantity of exercise for health effects may be different from what is recommended for enhancing fitness (American College of Sports Medicine 1990). Furthermore, in 1992 the American Heart Association released a report that identified lack of physical activity as the fourth modifiable coronary heart disease risk factor (in addition to smoking, dyslipidemia and hypertension) (Fletcher et al. 1992). This report also recognized the health value of moderate intensities and amount of exercise. The next major development in the recommendations came in a report published by the Centers for Disease Control and Prevention and ACSM in 1995, which emphasized accumulation of more than 30 min of moderate intensity activity each day (Pate et al. 1995). This recommendation received much attention and has been highly influential. Today physical activity can be defined as "Both exertion during routine daily activities and exercise for the sake of enhancing fitness" (Jacobson et al. 2005). Therefore, exercise nowadays can generally be considered one of the subcategories of physical activity (U.S. Department of Health and Human Services 1996, Powell, Paluch & Blair 2011).

Recommendations from the year of 2007 onwards for healthy adults for improving physical fitness and promoting and maintaining health required moderate-intensity endurance exercise for a minimum of 30 min, five days per week (Haskell et al. 2007). Examples of this type of exercise include vigorous walking and other activities that considerably increase heart rate. It is also possible to achieve the recommended physical activity by doing vigorous-intensity aerobic exercises at least 20 minutes on three days a week. Examples of these activities include jogging or other exercises which cause increases in ventilation and heart rate. The recommended level of physical activity can be achieved also by combinations of moderate- and vigorous intensity exercises. By exceeding the minimum recommended amounts of physical activity, one can have further improvements in physical fitness, reduce risks of chronic diseases and disabilities and prevent unhealthy weight gain because physical activity and health have a dose-response relationship. Figure 1 shows an example of a poster aimed at increasing participation in health-enhancing physical activity of Finnish adults (UKK Institute).

Currently, in some countries promotion of reducing sitting time is receiving even more attention than promotion of increase of physical activity by exercise. In 2013 in Finland, for example, reducing daily sitting time in the life course was named the first most important goal and increasing physical activity in the course of life as a second goal in a current health promotion campaign (Sosiaali- ja terveysministeriö). Similar recommendations can be also found in Canada where authorities have, for example, published sedentary guidelines for youth (Tremblay et al. 2011). These guidelines recommend that recreational screen time should be limited to 2 hours per day and that motorized transport, extended sitting time and time spent indoors should be limited throughout the day (Tremblay et al. 2011).

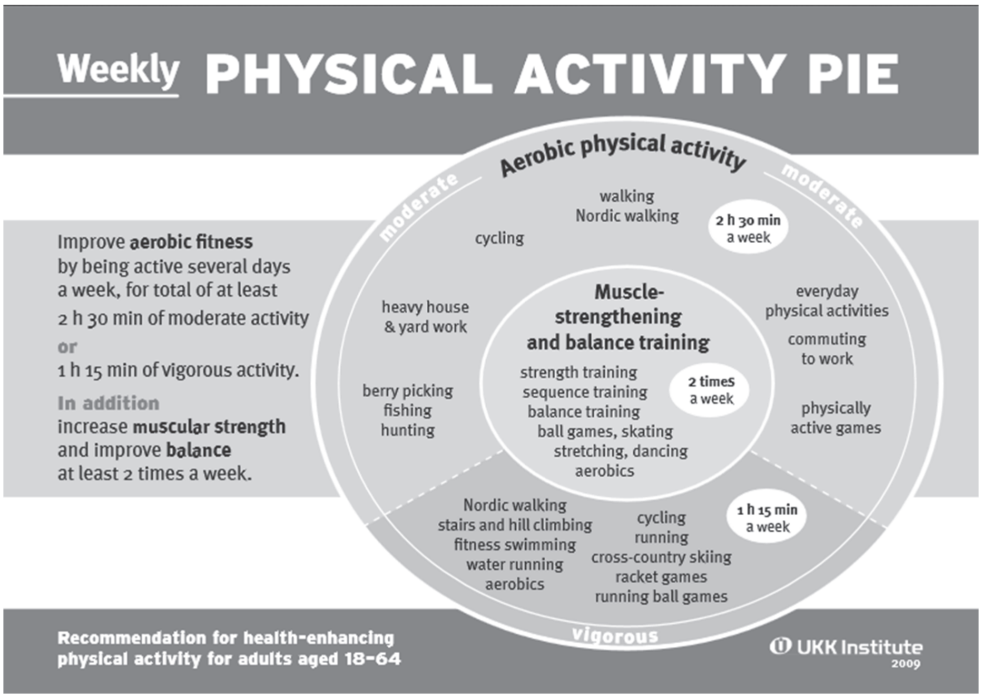

FIGURE 1 Recommendations for health-enhancing physical activity for adults in Finland (reproduced with kind permission by UKK Institute).

Recommendations for the elderly. Physical activity guidelines for older people have also been established based on physiological, clinical and epidemiological evidence. Recommendations of physical activity for older adults (Nelson et al. 2007) resemble the recommendations for adults issued by the ACSM and American Heart Association (Haskell et al. 2007) with some modifications and additions appropriate for older persons. Most importantly, in all activities, level of fitness, abilities and health of older adult should be taken into consideration and the intensities of activities should be adjusted accordingly. Flexibility activities should be performed for a minimum of 10 minutes twice a week to maintain range of motion necessary for daily life and regular physical activity. In addition, moderate-to-vigorous intensity physical activity (MVPA), progressive muscle-strengthening activities for all major muscle groups (a minimum of twice a week) and specific balance exercises should be performed to reduce the risk of falls and related injuries (Nelson et al. 2007). Recommendations in Finland for older people are the same as for younger except that strength, balance and flexibility training is recommended to be performed more often (2-3 times a week) and for over 80 year old the importance of balance training is highlighted (UKK Institute).

2.1.3 Daily physical activity

Our genome has not evolved as fast as social environment, meaning that humans require physical activity to maintain normal functioning and to prevent the incidence of several chronic diseases (Cordain, Gotshall & Eaton 1997). The modern environment limits physical activity in many ways and requires prolonged sitting at school, at work and at home. Estimates of physical activity energy expenditure for modern sedentary office workers are 4.2 $kcal \cdot kg^{-1}$ and 4.4 $kcal \cdot kg^{-1}$ (for women and men respectively), while in hunter-gatherer societies the corresponding values were 14.6 $kcal \cdot kg^{-1}$ and 24.7 $kcal \cdot kg^{-1}$ per day (Cordain, Gotshall & Eaton 1997).

Energy expenditure is a widely used way to define the amount of physical activity and the total energy expenditure includes three components: resting metabolic rate (RMR), energy expenditure associated to physical activity (AEE) and thermogenesis (diet-induced energy expenditure) (Horton 1986). Normally, RMR accounts for 60-70% of the total daily energy expenditure, while AEE accounts approximately for 20-30 %, and provides most variation between individuals (Vanhees et al. 2005). Body mass, skeletal muscle mass and lean body mass are the best predictors of RMR (Deriaz et al. 1992) and between individuals, 75 % of variability in RMR is predicted by lean body mass (Ford 1984). AEE include physical activity during occupation, home and household activities, personal care, transportation, leisure time and sports (Vanhees et al. 2005). Physical inactivity or sedentariness does not refer to zero energy expenditure but rather to no extra voluntary activity required for the necessary activities of work and daily living.

Physical activity can be divided by the mode, intensity and purpose of activity (relating to the context in which it is performed) (Physical Activity Guidelines Advisory Committee 2008). Activities not required for the necessary activities of daily living or work and are done at person's own discretion are classified as leisure-time physical activities (Physical Activity Guidelines Advisory Committee 2008). Leisure-time physical activities include exercise, conditioning or training, participation in sports and recreational activities (e.g.

going for a walk, gardening, dancing) (Physical Activity Guidelines Advisory Committee 2008). The mode of physical activity, in turn, refers to the type of activity, for example, walking, cycling or weightlifting.

Levels of non-exercise activity in normal populations. Even though exercise contributes to total energy expenditure, a major part of the day remains neglected unless energy expenditure outside of purposeful exercise is considered (Tremblay et al. 2007). Non-exercise activity constitutes a majority of energy expenditure even in the regular exercisers (Figure 2). As incidental movement happens sporadically throughout the day, this form of physical activity and energy expenditure is probably the most vulnerable to increasingly ubiquitous mechanization and automation in the today's society (Tremblay et al. 2007). Measurements of daily physical activity have shown that many people spend the majority of the day literally inactive with only minimal muscle activity (Klein et al. 2010). In fact, in industrialized countries three quarters of all workers have sedentary jobs that demand sitting for extended periods (Lis et al. 2007). In the U.S. people spent on average 55 % of their daytime in sedentary behaviours (Matthews et al. 2008) while in Europe 40.6 % of people sit more than 6 hours per day. The highest percentages of people sitting more than 6 hours per day were found in Denmark (men 55 %, women 56 %) and in Finland (men 51 % and women 46 %) (Sjöström et al. 2006).

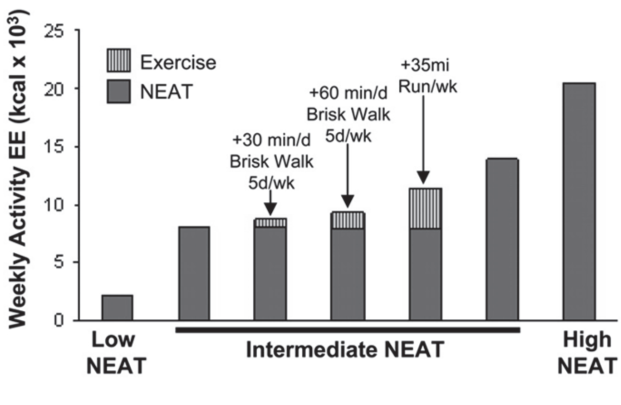

FIGURE 2 Weekly energy expenditure (EE) of physical activity. EE associated to exercise on top of EE of non-exercise activity thermogenesis (NEAT). Even in regular exercisers exercise does not normally constitute the majority of energy expenditure. (modified from Hamilton & Zderic 2007)

Levels of exercise in normal populations. Across the European Union member countries the prevalence of sufficient physical activity (MVPA) for health countries has been shown to be on average 29% ranging from 23% is Sweden to 44% in the Netherlands (Sjöström et al. 2006). In the U.K. 40.4 % (among 19-74 years old) met the current MVPA guidelines (over 30 min/day) (Wijndaele et al. 2014). Regular walking has been reported to be the most prevalent in Spain among the EU countries (Sjöström et al. 2006). Gender is related to physical activity in a way that men are 1.6 times more likely than women to be sufficiently active, slightly more likely to sit for at least 6 hours daily and less likely to be sedentary (Sjöström et al. 2006). Buehler et al. (2011) have compared active travel either by walking or cycling in Germany and the U.S. Proportion of "any walking" in the U.S. was 18.5 % while in Germany it was 42.3% and proportion of "any cycling" was in the U.S. as low as 1.8% and in Germany 14.1% (Buehler et al. 2011). The proportion of "30 minutes of walking and cycling" in U.S. was 7.7% and 1.0%, compared to 21.2% and 7.8% in Germany, respectively (Buehler et al. 2011). Among socioeconomic groups there is much less variation in active travel in Germany than in the U.S. German women, children, and seniors walk and cycle much more than their U.S. counterparts (Buehler et al. 2011).

Levels of exercise among older people. Decreases in physical activity with increasing age have been shown in both longitudinal (Armstrong & Morgan 1998, Bijnen et al. 1998, Bennett et al. 2006) and cross-sectional studies (Caspersen, Pereira & Curran 2000, Fogelholm et al. 2007, Kruger et al. 2008, Troiano et al. 2008). In the study of Bijnen et al. (1998) among retired Dutch men (65-84 years) the total physical activity time decreased by 33% during a ten-year follow-up. Similarly, among Finnish women (75-84 years at baseline), the proportion of those walking for fitness over three times per week decreased from 47% to 25% during an 8-year follow up. The corresponding values for men were 48% and 40% (Hirvensalo, Lampinen & Rantanen 1998). A substantial proportion of older adults does not participate in physical activity at the level recommended as beneficial to health despite the fact that health benefits of an active lifestyle are widely known (Fogelholm et al. 2007, U.S. Department of Health and Human Services, Centers for Disease Control and Prevention 2005, Ashe et al. 2008). In Finland, according to the Health 2000 survey, 40% of adults aged 65-74, around 30% of adults aged 75-84 and only around 20% of adults aged over 85 reported participation in physical activity at a minimal recommended level (Fogelholm et al. 2007).

Levels of non-exercise activity among older people. Among older adults walking, home exercises and gardening are the most common activities reported (Fogelholm et al. 2007, Hirvensalo, Lampinen & Rantanen 1998, Ashe et al. 2008, Rasinaho et al. 2007). In addition to those, older Finnish population favours cross-country skiing, swimming, cycling and dancing as exercise modalities (Hirvensalo, Lampinen & Rantanen 1998). Physical activity behaviour in the elderly may be determined by an array of demographic (e.g. age and education), behavioural (e.g. activity history, physiological (e.g. physical function, obesity, pain and chronic diseases) and environmental factors (e.g. accessibility and safety) (Trost et al. 2002, DiPietro 2001). The most frequently reported motives for physical activity among older people are social life and health promotion, whereas the main obstacles are lack of interest and poor health (Hirvensalo, Lampinen & Rantanen 1998, Rasinaho et al. 2007, Cohen-Mansfield, Marx & Guralnik 2003, Newson & Kemps 2007). In addition, many older people report fear of falling and injury, and feeling of insecurity when exercising (Sallinen et al. 2009, Legters 2002, Jorstad et al. 2005).

2.1.4 Adaptations and health effects

Physical inactivity. There is an increasing interest in identifying health risks associated with sedentary behaviours. The dose-response relationship between sitting time and mortality rates has been found to be comparable among those who are physically inactive and active, and across body mass index categories (Katzmarzyk, Gledhill & Shephard 2000). Indeed, epidemiological studies have shown that sedentary time predicts abnormal glucose metabolism (Dunstan et al. 2004, Dunstan et al. 2007), metabolic syndrome (Dunstan et al. 2005, Ford 2005, Bertrais et al. 2005), type II diabetes (Hu 2003, Hu et al. 2001), obesity (Hu 2003, Jakes et al. 2003), high blood pressure (Jakes et al. 2003), cardiovascular disease (Kronenberg et al. 2000) and all-cause mortality (Katzmarzyk et al. 2009) independently from exercise.

In addition to the negative health effect of total sedentary time, the pattern of the accumulation of this time seems to be also important. It has been shown that the total number of breaks in sedentary time is associated with significantly lower BMI, waist circumference, tri-glycerides, and 2-h plasma glucose, independent of total sedentary time (on average of light intensity, and lasting less than 5 minutes) (Healy et al. 2008). Based on these results it was suggested that breaking prolonged periods of sitting could be a valuable addition to the health recommendations, but biological and behavioural mechanisms and possible causal nature require further investigation (Healy et al. 2008).

Non-exercise activity. Epidemiologic studies have shown a negative relationship between indexes of obesity and levels of physical activity (Weinsier et al. 1995), although the role of low energy expenditure of non-exercise activity in the pathogenesis of obesity is difficult to show with direct data (Levine 2002). Obesity, in turn, has enormous health implications associated with the mechanical complications, metabolic comorbidities and cancer (World Health Organization 2000). Mechanical complications include arthritis, carpal tunnel syndrome, varicose veins, oedema and sleep disorders. Metabolic comorbidities include coronary artery disease, hypertension, hyperlipidaemia and diabetes (Levine 2002). Obesity-related cancers include breast and colon cancers (Levine 2002).

Exercise. Exercise and MVPA have several health benefits, including improvements in respiratory and cardiovascular function, decreased morbidity and mortality, reductions in coronary artery disease risk factors and several other benefits from reductions of falls and injuries to improved psychological health (American College of Sports Medicine 2010b). Many of the health effects are mediated by increasing different components of physical fitness, which are the most direct effects of physical activity (McArdle & Katch 2005). Figure 3 shows health deficiencies associated with lack of physical activity. More specific adaptations and health effects of different types of exercise (endurance training, high intensity interval training and strength training) are described in detail in the following paragraphs.

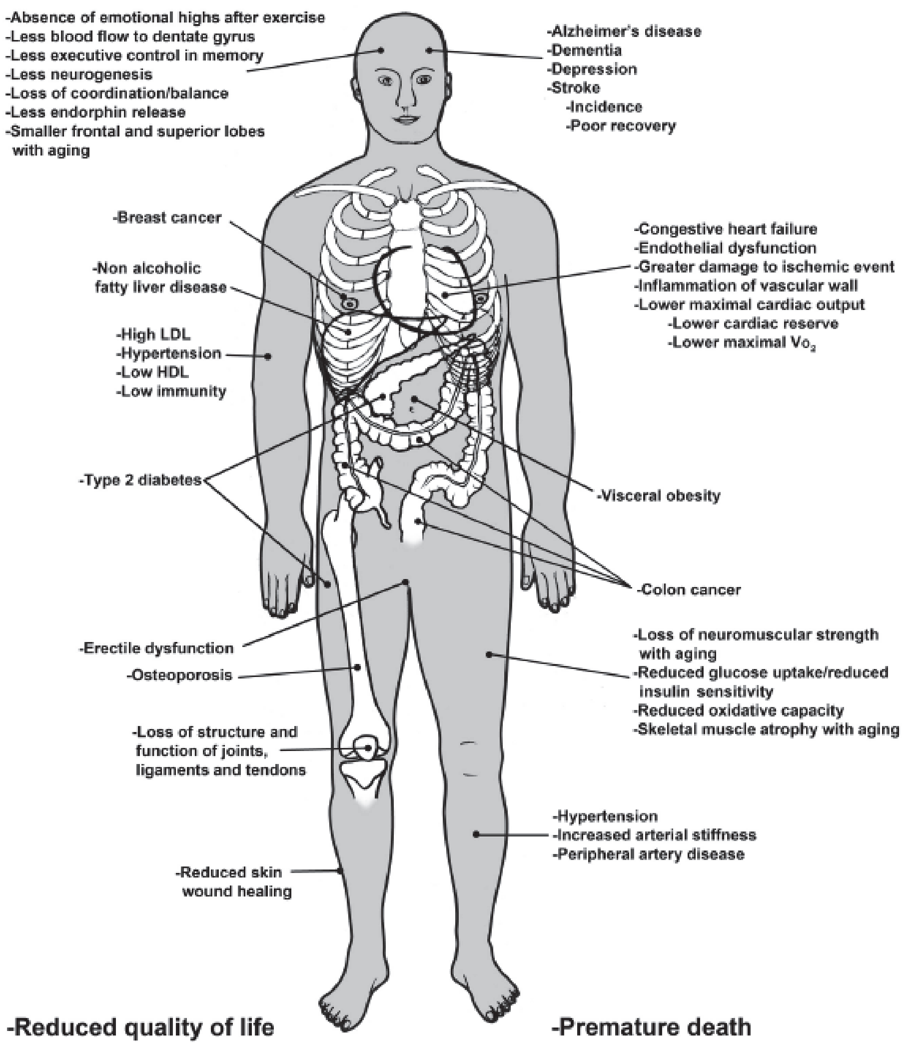

FIGURE 3 Health deficiencies accelerated by decreasing physical activity from higher to lower levels (Booth, Roberts & Laye 2012, reproduced with kind permission by John Wiley & Sons).

Endurance training. Regular endurance training induces major cardiorespiratory and muscular adaptations including improved respiratory capacity of muscle fibres, oxidative capacity and lipid utilization of specific muscle groups. Long-term endurance training improves maximal VO_2, which is generally accepted as a measure of cardiorespiratory fitness and has a high correlation with health and health risks (Blair et al. 1996, Wilder et al. 2006). Endurance training increases capillary density and mitochondrial size (Holloszy & Coyle 1984) and increases the size and stroke volume of the heart (Saltin et al. 1969). The most important metabolic adaptations to endurance exercise include greater reliance on fat oxidation, slower utilization of muscle glycogen and blood glucose and less lactate production on a given exercise intensity (Holloszy & Coyle 1984).

Endurance training is commonly divided into basic, high intensity and maximal training. Basic endurance training develops fat utilization capacity of muscles and increases capillary density of muscles (Rusko et al. 1986). Normally the duration of basic endurance training is from one hour to several hours and training intensity is 60-80 % of VO_{2max} (Rusko et al. 1986). High intensity endurance training, in turn, develops circulatory and respiratory functions, the glycolytic and oxidative capacities of the muscles and the elimination of lactic acid (McArdle & Katch 2005, Shephard & Åstrand 2000). High intensity training can be performed as constant speed (30-60 min) or as interval-type exercise (0.5-10 min / bout) and is performed at the intensity between the ventilatory thresholds (McArdle & Katch 2005, Shephard & Åstrand 2000). Maximal endurance training is performed above the second ventilatory threshold (V_{T2}) and improves VO_{2max} and maximal cardiovascular performance. Training is normally done in intervals of 3-10 minutes at a constant speed and for a total duration of 10-45 minutes (Holloszy & Coyle 1984, Åstrand et al. 2003).

High intensity interval training (HIT). HIT can be defined as 'physical exercise that is characterized by brief, intermittent bursts of vigorous activity, interspersed by periods of rest or low-intensity exercise' (Gibala et al. 2012). A growing scientific literature shows that HIT can serve as an alternative to more traditional continuous endurance training, inducing similar or superior physiological adaptations and health effects (at least when compared on a matched-work basis) (Helgerud et al. 2007, Wisloff et al. 2007, Tjonna et al. 2009, Hwang, Wu & Chou 2011). Low-volume HIT can elicit physiological remodelling comparable to continuous moderate-intensity training despite considerably lower total exercise volume (Gibala et al. 2012). The most commonly used model for low-volume HIT studies has been the Wingate test consisting of a 30s "all out" cycling (typically 4-6 bouts separated by ~4 min of recovery) (Gibala et al. 2012). Only six sessions of this type of training increase oxidative capacity of skeletal muscles (reflected by the protein content and/or maximal activity of mitochondrial enzymes) (Burgomaster et al. 2005, Gibala et al. 2006). Several weeks of low-volume HIT have been shown to elicit increased resting glycogen content, reduced rate of lactate and glycogen utilization, increased capacity for lipid oxidation, improved peripheral vascular function and structure, improved exercise performance and increased maximal oxygen uptake (Burgomaster et al. 2005, Gibala et al. 2006, Rakobowchuk et al. 2008).

Strength training. Muscle strength has been defined as maximum force generation capacity, in which force generation is regulated by neural factors (Macaluso & De Vito 2004). Muscle strength is muscle or muscle group specific and refers to the maximal force any muscle or muscle group can generate. Strength can be divided into isometric and dynamic (concentric and eccentric) components depending on the type of muscle actions. Human locomotion is a combination of the different components often consisting stretch-shortening cycle (Komi 2000). Strength can also be divided, based on energy output requirements, into maximal strength, explosive strength and muscular endurance. Increased muscle activation can be achieved by recruitment of more motor units, increases in the firing rate of motor units and changes in the pattern of motor unit activation (Komi 1986, Kamen 2005). The rate of force development (RFD) also influences muscle performance. Adaptations to prolonged strength training are due to a combination of several factors such as metabolic demands, neuromotor control, mechanical stress and endocrine activities (Kraemer & Ratamess 2005, Häkkinen & Pakarinen 1994). A key factor for successful strength training at any age or fitness level is an appropriate program design (Kraemer et al. 2005). Several strength training studies have shown that 2-3 training days a week is effective for untrained individuals, whereas 1-2 training days a week seems to be effective for maintaining attained strength levels in individuals who have already done strength training (e.g. (Hickson et al. 1994)). During the first weeks of strength training, neural adaptations are followed by muscle hypertrophy and result in gains in maximal strength of the trained muscles (Häkkinen 1994, Neptune, Sasaki & Kautz 2008, Sale 1988). Strength training does not have considerable effect on maximal oxygen uptake, but improves economy of the human movement (Kyröläinen et al. 2000) and physical performance in activities with extra load (Dudley & Djamil 1985). For normal people, who want to improve their general physical fitness, well-being and health, a strength training program should include exercises for hypertrophy, muscle strength and local muscular endurance (Kraemer & Ratamess 2005).

2.2 Assessment of physical activity and inactivity

Although physical activity assessment is generally very challenging, different objective and subjective methods are available to measure physical activity (Lagerros & Lagiou 2007). Objective methods to measure physical activity include, for example, accelerometry, heart rate monitoring and doubly labelled water, and are based on physiological and biological approaches (Lagerros & Lagiou 2007). In contrast, subjective or self-reported methods to measure physical activity include physical activity logs, records and questionnaires (Lagerros & Lagiou 2007).

Direct and indirect calorimetry. The most precise measure of energy expenditure is known as direct calorimetry and is based on measurement of body heat production (Horton 1983, Jequier 1987). Calorimetry is often performed in the laboratory with the individual in a small and confined airtight chamber and therefore, they are not convenient assessing energy expenditure related to a variety of free-living activity patterns. Energy expenditure can also be estimated by measuring the rate of carbon dioxide production and oxygen uptake associated with the energy transfer of substrate oxidation (Jequier 1987, Ferrannini 1988). It is based on assumed relationships between the caloric cost of substrate oxidation and VO_2 (Jequier 1987, Ferrannini 1988, Ravussin et al. 1986). Carbon dioxide and oxygen measurements can be based on stable isotope enrichments (deuterium and ^{18}oxygen) obtained from isotope-labeled bicarbonate or serial urine samples (doubly labeled water) or from expired ventilatory gas analysis. In ventilatory gas analysis fractional concentrations of O_2 and CO_2 and flow rate are measured as the air leaves the system and based on these VO_2 and VCO_2 can be determined. This measurement technique can be used for validation of other methods of physical activity (Starling et al. 1999). The doubly labelled water (DLW) method can be considered as a gold standard to assess total energy expenditure over an extended period of time, and because all physical activities increase energy expenditure it is used to validate devices in their ability to measure daily physical activities (Plasqui, Bonomi & Westerterp 2013).

Accelerometry. Accelerometers can be uniaxial, biaxial or triaxial and nowadays many of them are miniaturized micro electro mechanical and integrated into one platform (Mathie et al. 2004). Most commercially available accelerometers have a measurement range between 0.1-10g and frequency band between 0.25-7 Hz (Chen & Bassett 2005). Signal of accelerometer attached to the body is formed from 4 components: movement of the body, gravitational acceleration, external vibration and acceleration which is due to loose attachment of the accelerometer. Acceleration from the movement of the body is varying in different parts of the body and in different tasks. The measured acceleration signal is highly dependent to which part of the body accelerometer is attached. In studies of daily activities commonly used setting is one tri-axial accelerometer attached to waist (Mathie et al. 2004, Bouten et al. 1997). Activity counts are commonly used to describe intensity of physical activity measured by accelerometers (Balogun, Amusa & Onyewadume 1988) and digital integration is the most frequently used method to calculate activity counts (Chen & Bassett 2005). Accelerometers are used extensively to estimate energy expenditure and physical activity, although they are generally validated in laboratory settings limiting considerably the generalizability of the results to free-living situations (Crouter, Churilla & Bassett 2006). For example, Crouter et al. (2006) have shown that in general Actigraph and Actical devices tend to overestimate walking and sedentary activities and underestimate most other activities. Several accelerometer equations work well for classifying moderate activity but accuracy is compromised at other intensities (Crouter, Churilla &

Bassett 2006). Single regressions over- and underestimate EE during free-living activities (Crouter, Churilla & Bassett 2006). Accelerometers cannot detect static work or an increase of energy expenditure with ascent or when load is increased (for example, in strength training or ergometer cycling) (Haskell et al. 1993). Accelerometers have also been used as an objective monitoring of physical inactivity as they can provide information of patterns of physical activity (Matthew 2005). Data are output of counts per minute and count zero might indicate time spent in sedentary activity (especially if zero counts remain over long periods of time). However, as a zero count can also result from removal of the monitor, this information needs to be interpreted with caution (Choi et al. 2011). On the other hand, Actiheart device which combines heart rate with accelerometry, does not have this problem because heart rate is not recorded if monitor is not worn (Villars et al. 2012).

Heart rate. Heart rate can be measured conveniently in field conditions with commercially available heart rate monitors and heart rate belts. Heart rate elevation is considered the prime response to physical activity and it is easily assessed even for extended periods of time. Energy expenditure estimation of HR is based on the fact that HR and oxygen uptake tend to be linearly related within an individual throughout a large portion of the aerobic work range (Livingstone 1997), although it is subject to both intra- and inter-individual variability (Hebestreit & Bar-Or 1998). Several factors other than energy expenditure can affect HR including food intake, emotions, body position, ambient temperature, muscle groups used and type of muscle activity (Livingstone 1997). During light activity or inactivity, there is almost no slope between HR and energy expenditure (Rennie et al. 2001). There are several methods to estimate energy expenditure from heart rate, that are based in a way or another to a relationship between VO_2 and heart rate measured in laboratory conditions across physical activity intensities.

Questionnaires. Questionnaires are often used in epidemiological studies to assess physical activity as it is inexpensive, easy to administer and distribute, does not require a lot of motivation or time from the participant, and compared to other methods, is a rather quick way of measuring large populations (Lagerros & Lagiou 2007). However, questionnaires relies on subjective perception of physical activity and subjective interpretations of the questions and consequently under- and overestimation of physical activity is possible (Vanhees et al. 2005). Validation studies of physical activity questionnaires against accelerometers and pedometers report correlation coefficients varying between 0.26 and 0.78 (Shephard 2003) and against double labeled water 0.57 and 0.69, indicating that questionnaires can provide data about physical activity (Philippaerts, Westerterp & Lefevre 1999). Also it has been shown that increasing test score (MET min/week) in IPAQ (International Physical Activity Questionnaire) was related to a higher overall fitness, except for the highest MET quintile (Fogelholm et al. 2006). Surprisingly, 10% of young men reporting very high physical activity had, in fact, poor fitness, indicating that especially young men might overestimate their physical activity level (Fogelholm et al. 2006).

Pedometers. Pedometers are inexpensive, small devices worn at waist and measure ambulatory activity in terms of steps taken (Bassett et al. 1996). Pedometers are widely used in research and practice settings to quantify ambulation in free-living settings. When walking is the primary type of activity, pedometers have demonstrated reasonable precision for use in research and clinical settings. However, pedometers do not give information relating to intensity, duration or type of activity. Therefore, accurate quantification of energy expenditure, time spent in intensity- or type-specific activities cannot be assessed with pedometers (Murphy 2009).

Electromyography. Also electromyography (EMG) can be used to measure physical activity. The EMG method will be described in more detail in the following section because it was used in this study to quantify physical inactivity and activity.

2.3 Electromyography (EMG)

2.3.1 Principles of EMG

Electromyography can be defined as the study of muscle function through electrical signals that emanate from the muscles (Basmajian 1967). Electrical potential from the activation of muscle fibres spread temporo-spatially within and across the surface of the muscle. Potential difference of electricity can be recorded from the surface of the skin (surface EMG) or from inside of the muscle (intra-muscular EMG). EMG measurements depend on the specific demand of the measurement environment, applied technical specifications, the specific demands of the type of subjects being measured, and the normalizing technique used to reduce variability between subjects, different trials or conditions (Farina et al. 2004). Several factors influence the surface EMG including following nonphysiological factors: anatomic (e.g. thickness of subcutanous tissue layers), detection system (e.g electrode size and shape), geometrical (e.g. shift of the muscle relative to detection system), physical (e.g. amount of crosstalk from nearby muscles) and following physiological factors: fiber membrane properties (e.g. average muscle fiber conduction velocity) and motor unit properties (e.g. number of recruited motor units) (Farina et al. 2004).

During concentric muscle action, higher EMG activity occurs when the movement velocity increases, in contrary to eccentric muscle action, in which velocity of the movements does not seem to have an effect on EMG activity level (Aagaard et al. 2000). However, maximal EMG activity seems to be at the same level during concentric and eccentric muscle actions (Komi & Buskirk

1972, Komi et al. 2000), and EMG activity during concentric muscle action exceeds activity of isometric muscle actions (Komi et al. 2000). Normal human movement consists commonly of stretch-shortening cycles in which eccentric contraction (active stretch) of a muscle is followed by and immediate concentric contraction of that same muscle (Komi 1984). Compared to pure concentric action stretch-shortening cycle demonstrates considerable performance enhancement with increased force at given shortening velocity (Komi 2000). This phenomenon is characterised by very low EMG activity in the concentric phase, but a very pronounced contribution of the short-latency stretch-reflex component (Komi 2000). Several studies have determined the reproducibility coefficients of EMG measurements for various types of muscle actions and muscles e.g. (Komi & Buskirk 1972, Yang & Winter 1983, Arsenault et al. 1986, Gollhofer et al. 1990, Heinonen et al. 1994). From the results it can be concluded that the within day reproducibility is somewhat better than the day-to-day reproducibility.

2.3.2 Measurement methods of EMG

Traditionally, surface EMG is measured with a system consisting of the main unit, cables (possibly with preamplifiers) and commonly disposable electrodes (which are placed on the skin over the muscle to be measured) in laboratory settings (Konrad 2005). The main unit is working as a stand-alone unit or is either in wireless or tethered connection with the computer (Konrad 2005). These EMG systems are usually rather expensive and have a number of wires around the body, which make field measurements less convenient and applicable. Additionally, tethered connection with the computer or range of wireless connection can limit measurement possibilities considerably in field conditions.

The development of washable textile electrodes has opened up possibilities to manufacture clothing equipped with the textile electrodes that can record muscle activity during normal locomotion without skin preparation and the problem of wires hanging around the body (Scilingo et al. 2005). In addition to muscle activity measurement the textile electrodes have been used in ECG monitoring (Bouwstra et al. 2011, Marozas et al. 2011), electrical bioimpedance measurements (Marquez et al. 2009) and in ECG and pneumography monitoring in E-health care (Taccini et al. 2008).

Typically, electromyography is based on the measurement and analysis of individual muscles separately, which is often necessary in basic science. However, in many practical applications and applied science single muscle measurements are not practical or useful because of system complexity. In the textile electrodes size of the conductive area, and the inter-electrode distance are considerably larger than in the typical bipolar sEMG electrodes and the larger area is not muscle specific but collects data from entire muscle groups (Finni et al. 2007). In their study, Finni et al. (2007) compared traditional bipolar electrodes to EMG shorts with textile electrodes. Results of the study showed that signals from the textile electrodes were in good agreement with the traditionally measured surface EMG signal but gave slightly lower amplitudes than traditional electrodes. Within-session repeatability was similar between the two measurement methods. In conclusion, textile EMG electrodes integrated into clothing allow monitoring of the level of muscle activity from a group of agonist and synergistic muscles in field conditions.

2.3.3 Long-term EMG recordings

Until now, daily muscle activity has been mainly studied in animals (Alford et al. 1987, Fournier et al. 1983, Hodgson et al. 2001) while long-term EMG measurements in humans have focused on ergonomics and risk factors of muscular complaints (Ortengren et al. 1975, Thorn et al. 2007, Nordander et al. 2000, Mork & Westgaard 2005), antigravity effects (Edgerton et al. 2001), and have compared healthy individuals to stroke patients (Jakobi, Edwards & Connelly 2008) or to patients with osteoarthritis (Howe & Rafferty 2009). Furthermore, long-term muscle activities in healthy adults from the upper and lower limb muscles have been compared with conclusions that the amount of activity can vary widely between individuals and muscles (up to 6-fold) (Edgerton et al. 2001, Kern, Semmler & Enoka 2001, Monster, Chan & O'Connor 1978, Shirasawa et al. 2009).

In one of the first long-term EMG studies in humans, muscle activity of 12 men was recorded continuously over 8-h periods in functionally linked muscles from upper and lower limbs comprising of different proportions of muscle fibre types (Monster, Chan & O'Connor 1978). The main finding was that the duration of total muscle activity correlated highly with the proportion of type I fibres and a similar association has been observed in experimental animals (Alaimo et al. 1984, Blewett & Elder 1993, Hutchison et al. 1989, Kernell et al. 1998, Smith et al. 1977).

Klein et al. (2010) have studied human vastus lateralis muscle during a 24-hour period in adults (20-48 years). Average iEMG activity ranged from 3.2% to 12.1% of EMG_{MVC} indicating that only a fraction of maximum capacity of muscles are used in the normal daily life. On average, 66 ± 6% of total EMG duration was below 5% of EMG_{MVC} and only 6 ± 2% above 20% of EMG_{MVC}. The authors also tested effects of different EMG thresholds for inactive behaviour. The application of progressively higher threshold up to 4% of EMG_{MVC} reduced the EMG duration in a curvilinear manner (Klein et al. 2010).

Daily muscle activity patterns of normal healthy animals have been measured to define the conditions under which muscles retain their normal properties. Long-term EMG activity in some muscles of cats (Alaimo et al. 1984, Pierotti et al. 1991, Hensbergen & Kernell 1997), rats (Alford et al. 1987, Fournier et al. 1983) and monkeys (Hodgson et al. 2001, Hodgson et al. 2000) has been reported. Muscle activity of rats follows circadian cycles and correlate with their nocturnal behaviour (Blewett & Elder 1993), i.e., rats sleep during daylight and are active in the dark (Block & Zucker 1976, Moore & Bickler 1976, Bobillier & Mouret 1971). EMG activities in both the rat plantaris and soleus during the dark cycle were twice as high as activities during the light cycle

(Blewett & Elder 1993). Conversely in cats, muscles were active three times longer during the daytime than night time (Hensbergen & Kernell 1998). In the rat soleus muscle some motor units were active for 5–8 h/day, whereas extensor digitorum longus units were active for only 0.72 min/day (Hennig & Lomo 1985). Based on EMG turns analysis estimates suggest that the rat soleus may be active for as much as 16 h a day (Blewett & Elder 1993).

2.3.4 EMG in physical inactivity measurements

EMG has been used to objectively measure physical inactivity. There are many methodological considerations including differences in the threshold used to separate EMG activity from inactivity and the method used to normalize data, which alter the derived EMG intensity and duration. For example, Mork and Westgaard (2005) reported that visual placement of activity threshold resulted in capturing more EMG activity than using the same absolute threshold for all subjects in nocturnal trapezius measurements. In daytime recordings of agonist and antagonist muscles, Monster et al. (1978) used a threshold equal to 8% of the 90th percentile of the amplitude distribution. Downside of this analysis is that the 90th percentile may reflect very different intensities across individuals depending on the activities performed during the recording period (Klein et al. 2010). Most recent studies of long-term EMG have employed a relative threshold of 2% of the MVC (Jakobi, Edwards & Connelly 2008, Kern, Semmler & Enoka 2001, Shirasawa et al. 2009) although also 10 % of the MVC have been used (Howe & Rafferty 2009). EMG activities occur below 2% of MVC during postural tasks (Okada 1972) and during gait (Dubo et al. 1976, Ericson, Nisell & Ekholm 1986), therefore suggesting that some low-level activity has been unaccounted for in those studies. In addition, activation levels achieved during an MVC are often less than 100% (Behm, Button & Butt 2001, Gandevia 2009, Kooistra, de Ruiter & de Haan 2007) therefore resulting in underestimated MVC EMG and derived thresholds of %MVC.

Kern et al. (2001) have shown that EMG duration declined curvilinearly when the data was analysed with progressively higher threshold (from baseline up to 4% MVC). In some subjects EMG duration declined 50-60% but 24-h iEMG increased only 1.5-2% MVC for each 1% MVC threshold increment, therefore indicating that a small change in the analysis threshold results in moderate changes in mean iEMG but large changes in 24-h EMG duration.

3 AIMS OF THE STUDY

The aims of the present study were to validate novel EMG shorts to estimate energy expenditure and aerobic exercise capacity and to quantify activity and inactivity of thigh muscles during normal daily life in adults and elderly.

Spesific research aims were:

1. To investigate the validity and reliability of energy expenditure estimations with EMG shorts during locomotion in changing terrains and to compare EMG method to widely used heart rate and tri-axial accelerometry. (I)

2. To examine use of EMG shorts in estimating ventilatory thresholds during incremental treadmill running. Further, the timing of the EMG thresholds in relation to V_{T2} and onset of blood lactate accumulation (OBLA) were investigated in order to find out whether the EMG shorts could be used in performance testing and guiding athletic training. (II)

3. To examine the effect of different EMG thresholds on inactivity and activity durations in daily EMG recordings. (III)

4. To quantify thigh muscle inactivity and activity periods during normal daily life of ordinary people to gain knowledge of the typical activity levels and force reserves of the muscles. (III)

5. To quantify muscle inactivity and activity periods during normal daily life and simulated tasks in the elderly. In this context differences in muscle activity and energy expenditure in active and passive ways of transport were also studied. (IV)

4 METHODS

4.1 Study design

This research is based on two separate datasets, which are from two larger research projects: HeiMo Study and EMG24 Study (Figure 4). Data for the HeiMo Study was collected in the University of Jyväskylä during 2008 and the EMG24 data collection was done between 2009 and 2010.

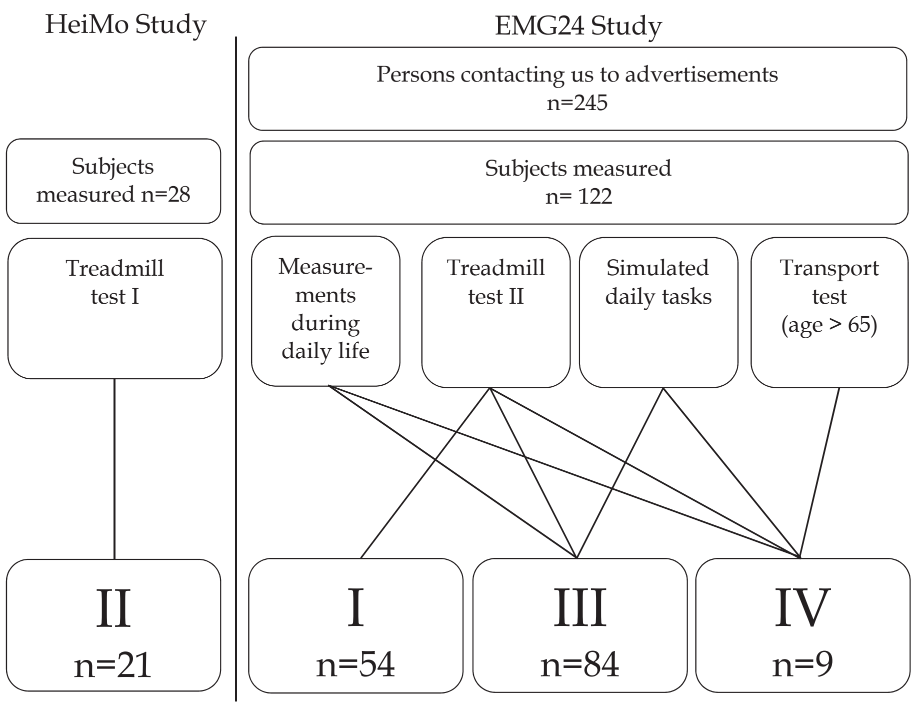

FIGURE 4 Flow chart of the study design.

In the EMG24 study all the subjects did the same tests, except the passive and active transport test that was performed only by subjects over 65 years.

Several researchers and research assistants have taken part in the different aspects of this research. Olli Tikkanen has had a major role in designing of the research setting, planning of the measurements, collection of the data, analysing of the data and writing of the scientific manuscripts (I, III and IV) related to EMG24 study. In HeiMo study he has been analysing the data and been responsible for the preparation of the manuscript (II). Tikkanen is the first author in all four scientific articles meaning that he has been carrying out most of the scientific work related to these articles.

4.2 Subjects and ethics

The ethics committee of the University of Jyväskylä approved both the EMG24 and HeiMo study protocols. Before the laboratory experiments subjects were informed about the study and written informed consent was obtained from all participants. Studies were conducted according to good scientific and clinical practice according to the Declaration of Helsinki. All the data were recorded, blinded, handled and registered according to Finnish Personal Data Act.

Volunteers for the EMG24 -study were recruited through advertisement in wall boards and email lists of local companies and institutes in Central Finland (staff of hospital, construction company, paper manufacturing machinery producer, University and city of Jyväskylä). In total 245 persons contacted us and were interested to volunteer in the study. Persons were screened for exclusion criteria (cardiovascular disease, current or previous injury in lower extremity or lower back or any condition that could affect leg muscle activation) and inclusion criteria of the group being as heterogeneous as possible in terms of sex, age, body composition and physical activity level (PAL). 122 of subjects met the inclusion criteria of being healthy with no major disorders or illnesses and were measured.

Finally, a subgroup of 63 persons was included in Study I and 84 subjects in Study III. In Study IV the aim of subject selection was to have a group of healthy elderly persons (age > 65). Exclusion criteria for the study were any self-reported prevailing injuries in back or lower extremities, use of beta blockers or hormonal medication, diabetes, exercise induced asthma, angina pectoris and exercise induced arrhythmia and inability to perform maximal treadmill test or daily activities included into to the study protocol. Sixteen elderly participants were selected to the study and ten of them provided a complete series of measurements. Data from one subject was excluded due to corrupted data. Finally, nine individuals were included in Study IV.

A total of twenty-eight males (25 ± 3 yrs., 178 ± 5 cm, 71 ± 8 kg) were recruited to the HeiMo -study through personal contacts and advertisements in local sports facilities. Participants were classified as endurance runners (n=12) and recreationally active persons (n=16). Seven participants were lost due to methodological reasons leaving eight endurance runners and thirteen recreationally active persons. The endurance athletes were national level endurance runners or orienteers (83% of them training daily and the rest 4-6 times per week). The recreationally active participants had a heterogeneous background ranging from ball games to jogging and strength training (53% exercising less than 3 times per week and the rest exercising 4-6 times per week). Exclusion criteria were as follows 1) flu or fever less than one week before testing session, 2) any injury in muscles, joints or bones of the leg, which would affect running, 3) abnormal ECG pattern or 4) decision of the doctor to exclude subject from the study, because of any health-related issue.

4.3 Test procedures

4.3.1 Measurements during normal daily life (III and IV)

Measurements during normal daily life were performed either after the laboratory assessments or on separate days but not after the treadmill test. In the morning of each measurement day, the subjects came to the laboratory where the EMG recording devices were put on and set to record. Then they left for their normal living environments with instructions to live normal daily life as usual. To control the reliability of the EMG signal, the subjects were asked to perform and mark down to a diary special reference tests (15 seconds each) including lying down, standing and squatting preferably every 3 hours. The subjects were told to remove the equipment when taking a shower or swimming, or at bedtime the latest. When going to toilet, the subjects were instructed to carefully roll the shorts down and then roll the shorts back on. Measurement days were assigned for the subjects depending on their schedules, and some measurements were also done during weekends. During the measurement days, the subjects marked down the activities they have performed in ½ hour blocks, including sitting, standing, walking, bicycling and exercise for fitness, if any.

4.3.2 Treadmill tests and simulated activities of daily living

In the EMG24 -study the treadmill test (Figure 5), each load lasted three minutes except the last load which was done until exhaustion. The treadmill inclination was 0° unless otherwise reported. The first six loads were the same for all subjects: 4 km · h^{-1}, 5 km · h^{-1}, 5 km · h^{-1} with 4° descent, 5 km · h^{-1} with 4° ascent, 6 km · h^{-1} and 7 km · h^{-1}. From this onwards, participants under age of 30 years performed one running load (10 km · h^{-1} for females and 12 km · h^{-1} for males). The next step for all participants was walking 5 km · h^{-1} with 8° ascent. After walking for 3 minutes with this load it was estimated, how close participants were to their maximal oxygen consumption. If two out of three following criteria were fulfilled participants continued with the same load: 1)

VO_{2max} over 85 % of estimated maximum, 2) heart rate over 90 % of estimated maximum, 3) Borg rating of perceived excretion over 16. If two out of three criteria were not fulfilled, participants continued the test walking 7 km · h^{-1} with 10° ascent until exhaustion. This non-standard test protocol was chosen to simulate daily activities better than traditional VO_{2max} test protocols, as uphill and downhill walking is rather a common activity in normal daily life. The end of the test was done by walking (instead of more commonly used running) because many of the subjects were unaccustomed to running and safety could have been compromised especially with older subjects. Twenty six subjects performed the running load. Seven subjects did not do the last walking load (7 km · h^{-1}10° ascent) since they got exhausted already in the previous load (5 km · h^{-1} 8° ascent).

FIGURE 5 Treadmill testing with simultaneous VO2, HR and ACC measurements (downhill and uphill walking; for subjects over 40 years medical doctor was present to ensure safety of subjects).

The performance testing session of Study II consisted of a VO_{2max} test on the treadmill. Warm-up duration was 5 min using a speed slow enough to stay under speed of V_{T1} but high enough to enable running rather than brisk walking, as transition from walking to running changes relative activation of muscles and could thus bias determination of EMG threshold. Shortly after the warm-up, breathing gases were collected for one minute and blood samples for lactate assessment were taken. A three-minute ramp protocol with 1 km·h^{-1} increments was used for the VO_{2max} test. The initial speed varied individually from 5 to 11 km · h^{-1} and was chosen based on training history, estimated fitness level of the subject and heart rate response during warm-up. The tests were terminated either a) voluntarily by the participants or b) when the subject could no longer maintain required running speed. The treadmill was stopped briefly after every ramp stage in order to take blood samples from a fingertip for lactate assessment (Lactate Pro, Arkray, Kioto, Japan). Breath-by-breath respiratory gases were collected and analysed using Sensor Medics Vmax 229 gas analyser (Yourbalinda, CA, USA). Heart rate was measured using wrist-top computer and heart rate belt (Suunto T6, Vantaa, Finland). EMG was recorded continuously with EMG shorts having embedded textile electrodes (Myontec Ltd, Kuopio, Finland).

4.3.3 Maximal voluntary contraction (MVC) tests (I, III and IV)

Subjects wore the shorts with textile electrodes (Myontec Ltd, Kuopio, Finland) during the activity laboratory test and performed bilateral maximal voluntary isometric contractions (MVC) in the knee extension/flexion machine (David 220, David Health Solutions, Helsinki, Finland) with 140° knee angle in both flexion and extension (Figure 6). The EMG values from MVC were used to normalize all EMG data. In all MVC tests subjects were first familiarized with the testing actions. At least 3 trials of 3-5 seconds were performed (with 1 minute rest period between trials) in each test and if torque improved more than 5 % in the last trial more trials were done. In all performances loud verbal encouragement was used to push subjects to their best.

FIGURE 6 Isometric maximal voluntary contraction (MVC) in bilateral knee extension (on left) and flexion (on right).

4.3.4 Active and passive transport tests (IV)

The tests consisted of four different tasks simulating passive and active ways of transport (Table 2 and Figure 7) and were performed on a separate day.

TABLE 2 Active and passive transport tests.

1. Transport by bus
- Walking to bus
- Sitting in bus
- Walking from bus
2. Using elevator
- Up to and down from the fourth floor
3. Walking
- Walking 1 km with self-selected pace
4. Negotiating stairs (no additional load)
- Ascending stairs until exhaustion (max. 5 flights of stairs)
- Descending stairs (the same amount of floors as in ascending)
5. Negotiating stairs (5kg bag in each hand)
- Ascending stairs until exhaustion (max. 5 flights of stairs)
- Descending stairs (the same amount of floors as in ascending)

Passive transport consisted of 50 m walk to a bus and sitting in it for two minutes (estimated as 1 km distance by bus in an urbanized area) and then walk again 50 m. During the second passive task the subjects used elevator to ascend and descend to the fourth floor. Active tasks were one kilometre walk at self-selected pace and ascend as many flights of stairs as possible (maximum 5 flight of stairs). The subjects were instructed to climb the stairs as long as possible until they felt too exhausted to continue. After breathing rate and HR had decreased close to normal levels while sitting they descended back to the ground floor. First stair negotiations were done with no additional load and then carrying 5 kg bags in both hands. All tasks were performed with a self-selected pace.

FIGURE 7 Subject performing active and passive transport tests with measurement equipment (portable gas analyser system, heart rate monitor, tri-axial accelerometer and EMG shorts). Pictures from left to right: in the elevator, walking (active transport), stair ascent and stair descent with 5 kg bags in each hand.

4.4 Measurements and data analysis

4.4.1 Anthropometrics

Body composition including fat percentage and visceral fat was measured with bio impedance device (InBody 720, Biospace Ltd, Soul, Korea) in a fasting state (Figure 8). Resting metabolic rate (RMR) was measured for calculation of metabolic equivalent (MET). Subjects filled in activity and health questionnaires in which, for instance, their habitual physical activity, percentage of time spent sitting during working hours and health status were asked.

FIGURE 8 Resting metabolic rate (on left) and body composition measurement with bioimpedance device (on right).

4.4.2 EMG measurements

EMG was measured with shorts made of knitted fabric similar to elastic clothes used for sport activities or as functional underwear with the exception of capability to measure EMG from the skin surface of the quadriceps and hamstring muscles (Figure 9) (Myontec Ltd, Kuopio and Suunto Ltd, Vantaa, Finland). To obtain the average rectified value of EMG (aEMG), the shorts were equipped with conductive electrodes and wires integrated into the fabric, which transfer the EMG signals from the electrodes to the electronics module. The textile electrodes are sewn onto the internal surface of shorts and consist of conductive yarns including silver fibres and non-conductive synthetic yarns woven together to form a fabric band. The electrodes are located such that the bipolar electrode pair lies on the distal part of the quadriceps and hamstrings, and the reference electrodes longitudinally at lateral sides (over tractus iliotibialis) on left and right side. Sizes of the electrodes were 2.5 x 9.5 – 14 cm for quadriceps muscles, 1.5 x 7.5 – 8 cm for hamstrings muscles and 2 x 29 – 33 cm for lateral grounding electrodes depending on the size of the shorts. Shorts were equipped with adjustable zipper in the waist and hems, and elastic Velcro straps in the hem for improved fit. Electrode paste (Redux Electrolyte Crème, Parker Inc., USA) was added on the electrode surfaces prior to every measurement day to improve and stabilize conductivity between the skin and electrodes. The subjects were also given a small bottle of the paste with them and instructed to add more paste after shower, for example. After every measurement day the shorts (electronics module detached) were washed with washing powder either by hand or in the washing machine.

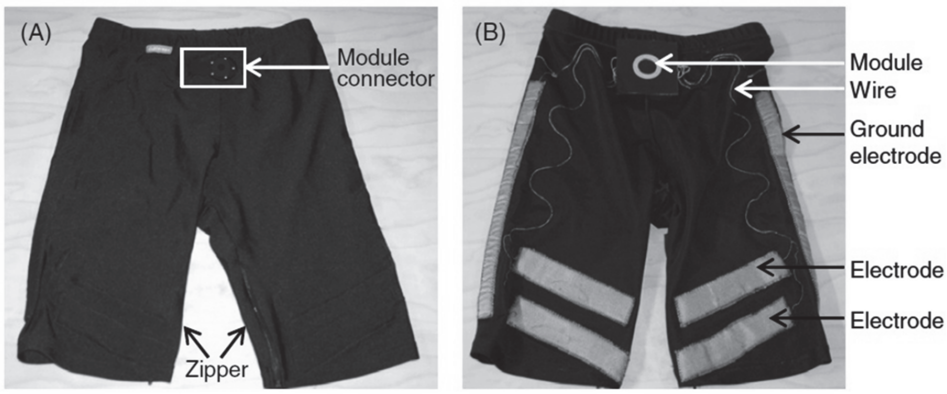

FIGURE 9 Picture of the EMG shorts with embedded textile electrodes, wires and connector for electronic module. The shorts viewed from front (A) and front side inside out (B).

The recording electronic module contains signal amplifiers, microprocessor with firmware, data memory and PC interface. In the module, the EMG signal is measured in its raw form with a sampling frequency of 1000 Hz and a frequency band 50 Hz – 200 Hz (-3dB). The raw EMG signal was first rectified and then averaged over non-overlapping 100 ms intervals. The averaged data was stored in the memory of the module from which the data was downloaded to a PC using the specifically designed HeiMo PC-software (Myontec Ltd, Kuopio, Finland) and then analysed in MegaWin software (Mega Electronics Ltd., Kuopio, Finland).

4.4.3 EMG analysis

Treadmill tests. In the treadmill test of Study I, EMG data from the last 60 seconds of each load were averaged and further analysed. The EMG signal from each of the four muscles (right quadriceps, right hamstring, left quadriceps, and left hamstring) was normalized to the maximal EMG values (EMG_{MVC}) taken as an average from a 1 s period during MVC for the given muscle. Right and left quadriceps values were averaged to form quadriceps variable [aEMG(Q)], right and left hamstrings to form hamstring variable [aEMG(H)] and all channels to form the variable for quadriceps and hamstrings [aEMG(QH)].

In Study II, participants' individual aEMG (sum of quadriceps and hamstrings) was averaged from last 30 sec of each running speed of treadmill test. To determine one or two breakpoints in the EMG response, we used a computer algorithm that models aEMG response to exercise using two-segment linear regression. With this method, a single linear regression is initially fitted to all data points and is used for later statistical comparisons and then a brute force method is used to fit two lines to the data points. Regression lines are then calculated for all possible divisions of the data into two contiguous groups, and the pair of lines yielding the least pooled residual sum of squares is chosen as representing the best fit (Lucia et al. 1999).

Artefact correction. From daily measurements of Study III and IV the entire EMG data was first visually assessed and corrected for artefacts. Use of automated algorithms was considered unreliable and difficult as data was not recorded in raw format but averaged over 100 ms intervals due to limited memory capacity of the module. Artefact removal and correction procedures were developed and refined with use of EMG shorts with online measurements possibility (Myontec Ltd, Kuopio, Finland). In the separate laboratory testing session, different intentionally induced artefacts (i.e. movement of electrodes, module and lead wires; applying different degrees of pressure on electrode locations, placing shorts very close to electrical devices etc.) were compared to normal activities of daily living, and data was simultaneously screened on computer in real-time. With this procedure it was possible to educate research personnel responsible for artefact correction to differentiate between real muscle activity and artefacts with a good degree of accuracy. The activity diaries and aEMG values during MVC (EMG_{MVC}, see below) were compared to the signal and if non-physiological signals were observed the data were operated with four possible methods (explained in more detail in article III): 1) Brief high amplitude (> 100 %EMG_{MVC}, < 1 s) artefacts were replaced with mathematical interpolation from values prior to and after the artefact. 2) Continuing artefact occurring during obvious bilateral movement (i.e. walking) was corrected by copying the data from contralateral channel. 3) In the case the artefact was longer than 30 min, the signal was removed from that particular channel and 4) in case the signal was consistently abnormal throughout the measurement day(s) the particular channel was removed fully from the analysis.

Baseline correction and data normalization. Signal baseline was determined as moving 5 minute minimum. The minimum of the following 5 minute data window was subtracted from each data point. The 5 min window was tested to be the best one to correct for minor baseline fluctuations without affecting the actual signal amplitude, inactivity times or activity burst durations. Maximal EMG values (EMG_{MVC}) were taken as an average from a 1 s period during MVC. The EMG signal from each of the four muscles (right quadriceps, right hamstring, left quadriceps, and left hamstring) was normalized to the EMG_{MVC} value in a given muscle, and the mean of the four channels is presented in the results as % of EMG_{MVC}. Also the thresholds for light, moderate and vigorous intensities were determined channel-by-channel from normalized EMG before averaging the four channels.

Threshold level determinations. Threshold levels between different muscle activity intensities during normal daily life were based on the standing reference test and an incremental treadmill walking test. The threshold between inactivity and light-intensity activity was set as an EMG value corresponding to 90% of the EMG value of standing on each individual and each channel. Thus, inactivity in this report represents the true individual behaviour below standing activity. The thresholds between light and moderate, and moderate and vigorous intensity were defined as 3 METs (metabolic equivalent) and 6 METs, respectively. These thresholds were assessed from the incremental treadmill walking test in the following way: From each load EMG was taken as one minute average from the middle of the load and VO_2 as an average from two last minutes of the load. VO_2 values were transformed to METs by division with resting metabolic rate (RMR). EMG values from each load were plotted against the corresponding MET values, and the EMG values corresponding to 3 METs (threshold for moderate intensity) and 6 METs (threshold for vigorous intensity) were calculated by regression analysis and used as individual threshold values. In the regression, additional point was added for 1 MET=0 EMG representing the resting state and the highest VO_2 value was excluded since the normal daily activities are lower and the highest value could have biased the regression equation.

Calculation of variables. Determination of burst variables is shown in Figure 10. The artefact corrected and normalized EMG data was run through a custom made Matlab script (MATLAB, MathWorks, Massachusetts) where the following EMG variables were calculated: average EMG from the entire recording period (% of EMG_{MVC}); total inactivity duration (min); durations of five longest continuous inactivity periods (min); light intensity activity time (min); moderate intensity activity time (min); vigorous intensity activity time (min); number of bursts (#); average duration of bursts (s); average amplitude of all bursts (% of EMG_{MVC}); burst rate (bps); total area of bursts (% of EMG_{MVC} * s). After the variables (e.g. inactivity time, burst amplitude) were extracted from each four channels, they were averaged across different days within individual. Then, the different variables from the four muscle groups were averaged to get one descriptive variable for each subject, and these averaged values were used for further analysis. The distribution of muscle activity for different levels was calculated for different percentages of EMG_{MVC}: 0-1, 1-2, 2-3, 3-4, 4-5, 0-5, 5-10, 10-20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-80, 80-90, 90-100 and >100. After that the calculations were completed with the individual threshold levels for inactivity, light-, moderate- and vigorous-intensity activity.

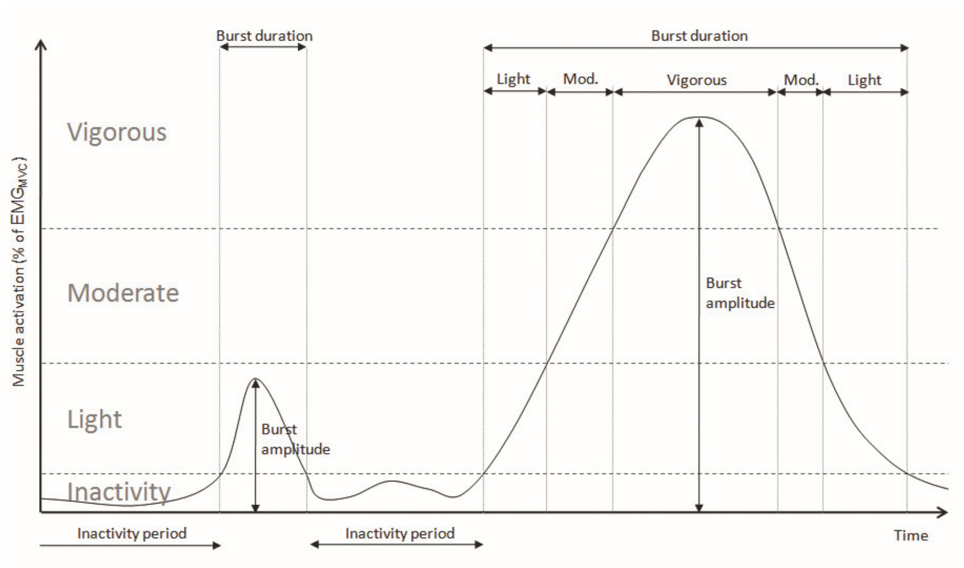

FIGURE 10 Analysis of burst characteristics and muscle activities. Schematic drawing depicting analysis of burst amplitude, duration, inactivity periods and differentiation to light, moderate and vigorous muscle activities. The thresholds for inactivity, light, moderate and vigorous activities were determined individually (see text).

Repeatability of data. Repeatability of the EMG data was assessed using the reference tests from 20 subjects during 1-3 days. The reference test consisted of lying down quietly for 15 s, standing quietly for 15 s and remaining in half-squat position for 15 s. From each task average EMG values from a 10 s period were analysed. Intraclass correlation was calculated between aEMG values of two tests within the same day. The mean intraclass correlation of all four channels was 0.73 ± 0.19 in lying down, 0.75 ± 0.16 during standing and 0.73 ±

0.09 during half-squat. Day-to-day intraclass correlations of all four channels were 0.80 ± 0.37 in lying down, 0.97 ± 0.03 during standing and 0.90 ± 0.07 during half-squat. It should be noted that these analyses were done before signal baseline correction, which can explain the higher day-to-day than within-day repeatability.

4.4.4 Ventilatory gases (I, II and IV)

Ventilatory gases in studies I and IV were measured breath-by-breath during treadmill testing and resting with Jaeger Oxycon Pro with LabManager 3.0 software (Viasys Healthcare Gmbh, Hoechberg, Germany) which was calibrated before every participant. Nasal respiration was blocked with a nose clip (Nose Clip Disposable Series 9014, Hans Rudolph Inc. Shawnee, USA). In transport tests of Study IV portable gas analyser (Oxygon Mobile, VIASYS Healthcare Gmbh, Hoechberg, Germany) with a face mask was used.

In Study I resting metabolic rate was determined as an average oxygen uptake over 10 minutes that was preceded by 20 minutes of quiet bed rest. In the treadmill test respiratory gases from the last 60 seconds of each load were averaged and further analysed. Energy expenditure (EE) was calculated from oxygen consumption (VO_2) and respiratory equivalent ratio (RER) with the following equation: $EE\ (kcal \cdot min^{-1}) = (1.2 * RER + 3.85) * (VO_2 * 1000^{-1})$

In the treadmill testing of Study II breath-by-breath respiratory gases were collected and analysed using Sensor Medics Vmax 229 gas analyser (Yourbalinda, CA, USA). Breathing variables were averaged from last 30 sec of each running speed. V_{T2} was determined by visual observation using the methodology previously described by Davis (Davis 1985). The following indicators were used to detect V_{T2}: 1) steep rise in lactate concentration, 2) steep rise in ventilation-oxygen consumption ratio, 3) steep rise in ventilation-carbon dioxide production ratio and 4) steep decrease in true O_2. Two independent observers visually detected V_{T2} following the criteria described above. If they did not agree, opinion of a third investigator was included.

4.4.5 Blood lactate (II)

The treadmill was stopped briefly after every ramp stage in order to take blood samples from a fingertip for lactate assessment (Lactate Pro, Arkray, Kioto, Japan). Onset of blood lactate accumulation (OBLA) was defined as the running speed corresponding to a blood lactate concentration of 4.0 $mmol \cdot L^{-1}$ (Buckley, Bourdon & Woolford 2003). Linear interpolation was used between two data points closest to 4.0 $mmol \cdot L^{-1}$ to acquire exact timing of OBLA.

4.4.6 Heart rate (I, II and IV)

Heart rate was monitored with Suunto T6 wrist computer and heart rate belt (Suunto Oy, Vantaa, Finland). HR was measured continuously during the tests and resting HR rate was determined as lowest average 5 second value. In the treadmill test of Study I and IV the last 60 seconds of each load were averaged and further analysed while in Study II last 30 seconds of each load were used. Heart rate was calculated as % of maximum and the highest value from the treadmill test was used as maximum value.

4.4.7 Accelerometry (I)

Acceleration was measure with tri-axial accelerometer (HM120, Alive Technologies Pty. Australia) worn on hip. Acceleration signal was filtered with 0.5-11 Hz band-pass filter with finite impulse response to decrease effects of gravity and high frequency artefacts (Van Someren et al. 1996). After filtering the signal was rectified and moving average with 10s window was applied. Activity counts were calculated separately to x, y and z values of acceleration. Sum vector of x, y and z was calculated with equation $xyz = (x^2 + y^2 + z^2)^{1/2}$. Activity counts were calculated as area under the curve (integration) from 60 s time periods. This activity count describes physical activity from a given 60 s period.

4.5 Statistical analyses

In Study I to evaluate the heterogeneity, the different background variables were described by using means and standard deviations. The main focus was in the comparisons of different methods measuring the EE. Firstly, Pearson's correlation coefficients, the mean, standard deviation and standard error of coefficients were calculated for each subject with respect to each method. This approach follows Diggle et al. (1994) which suggests that the individual data can be summarized into a derived variable such as a correlation or a regression coefficient (slope). Then, the dimension of the data is decreased into one dimension and the standard ANOVA or Student's T-test can be used to test the differences between methods with the significance level $p<0.05$ (Diggle, Liang & Zeger 1994). Besides the derived variable approach for each method, we fitted linear mixed models, which could also be used for a prediction purposes both at the population level and at the individual level. The selection of fixed and random parameters to be included to the model was performed using a maximum likelihood approach. The final model was calculated using a restricted maximum likelihood method. An Akaike information criterion (AIC) was applied as a measure for goodness of fit of different methods (Akaike & Hirogu 1974). For comparison purposes in this analysis, AIC value was divided by the number of data points to get AIC/n value. Reliability of test-retest was described with correlations and typical errors.

In Study II mean and standard deviation (SD) was used to describe the variables. Participants' individual aEMG, heart rate and breathing variables were averaged from last 30 seconds of each running speed. Normality of the data was tested with Saphiro-Wilk test. A one-way ANOVA with post hoc test using the Bonferroni correction was used to test differences between different methods. Bland & Altman procedures were used to test agreement between different methods (Bland & Altman 1986). Pearson's correlation coefficients were used for correlations. Significance level was set at $p < 0.05$.

In Study III data is presented as mean ± standard deviation. The differences between the genders were studied with independent samples Mann-Whitney U-test after checking distribution of the data with Saphiro-Wilk test. Significance level was set at $P<0.05$.

In Study IV data is presented as mean ± standard deviation, except transport test results, which are presented in median ± standard deviation (because all test done for those results are based on median values). Nonparametric analyses were used because of non-gaussian distribution with high skewness and kurtosis. To reveal differences between passive and active tasks the Wilcoxon Signed Ranks Test (2-tailed) was used and Kendall's Tau-b (2-tailed) was applied for correlations. Significance level was set at $P<0.05$. In all studies statistical analyses were performed with PASW Statistics v.18.0 (SPSS Inc. Chicago, Illinois, US).

5 RESULTS

5.1 Descriptives

Characteristics of the subjects in the separate studies are given in Table 3. Examples of daily EMG recordings are shown in Fig 11 illustrating increasing EMG activity with increasing workload in treadmill test (A) and different daily EMG activity patterns between two individuals (B and C).

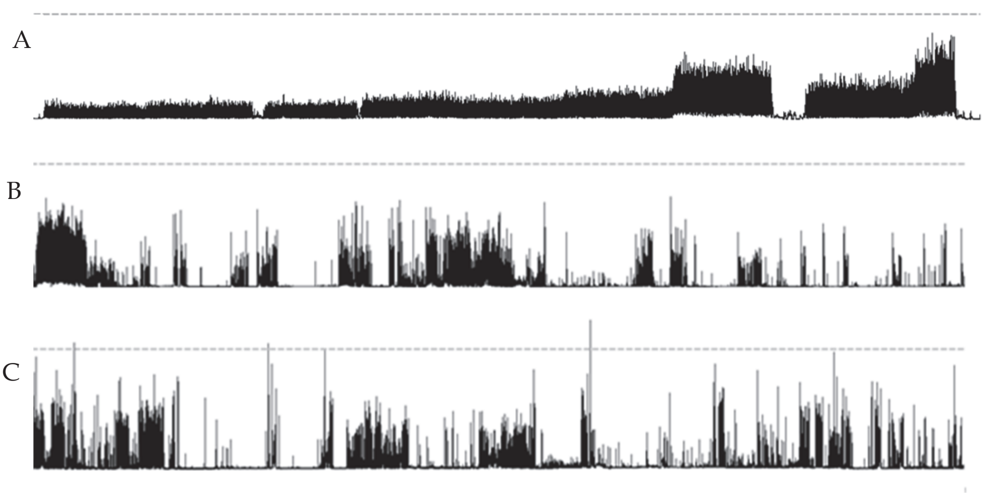

FIGURE 11 Example EMG data (right quadriceps and hamstrings combined) from A) Treadmill II test, B) and C) Daily EMG data from two separate subjects. Horizontal dashed line represents 100 % of EMG_{MVC}.

5.2 Validity and reliability of the EMG method

5.2.1 Prediction of energy expenditure (I)

In order to compare the validity of EMG, ACC and HR in estimating energy expenditure (treadmill test, Fig. 11A), correlations and the AIC method was used. Both correlation and AIC/n were ranking the different measurement methods similarly (Table 4). When all loads were included in the analysis, heart rate was the best predictor of EE according to correlation and AIC/n. At low loads hamstrings aEMG was the best predictor and at level loads acceleration provided the best prediction for EE. Figure 12 illustrates example graphs of the highest and lowest individual correlations for different methods.

To be able to predict momentary energy expenditure, prediction equations were calculated, which consisted of the same random coefficients as the models of Table 4 (covariates were added to the model). Level loads were excluded for simplicity as natural environments contain uphills, downhills, stairs etc. and for practical reasons only variables that need no laboratory measurements were included (age and sex).

TABLE 3. Characteristics of the subjects.

	Study I		Study II		Study III		Study IV	
	Men	Women	Endurance runners	Recreationally active	Men	Women	Men	Women
N	28	26	12	15	40	44	6	3
Age (yrs)	39.2 ± 13.7	39.6 ± 14.2	24.8 ± 2.8	25.4 ± 2.7	44.2 ± 16.5	44.1 ± 18.0	72.0 ± 2.6	71.0 ± 3.6
Height	180.1 ± 7.2***	166.7 ± 5.1	178 ± 4.7	177 ± 5.7	178.5 ± 6.6***	166.0 ± 5.6	174.0 ± 2.1	161.0 ± 5.8
Weight	79.4 ± 13.0***	62.7 ± 7.7	69.1 ± 8.2	73.2 ± 7.8	78.0 ± 11.9***	62.3 ± 8.6	70.9 ± 10.1	51.9 ± 13.0
BMI	24.4 ± 3.1*	22.5 ± 2.4	23.3 ± 3.0	21.8 ± 2.9	24.4 ± 2.8	22.6 ± 2.8	23.1 ± 3.6	21.9 ± 3.7
Fat %	16.9 ± 5.3**	21.6 ± 7.6	10.5 ± 3.3	15.0 ± 6.7	17.1 ± 5.8	22.3 ± 8.6	19.7 ± 7.5	31.9 ± 16.7

* = P < 0.05; ** = P < 0.01; *** = P < 0.001 differences between groups within the study.

Prediction equations are shown in Table 5 and include only variables that were significant or interacted significantly. The studies on the accuracy of the equations are the following. Table 5 shows also AICs for prediction equations and the correlation coefficients between the observed and the predicted EE at the population and individual level calculated for the individuals of the data. The individual level model provides more accurate EE prediction than the population level model (Figure 13).

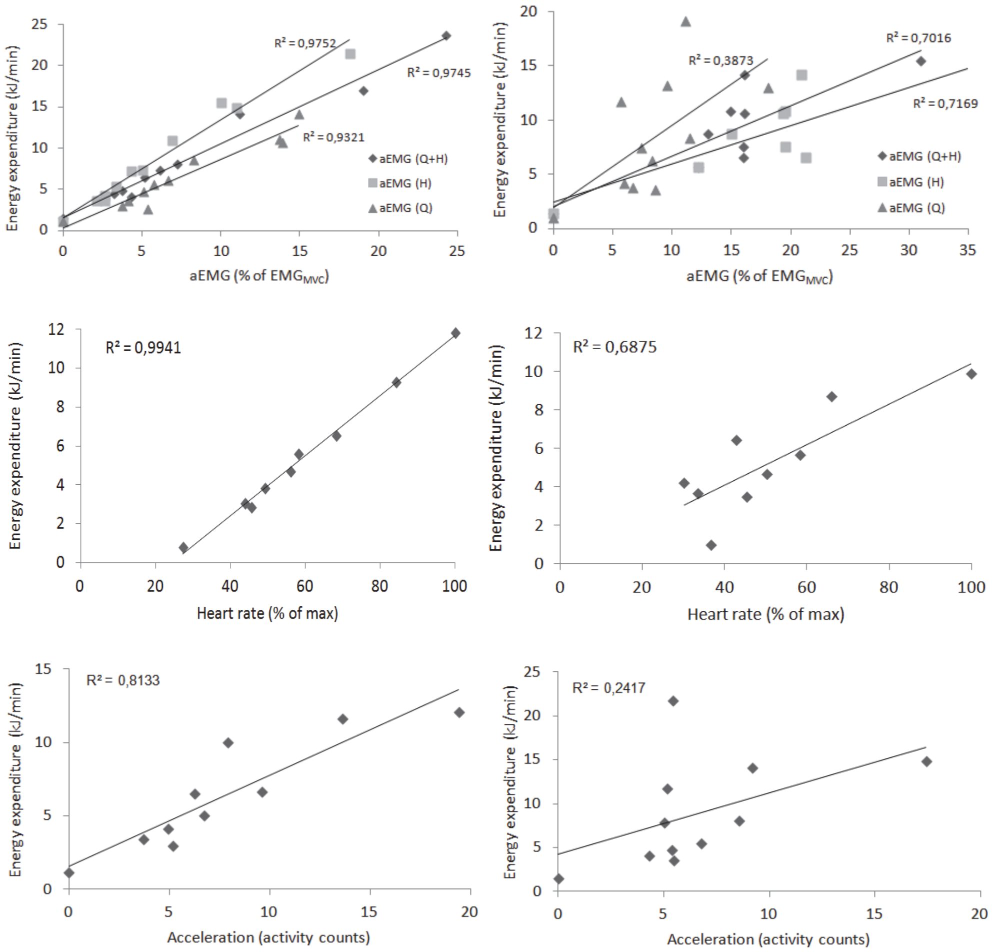

FIGURE 12 Example graphs of the highest (left panel) and the lowest correlations (right panel) for different methods between absolute EE and aEMG (Q+H), aEMG (Q), aEMG (H), HR and ACC including all loads.

TABLE 4 Averages of R-values of individual correlations [(mean (SD)] and AIC/n values between energy expenditure (EE), aEMG (Q+H) from quadriceps and hamstrings (n=52), aEMG (Q) from quadriceps (n=54), aEMG (H) from hamstrings (n=52), heart rate (HR; n=54) and acceleration (ACC; n=51).

	aEMG (Q+H)	aEMG (Q)	aEMG (H)	HR	ACC
All loads		ns			
R-values	**0.94 (0.03)**	**0.91 (0.07)**	**0.94 (0.03)**	**0.96 (0.04)**	**0.77 (0.10)**
AIC/n	**4.38**	**4.86**	**4.46**	**3.66**	**5.38**
Low loads				ns	
R-values	**0.89 (0.08)**	**0.79 (0.10)**	**0.93 (0.07)**	**0.89 (0.23)**	**0.80 (0.07)**
AIC/n	**3.47**	**3.96**	**3.18**	**3.52**	**3.75**
Level loads			ns		
R-values	**0.97 (0.03)**	**0.97 (0.05)**	**0.96 (0.04)**	**0.95 (0.08)**	**0.99 (0.02)**
AIC/n	**3.32**	**3.42**	**3.653**	**3.649**	**2.47**

All correlations between different methods were significantly different (at level of 0.05 > P < 0.001) unless marked in the table (ns=non-significant). All correlations between different load categories (all, low and level loads) were significantly different (on level of 0.05 > P < 0.001) except aEMG (H) between all loads and low loads; and heart rate between all loads and level loads.

TABLE 5 Prediction equations for energy expenditure (EE; kJ ·min^{-1}) from aEMG(QH), aEMG(Q), aEMG(H), heart rate (HR) and acceleration (ACC) and AIC and the correlation coefficients between the observed EE and the predicted EE at the population level (Cor P) and the predicted EE at the individual level (Cor I). The prediction value of the model is the best when AIC is the lowest.

Regression	AIC	Cor (P)	Cor (I)
All loads:			
EE = 0.627 + 0.254·Sex + 0.015·Age + (0.968 + 0.179·Sex - 0.011·Age) ·aEMG(QH)	2439	0.76	0.95
EE = 0.514 + 0.203·Sex + 0.010·Age + (1.375 + 0.265·Sex - 0.017·Age) ·aEMG(Q)	2659	0.70	0.91
EE = 1.241 + 0.634·Sex + 0.012·Age + (0.682 + 0.121·Sex - 0.007·Age) ·aEMG(H)	2391	0.75	0.95
EE = -4.832 - 0.659·Sex + (0.094 + 0.030·Sex) ·HR	1808	0.86	0.97
EE = 1.249 + 0.503·Sex + (0.774 + 0.353·Sex) ·ACC	2810	0.75	0.79
Low loads:			
EE = 0.745 - 0.001·Age + 0.511·Sex + (0.933 - 0.009·Age) ·aEMG(QH)	1102	0.62	0.92
EE = 1.398 -0.007·Age +0.880·SexM + (0.886-0.008·Age) ·aEMG(Q)	1253	0.56	0.83
EE = 1.141 - 0.005·Age + (0.788 - 0.006·Age) ·aEMG(H)	1006	0.62	0.95
EE = -3.928 - 0.854·Sex + (0.083 + 0.031·Sex) ·HR	1126	0.69	0.93
EE = 1.041 + 0.326·Sex + (0.622 + 0.250·Sex) ·ACC	1134	0.76	0.85

aEMG in % of EMG_{MVC}; HR in beats per minute; ACC in counts per minute; Age in years; Sex (1 for men, 0 for women)

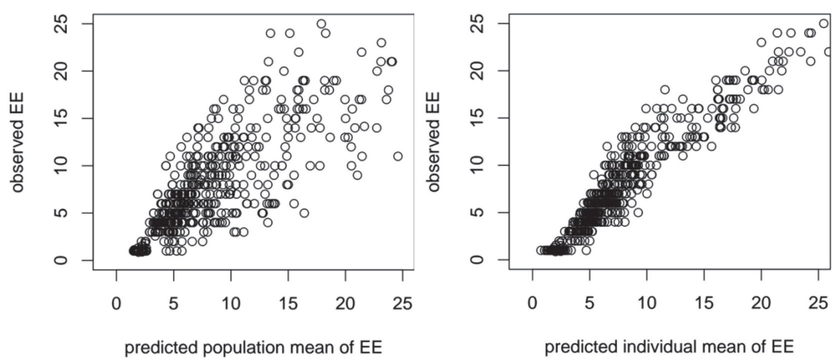

FIGURE 13 Energy expenditure prediction from hamstring EMG with the population and individual level models (in all loads).

5.2.2 EMG threshold and ventilatory thresholds (II)

Mean VO_{2max} for the recreationally active subjects was 50 ± 7 mL·kg^{-1}·min^{-1} and 64 ± 8 mL·kg^{-1}·min^{-1} for the endurance athletes (P<0.001). Running speed at the end of the test was 14.8 ± 1.7 km · h^{-1} for recreationally active subjects and 19.0 ± 1.4 km · h^{-1} for endurance athletes (P<0.001). Blood lactate peaked at 12.1 ± 1.7 mmol·L^{-1} and 12.1 ± 1.6 mmol·L^{-1}, in recreationally active and endurance athletes, respectively. In the group level, the EMG threshold existed with the difference in the slope being 27.6 ± 11.8 (slope increased from 10.4 ± 2.4 to 38.0 ± 11.6) in endurance athletes and 19.9 ± 15.2 (slope increased from 13.3 ± 8.1 to 33.2 ± 19.2) in recreationally active subjects. The difference between the groups in the change of slope was non-significant. There were no significant differences between the occurrence of OBLA, V_{T2} and EMG_T in recreationally active subjects but in athletes lactate and running speed differed significantly between OBLA and EMG_T (Table 6). In athletes VO_2, lactate and running speed were similar in the EMG_T and V_{T2} (Table 6).

TABLE 6 Comparison between mean values of VO_2, lactate, and running speed at OBLA, V_{T2} and EMG_T for endurance athletes group (n=8) and for recreationally active subjects (n=13). Values are expressed as mean and standard deviation.

	VO₂ (mL · kg^{-1} · min^{-1})	*Lactate* (mmol · L^{-1})	*Running speed* (km · h^{-1})
Endurance athletes			
OBLA	55.7 ± 6.4	4.0 ± 0.0*	16.4 ± 1.0*
V_{T2}	59.2 ± 6.6	5.3 ± 1.2	17.1 ± 0.8
EMG_T	61.7 ± 6.2	7.1 ± 2.7*	17.8 ± 0.9*
Recreationally active			
OBLA	39.8 ± 9.9	4.0 ± 0.0	10.8 ± 2.1
V_{T2}	43.0 ± 7.0	5.4 ± 1.3	12.0 ± 1.2
EMG_T	40.6 ± 8.6	5.2 ± 2.5	11.2 ± 1.8

*Running speed (P=0.018) and lactate (P=0.004) concentration were significantly different between OBLA and EMG_T in endurance athletes. No other differences were found.

For the entire group, the correlation coefficient between EMG_T and V_{T2} was 0.86 (P<0.001) and 0.84 (P<0.001) between EMG_T and OBLA. When the groups were examined separately the correlations persisted similar, only in athletes the correlation between VO_2 at EMG_T and VO_2 at OBLA did not reach statistical significance (Figure 14).

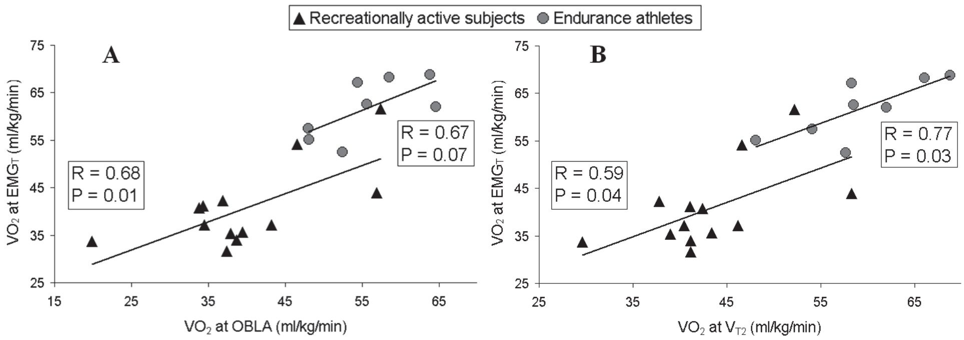

FIGURE 14 Relationship between VO_2 at EMG_T and OBLA (A); and VO_2 at EMG_T and V_{T2} (B) for recreationally active subjects (n=13; black triangles) and endurance athletes (n=8; grey circles).

To compare the degree of agreement between EMG_T, V_{T2} and OBLA Bland-Altman plots were utilized (Figure 15). Although all cases fell inside 2SD range in both groups, the limits of agreement were more than 50% smaller in the athletes than in the recreational group. Compared to V_{T2} method, the mean value of EMG_T was positive in the Bland-Altman plots demonstrating that method is giving slightly higher (i.e. thresholds are occurring at higher running speeds) values than V_{T2} method (Figure 15 E). Contrary, OBLA yields slightly lower values than V_{T2} (Figure 15 F).

The above results were analysed using the sum of quadriceps and hamstring muscle EMG signal. We also analysed these muscle groups separately to find out if additional value could be obtained for athletic training. From hamstring muscles the EMG_T threshold was detected in all recreationally active subjects but only in six endurance athletes. In quadriceps the threshold was identifiable in nine recreationally active and six athletes. Compared to the EMG_T of combined muscles, the EMG_T of the hamstrings occurred on average at 0.4 ± 1.2 km · h^{-1} lower running speeds in recreationally active subjects, and at 0.2 ± 0.4 km · h^{-1} lower running speeds in endurance athletes. Compared to the EMG_T of combined muscles, the EMG_T of the quadriceps occurred on average at 0.2 ± 2.0 km · h^{-1} higher running speeds in recreationally active subjects, and at 0.3 ± 0.5 km · h^{-1} higher running speeds in endurance athletes.

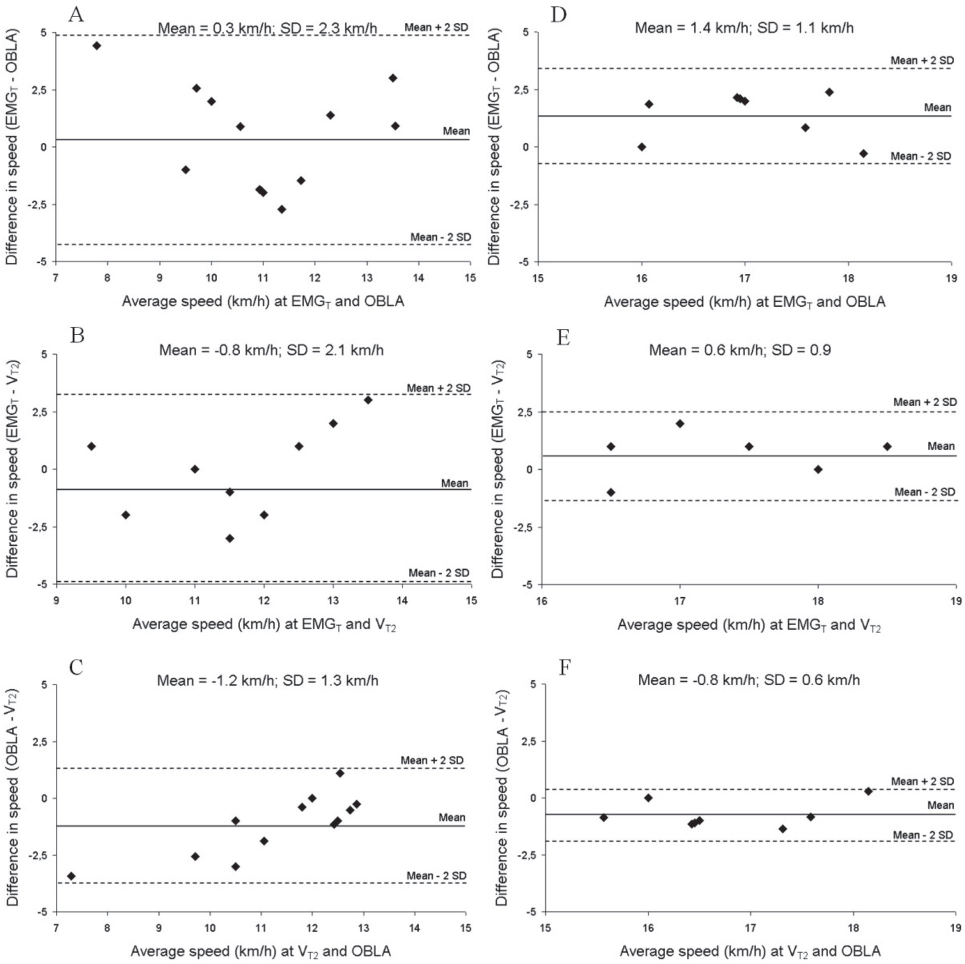

FIGURE 15 Bland-Altman plots for running speed ($km \cdot h^{-1}$) data corresponding to EMG_T, V_{T2} and OBLA. Recreationally active subjects (*n*=13) on the left side (A, B, C) and endurance athletes (*n*=8) on the right side (D, E, F). The solid line represents mean and dashed lines 2SD range. Note, that some data points are on top of each other.

5.2.3 Inactivity threshold (III)

Individually determined inactivity threshold is based on the observed difference in muscle activity between lying down and standing shown in Figure 16. The individually defined inactivity, moderate activity (3 MET) and vigorous activity (6 MET) thresholds were 2.5 ± 1.7, 6.3 ± 3.7 and 14.2 ± 8.8 % EMG_{MVC}, respectively.

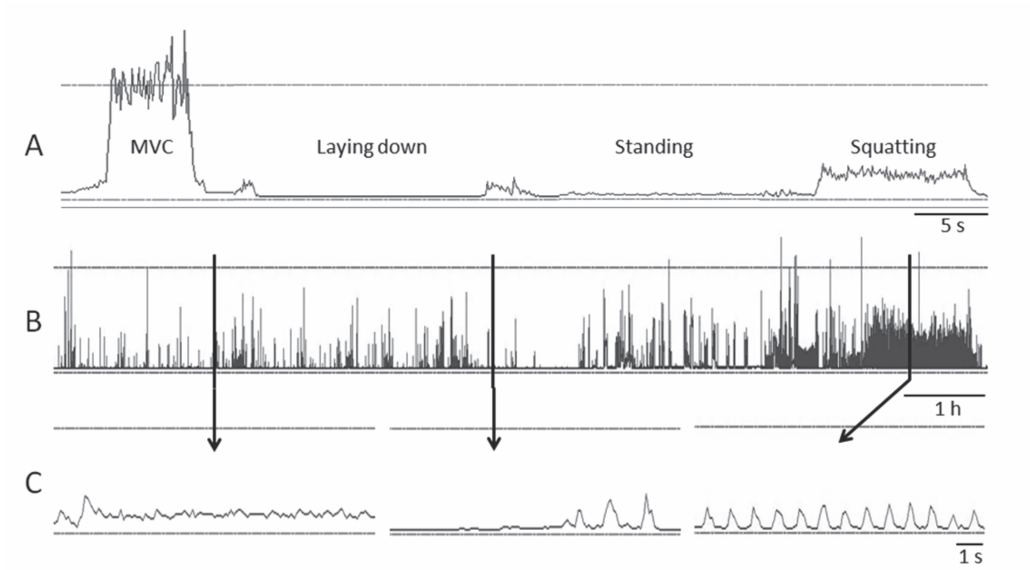

FIGURE 16 Example EMG data from laboratory and field measurements (averaged EMG data of left quadriceps femoris from one subject). Part A shows from the laboratory measurement session MVC of knee extension, lying down, standing still and squatting. Part B shows EMG activity during the entire day. Part C shows zoomed areas from daily EMG data (thick vertical lines show which parts of the data are zoomed). Horizontal lines represent baseline and 100 % of EMG_{MVC}.

Table 7 shows comparisons of total daily activity and inactivity times calculated using the individual inactivity thresholds and absolute thresholds of 1, 2 and 5 % of EMG_{MVC}. On average, the 2 % EMG_{MVC} threshold yields activity and inactivity times similar to the individually determined threshold.

TABLE 7 Inactivity times during normal daily life based on different thresholds. The first row represents results using individually determined threshold below standing activity (mean of four muscle groups) that is compared to the absolute % levels of each individual's EMG amplitude during maximal voluntary contraction (EMG_{MVC}).

Inactivity threshold	**Inactivity time (% of total time)**	
	Mean	**SD**
90 % of EMG of standing	67.5	11.9
1 % EMG_{MVC}	54.5	17.1
2 % EMG_{MVC}	68.2	15.4
5 % EMG_{MVC}	81.4	11.9

5.3 Simulated activities of daily living (III and IV)

Muscle activities during the different functional tasks in the laboratory are shown in Figure 17. For example, muscle activity during standing is almost 2.5 times higher than during sitting. Downhill walking yields similar average muscle activity as walking on level ground and muscle activity is increased on average 30.8 % in 4° uphill compared to no ascension with same walking speed (5 km · h^{-1}). While stairs ascend is typically considered as non-exercise activity it produces EMG amplitudes over 20 % of EMG_{MVC} that are much higher than in brisk walking.

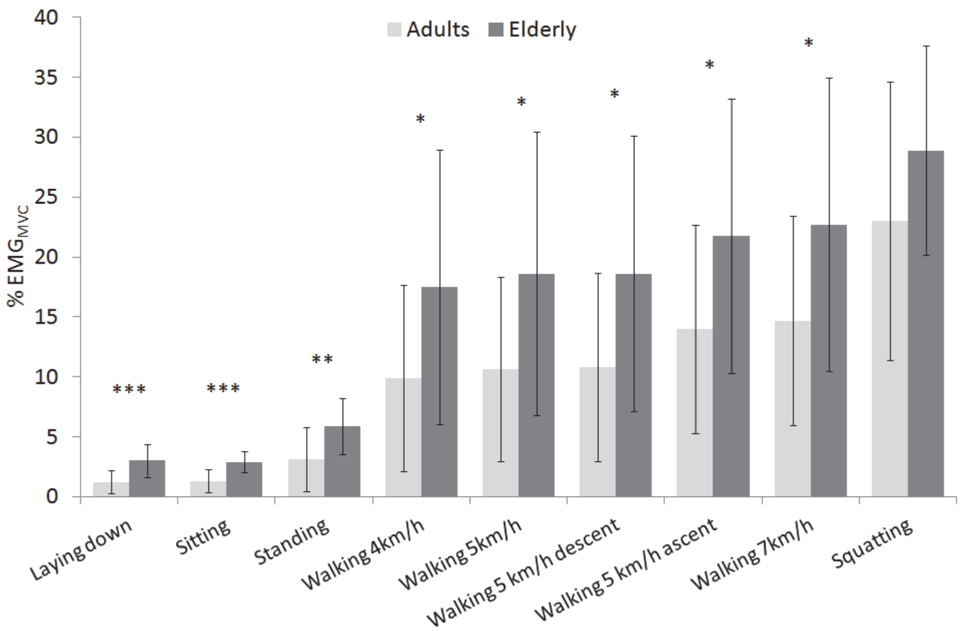

FIGURE 17 Average (±SD) quadriceps and hamstring muscle activity for different daily tasks measured in the laboratory (n=63-84 for adults; n=8-9 for older people). * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$ differences between adults and older people.

5.4 Active vs. passive transport (IV)

Cardiovascular and neuromuscular loading during tasks simulating active and passive transport are shown in Figure 18. The mean muscle activity was the lowest when using a lift (5 % of EMG_{MVC}) followed by passive transport which included sitting and walking (13 % of EMG_{MVC}). Mean muscle activity was the highest during unloaded and loaded ascent reaching 29 and 32 % of EMG_{MVC}, respectively. In unloaded and loaded stair descent the mean muscle activity was of similar magnitude as in walking.

Oxygen consumption did not follow the trend of muscle activation being significantly lower ($P < 0.01$) during unloaded and loaded ascending than during walking. Oxygen consumption during elevator use (7 ml $\cdot$ kg^{-1} $\cdot$ min^{-1}) was comparable to the energy requirement of unloaded (6 ml $\cdot$ kg^{-1} $\cdot$ min^{-1}) and loaded descent (8 ml $\cdot$ kg^{-1} $\cdot$ min^{-1}).

The average EMG during walking was 1.8 ± 0.3 times higher than in passive transport. In turn, the cumulated EMG of walking 1 km was 3.5 ± 2.7 and cumulated VO_2 2.2 ± 0.4 times higher than in passive transport. 1 km walking time was negatively correlated with average EMG (τb= - 0.556, p= 0.037) and average VO_2 during walking (τb= - 0.667, p= 0.012).

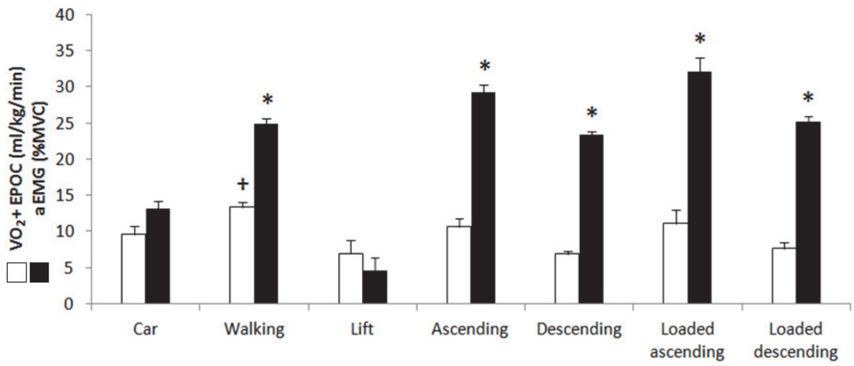

FIGURE 18 aEMG and VO_2 + EPOC during different tasks in the older people. * = p<0.01 in aEMG between passive and corresponding active tasks. † = p<0.01 difference in VO_2+EPOC between walking and using car.

5.5 Daily muscle inactivity (III and IV)

In adults thigh muscles were inactive for 67.5 ± 11.9 % of the measurement time during normal daily life (Figure 19). Inactivity ranged from 39.9 to 90.9 % of the measurement time highlighting large inter-individual differences in physical activity behaviour. In older people thigh muscles were inactive for 49.6 ± 3.9 % of the measurement time (range from 43.1 to 54.7 %). The 5 longest continuous inactivity periods for each individual are shown in (Figure 20). The longest continuous inactivity periods were all longer in older people than in younger lasting for 20.9 ± 10.0 min vs. 13.9 ± 7.3 min; 14.6 ± 5.6 min vs. 9.8 ± 4.5 min; 11.6 ± 4.5 min vs. 8.0 ± 3.4 min; 9.7 ± 3.5 min vs. 7.0 ± 3.0 min; 8.8 ± 3.1 min vs. 6.3 ± 2.7 min for 1st, 2nd, 3rd, 4th and 5th longest inactivity periods (old vs. younger), respectively. Bivariate correlations revealed that the longest inactivity period was associated with the 2nd (R^2=0.80), 3rd (R^2=0.72), 4th (R^2=0.70) and 5th (R^2=0.68) longest inactivity periods (P<.001). Thus the longest inactivity period represents the trend of the lengths of other inactivity periods, also.

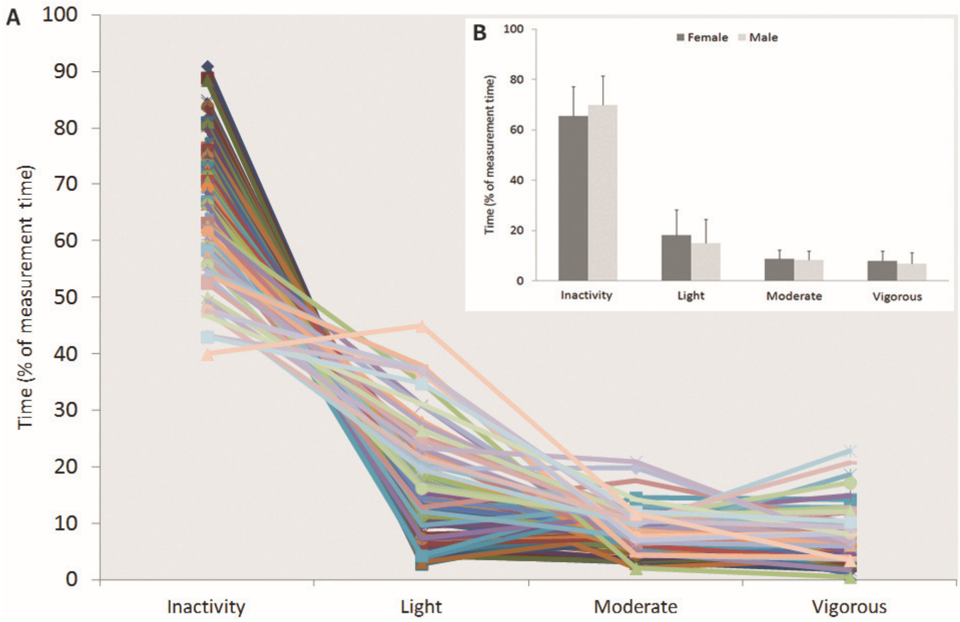

FIGURE 19 A) Time spent at different muscle activity levels during normal daily life based on individual threshold values (2.5 ± 1.7, 6.3 ± 3.7 and 14.2 ± 8.8 % EMG_{MVC} for inactivity, moderate activity and vigorous activity thresholds, respectively). Each line represents one individual (n=84). B) Duration of mean (±SD) quadriceps and hamstring muscle activity at different intensities did not differ between males (n=40) and females (n=44) during an 11 hour measurement.

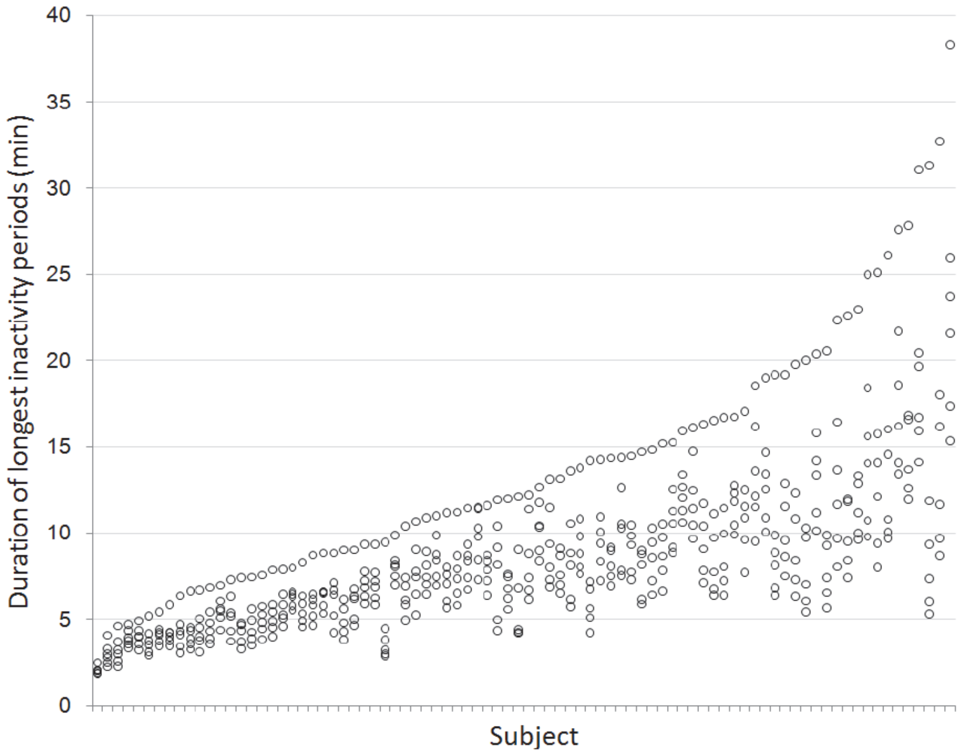

FIGURE 20 Five longest inactivity periods for all subjects (subjects arranged according to longest inactivity period; n=84). Each vertical row represents durations of five longest inactivity periods of one subject.

5.6 Daily muscle activity (III and IV)

Mean muscle activity (4.0 % vs. 5.9 %) and burst amplitude (5.8% vs. 10.3 %) was significantly higher during normal daily life in the older compared to younger (Table 8). To provide reference points, activity of approximately 6 % of EMG_{MVC} relates to activity of standing and walking 4 km · h^{-1} to 17 % of EMG_{MVC} in the older people, although individual variations are rather high in walking (Figure 17). Burst duration was considerably longer in older subjects compared to younger (2.2 ± 2.5 vs. 1.4 ± 1.4 s, respectively) and older subjects had less muscle activity bursts when compared to younger subjects (10,563 ± 4,694 vs. 12,600 ± 4,000 / day). Activity times were higher in all activity intensity categories for older subjects (activity times for light (11.4 ± 6.0 % vs. 8.5 ± 3.4 %), moderate (30.2 ± 7.6 % vs. 16.7 ± 9.9 %) and vigorous activity (8.8 ± 5.2 % vs. 7.3 ± 4.2 %), respectively). Inter-individual variances for adults were considerably high in light, moderate and vigorous activities ranging from 2.8 to 45.0 %, 2.0 to 20.9 % and from 0.5 to 22.8 % of measurement time, respectively.

Table 9 shows the time spent at different EMG intensities in detail. In all subjects 97 % of the measurement time muscle activity was below 30 % of EMG_{MVC} and less than 2 min was at intensities above 70 % EMG_{MVC}. Accumulated time over 50 % of EMG_{MVC} was only 5.1 ± 6.4 min (range 0.0–21.2 min). Women had significantly more (15.7 %, P<0.05) activity bursts than men and time over 50 % EMG_{MVC} was 73 % longer than in men (p<0.05). Overall, women spent more time at intensities above 40 % EMG_{MVC} compared to men (p<0.05). In adults the number of bursts (11 591 ± 4 331 vs. 13 410 ± 3 549) and time over 50 % EMG_{MVC} (3.7 ± 5.4 vs. 7.1 min) was significantly different (P<0.05) between men and women, respectively.

TABLE 8 EMG volume and rate indicators from normal daily life for normal population and older people presented relative to isometric MVC (±SD).

	Adults (n=84)		**Older people (n=9)**	
	Mean	**SD**	**Mean**	**SD**
EMG volume indicators				
Average amplitude (% EMG_{MVC})	4.0*	2.6	5.9	2.4
Average burst amplitude (% EMG_{MVC})	5.8***	3.4	10.3	3.9
Total area (% EMG_{MVC} * s)	133 268	83 046	186 931	76 121
Time over 50 % EMG_{MVC} (min)	5.1	6.4	7.4	6.2
Activity time (min)	215	86	187	43
EMG rate indicators				
Number of bursts	12 544	4 021	10 563	4 694
Average burst duration (s)	1.4	1.4	2.2	2.5
Burst rate (bps)	0.39	0.15	0.28	0.11

* = P < 0.05; ** = P < 0.01; *** = P < 0.001 differences between adults and older people.

TABLE 9 Time spent at different EMG intensities (relative to isometric MVC) in normal daily life for adults (n=84) and older people (n=9). Time expressed as percentage from total measurement time and as minutes and seconds.

	Adults		**Adults**		**Older people**		**Older people**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
EMG_{MVC}	**Time (%)**		**Time (mm:ss)**		**Time (%)**		**Time (mm:ss)**	
0–1 %	54.5*	17.0	361:39	126:20	41.1	16.7	280:00	127:42
1–2 %	13.6	7.3	91:11	51:32	12.7	9.2	83:00	56:50
2–3 %	6.4	3.9	42:48	27:54	6.4	3.7	42:12	21:42
3–4 %	4.0	2.5	26:37	17:15	5.1	4.2	34:36	28:42
4–5 %	2.8	1.5	18:51	10:17	3.4	1.5	23:00	10:18
0–5 %	81.4**	11.9	541:06	120:08	68.8	13.0	462:54	97:42
5–10 %	8.2**	5.5	53:44	34:19	14.3	10.5	96:48	69:24
10–20 %	5.8**	3.4	38:10	21:53	9.3	3.1	62:12	21:48
20–30 %	2.2*	1.9	14:40	11:28	3.7	1.9	24:36	12:08
30–40 %	1.1*	1.1	07:01	06:30	1.8	1.1	12:10	7:30
40–50 %	0.6	0.6	03:53	03:40	0.9	0.6	6:00	4:05
50–60 %	0.3	0.4	01:59	02:14	0.5	0.4	3:20	2:25
60–70 %	0.2	0.2	01:07	01:23	0.3	0.2	1:45	1:24
70–80 %	0.1	0.1	00:40	00:53	0.1	0.1	0:57	0:48
80–90 %	0.1	0.1	00:25	00:36	0.1	0.1	0:33	0:31
90–100 %	0.0	0.1	00:16	00:25	0.0	0.0	0:19	0:19
≥100 %	0.1	0.2	00:38	01:16	0.1	0.1	0:41	0:57

* = P < 0.05; ** = P < 0.01; *** = P < 0.001 differences between adults and older people.

6 DISCUSSION

The purpose of this study was to investigate the accuracy of EMG clothing to estimate energy expenditure and exercise capacity, and to quantify inactivity and activity during normal daily life in healthy adults and elderly. The EMG shorts were shown to predict EE similarly to the other commonly used methods. When calibrated with individual values EMG was shown to provide more accurate EE estimations at low levels of physical activity in changing terrains than accelerometry or heart rate. EMG can also be used to estimate exercise capacity by assessing EMG threshold during the incremental running test. This study also demonstrated advantages of individually determined task specific inactivity and activity thresholds in comparison to the threshold based on absolute activity values. It is shown that the EMG shorts can also distinguish standing from sitting. Overall, this study reports detailed information of muscle inactivity and activity that is normal to daily life and occurs in regular daily tasks in adults.

6.1 Accuracy and reliability of the EMG method

6.1.1 Prediction of energy expenditure (I)

Muscles perform variety of functions by acting as tensile struts, brakes and motors during different periods during the stride (Griffin, Roberts & Kram 2003) and therefore, the energy expenditure of muscles during the stance phase is a mix of energy used to generate force isometrically and to perform work (Griffin, Roberts & Kram 2003). Despite this complexity of muscle function during walking, the metabolic cost of walking should be proportional to the magnitude and rate of generating force, if muscles work with consistent relative shortening velocities and efficiencies in different walking speeds (Griffin, Roberts & Kram 2003). Bourdin et al. (1995) have shown a close relationship between EMG characteristics and the energy cost of running per unit distance. There are no previous studies assessing validity of EMG shorts in estimating EE. Because people spend more time in sedentary and light activities than in moderate and vigorous activities, estimation of EE at low intensities is of great importance in long term measurements (Westerterp & Plasqui 2004). Even though this study contained also low intensity loads, many activities of daily living (e.g. standing and strolling) have even lower intensity than the slowest walking speed (4 km · h^{-1}) used in this study. In this regard, Study III shows that EMG can accurately distinguish standing from sitting. Normally, heart rate monitors or accelerometers worn on waist are not capable of differentiating between standing and sedentary behaviours. Although some special accelerometers and algorithms have been developed to differentiate between standing and sitting, those are not yet widely used in research.

In general, the present results of Study I show that EMG, heart rate and accelerometry all predicted EE relatively well, although accuracy of EMG was poorer at the population based model and individual calibrations improved accuracy considerably. It was shown for the first time that EMG shorts can be used in EE estimations across a wide range of physical activity intensities in a heterogeneous subject group during walking and running. Hamstrings EMG provided more accurate EE estimations than quadriceps EMG in all and low loads according to AIC and correlations (Table 4). Accelerometer was the best predictor of EE at level loads, but according to AIC and correlations its accuracy was considerably lower in all loads that included also uphill and downhill (Table 4). Correlations of heart rate were found to be considerably lower at low loads than at level and all loads (Table 4).

At low loads correlations were significantly lower (except for aEMG (H)) than at all loads possibly indicating that EE estimation seems to be more challenging at low intensities. Prediction accuracy of aEMG(Q) was considerably lower for low and all loads than at level loads (Table 4). One reason for this finding could be that some subjects were unaccustomed to treadmill walking and especially some older subjects seemed uncertain when walking on a treadmill. For older subjects maintaining balance at the lowest walking speeds could be a reason for excessive coactivation of quadriceps (Schmitz et al. 2009). The lowest walking speeds were also performed first, leaving less time for adaptation to treadmill walking compared to higher speeds.

Regarding the accuracy of EE prediction, individual correlations and AIC ranked the EMG, ACC and HR methods in the same order within a certain load categorization. It has to be noted that AIC tells how well a model can predict EE in a relative sense. Even though individual correlations between EE and different methods were rather high, correlations do not take into account the slope of the curves between different individuals. Therefore, to account for the effect of the method on EE it is necessary to establish a linear regression equation for EE and the method used (e.g. HR, ACC or EMG) for each subject at several activity intensities, at the first stage, and the linear mixed model at the second stage. This kind of individual calibration will improve EE estimations accounting for individual factors affecting EMG (e.g. walking technique, muscle mass, thickness of subcutaneous fat tissue), HR (e.g. cardiovascular fitness, resting and maximum heart rate) and ACC (e.g. walking technique and body mass).

EE prediction equations. The equations to predict instantaneous EE (Table 5) provide a convenient way to estimate energy expenditure in long-term EMG measurements without laboratory measurements. The accuracy of the prediction equations were evaluated in three ways: AICs and correlations between the observed EE and predicted EE at the individual level have the same information. Thus, they rank the accuracies of five methods similarly. At all and low loads, the standard deviation of residual in the ACC model is larger when compared to others. When considering the correlations between the observed EE and predicted EE at the population level, we can see interesting differences. Note that both prediction types are affected by the accuracy of the fixed coefficients. At all loads, ACC and aEMG(H) behave similarly. One reason for that may be that the standard deviation of random coefficient of aEMG(H) is larger and further aEMG(H) has random constant. Therefore, the prediction at the population level may be more challenging. At low loads, the standard deviation of the random coefficient for aEMG(H) is larger when compared to ACC.

Differences between quadriceps and hamstring muscles. Because aEMG (Q) and EE correlations were significantly higher at level loads than at low and all loads, it seems that, especially at low loads, the accuracy of aEMG (Q) in predicting EE is decreased considerably. One reason for this finding could be that some subjects were unaccustomed to treadmill walking and especially some older subjects seemed uncertain when walking on a treadmill. For older subjects maintaining the balance at lowest walking speeds could be a reason for extraneous coactivation of quadriceps as it has been shown that older people have higher coactivation during walking to increase stiffness of joints (Schmitz et al. 2009) possibly to be able to react faster to sudden perturbations. Also the lowest walking speeds were done first on the treadmill leaving less time for adaptation to treadmill walking compared to higher speeds which were done later in the test.

Hamstring aEMG had high correlation at all data categories (0.94, 0.93, and 0.96 for all, low and level loads, respectively). Hamstrings aEMG predicts EE better, or at least as accurately, as aEMG from quadriceps or both quadriceps and hamstrings values averaged. This might be due to fact that hamstrings are responsible for propulsion in walking (Neptune, Clark & Kautz 2009) while rectus femoris of quadriceps is mainly responsible for leg swing which accounts approximately only 10% of metabolic cost of walking in level ground (Gottschall & Kram 2005). Hamstrings seem to provide a better estimation of EE in locomotion, although in all daily activities it might be advisable to use both muscle groups combined. As daily activities include activities other than locomotion, having more muscles in the analysis seems well-grounded.

Accelerometry. Several articles have previously shown the validity of accelerometry in predicting EE in locomotion on level ground. In the present laboratory experiments varying terrestrial conditions were simulated using different slopes of uphill and downhill. Due to the nature of uphill walking, it requires extra positive work but does not produce accelerations proportional to the extra muscle work needed (and opposing condition in downhill walking). That probably explains why, in the present study, the accuracy of EE estimations by accelerometry were lower when locomotion included also uphills and downhills. This finding is in line with studies that found that standard analysis of body accelerations cannot predict accurately EE of uphill or downhill walking (Terrier, Aminian & Schutz 2001) and that the acceleration counts for stair ascending and descending are quite similar, although the EE for stair ascending was more than two times that of stair descending (Kozey et al. 2010). In addition, limitations of accelerometry include their inability to detect additional energy cost of static work, moving in soft terrain or upper body movement (Schutz, Weinsier & Hunter 2001). Furthermore, accelerometry is inaccurate in measuring EE during cycling (Brandes et al. 2012) which is a common active way of commuting. Therefore, basically the accuracy of accelerometers is limited to assessing EE of dynamic work, such as locomotion on level ground (Schutz, Weinsier & Hunter 2001). As hills and stairs are common in normal daily environments, the validity of accelerometry is lower in real life situations than shown in level treadmill validation studies. Despite all the limitations, accelerometers predict energy expenditure relatively well and new accelerometer models, with raw data recording possibility and detection of different postures, is probably going to further improve the accuracy of accelerometry.

Heart rate. HR and oxygen uptake tend to be linearly related within individual throughout a large portion of the aerobic work range (Rennie et al. 2001), which was also seen in this study as correlation values for HR were very high for all and level loads. But several factors other than VO_2 can affect HR including emotions, food intake, body position, muscle groups used, type of muscle activity and ambient temperature (Hebestreit & Bar-Or 1998) and probably effect of some of these factors is demonstrated in the results as correlations were significantly lower for low loads (and standard deviations were considerably higher) than for all and level loads. It also has to be noted that the prediction equations for HR contain a negative constant that is nonphysiological. Therefore, the prediction equation using HR is limited for HR values larger than 44.28 bpm for men and 51.40 bpm for women at all loads, HR values larger than 41.94 bpm for men and 47.32 bpm for women at low loads. Furthermore, test-retest reliability for HR was considerably lower than for EMG and ACC.

6.1.2 EMG threshold and ventilatory thresholds (II)

The abrupt increase in EMG activity during incremental exercise at EMG_T has been suggested to be due to impairment of excitation-contraction coupling by accumulation of hydrogen ions (Green & Patla 1992) and high lactate levels (Favero et al. 1997). Further, it could be explained by a progressive recruitment of motor units with possible participation of type IIa and IIb fibres (at the first and second EMG_T, respectively) producing larger action potentials (Nagata et al. 1981). This theory is supported by muscle biopsy samples that have shown, that in vastus lateralis at about 40 % of VO_{2max} almost only type I fibres are recruited, whereas at about 60 % of VO_{2max} both type I and IIa are activated and during strenuous exercise (at about 90 % of VO_{2max}), fibres of type I, IIa and IIb are recruited (Vollestad & Blom 1985). As EMG_T occurred in the present study at 92 % or 81 % of VO_{2max} (in endurance athletes or recreationally active persons, respectively) it may relate to the recruitment of Type IIb muscle fibres, thus representing the second EMG_T according to the definition of Lucia et al. (1999). This is supported by the fact that in their study the second EMG_T occurred at similar exercise intensities as in the present study (at 87 % of VO_{2max} in vastus lateralis and at 88 % of VO_{2max} in rectus femoris). Also in the study of Hug et al. (2003) the second EMG_T occurred at a similar exercise intensity of 86 % of maximal cycling power (EMG_T was detected from eight muscles from the thigh and calf area; no significant differences were found in intensity of EMG_T occurrence between muscles).

Lucia et al. (1999) hypothesized that ventilation shows a first deflection point (V_{T1}) when muscle work is increased (at an exercise intensity corresponding to EMG_{T1}) and is further increased (V_{T2}) when additional motor units are recruited, that is, recruitment of type IIb fibres at EMG_{T2}. Indeed several investigations have shown simultaneous increases in ventilation and EMG during incremental exercise (Lucia et al. 1999, Airaksinen et al. 1992, Mateika & Duffin 1994, Viitasalo et al. 1985). In Study II, there were no differences in VO_2, lactate or running speed between V_{T2} and EMG_T methods. There was a trend that EMG_T occurs slightly after V_{T2} as illustrated by positive mean value in Bland-Altman plots (Figure 15 E). Practically, if EMG_T is used to guide training intensity, this finding should be kept in mind, especially, since the lactate level was significantly higher at EMG_T than at OBLA (Table 6), although OBLA represents only an absolute level of blood lactate concentration.

Although several studies have shown that EMG_T can be used to detect ventilatory thresholds during cycling (Lucia et al. 1999, Chwalbinska-Moneta et al. 1998, Bearden & Moffatt 2001, Hug et al. 2003, Jurimae et al. 2007), this has not been shown previously during running. Taylor and Bronks (1994) stated that EMG is not a viable method to detect aerobic-anaerobic transition phase in treadmill running (Taylor & Bronks 1994). In their study, background of the subjects was not reported in detail though the subjects were described as being "trained males" VO_{2max} averaging 58.5 ± 2.2 mL $\cdot kg^{-1} \cdot min^{-1}$, mean mass 76.4 kg, mean height 178.5 cm and BMI 24.0 (calculated from the mean values) (Taylor

& Bronks 1994). From these descriptions, it is reasonable to assume that subjects were not endurance athletes or, at least not high level endurance athletes. Their subjects also had about 8 % lower VO_{2max} than the endurance athletes in our study. Therefore, in combination with the study by Taylor and Bronks (Taylor & Bronks 1994), Study II may suggest that EMG is not a viable method to detect ventilatory thresholds in inexperienced runners. Further, in the present study, differences in performance characteristics between the two groups were not that considerable, so it can be disputed as to whether or not these subject groups correctly represented recreationally active and athletes. In spite of this, the limits of agreement differed considerably between these groups showing large influence of training status on the accuracy of EMG_T in predicting V_{T2}. This may be related to more stable and constant running technique of experienced runners. In inexperienced runners changes in running technique and muscle activation patterns may be distracting factors in the threshold determination. For example, at some running speeds inexperienced runners might not be able to relax their muscles enough in the recovery part of the stride cycle therefore eliciting a higher EMG value than what is needed to achieve a given running speed.

In the study of Taylor & Bronks (1994) EMG_T occurred at 79 % of VO_{2max} compared to the corresponding values of 92 % or 81% of VO_{2max} found in the present study in the group of endurance athletes or recreationally active persons, respectively (Taylor & Bronks 1994). Beside the study population, some differences between these studies may be due to the measurement equipment. In the study of Taylor & Bronks EMG_T was detected from individual muscles (vastus lateralis, biceps femoris and gastrocnemius) (Taylor & Bronks 1994) while in the present study, whole muscle groups were measured and EMG_T was detected from several groups of muscles (vastus lateralis, vastus medialis, vastus intermedius, rectus femoris, biceps femoris, semimembranosus and semitendinosus). We assume that this is particularly important in running as modest changes in technique may be used to compensate for fatigue (Finni et al. 2003). Also, in running it is possible to increase running speed by either increasing quadriceps or hamstrings activation, or both. Therefore, EMG_T detection from individual muscles can give different results and may not reflect systemic response similarly as V_{T2}.

6.1.3 Inactivity threshold (III and IV)

Study III introduces new individually determined task-based inactivity threshold. There was a clear need to have more adaptable threshold than one based on absolute value of muscle activity due to large variability in MVC torques and EMG_{MVC} values between subjects. If, for example, 1.7 ± 0.2 % of EMG_{MVC} would have been used (determined from the baseline) as inactivity threshold as used by Klein et al. (2010), some of the strongest subjects would not have exceeded the threshold during standing, which would then had been mistakenly classified as inactivity. Indeed, we used quiet standing as a reference activity as it can be considered as the lowest level of activity in daily life. Inactivity threshold was set to 90 % of activity of standing to ensure that standing would be classified as activity in all cases. Individual inactivity threshold is especially important when subjects differ largely in their force production capabilities, as in the present heterogeneous study group. The individually determined threshold (2.5 ± 1.7 % EMG_{MVC}) yielded approximately the same inactivity times as 2 % EMG_{MVC} threshold, but with smaller variation in inactivity times (SD 11.9 and 15.4, respectively). The inactivity threshold of 1 % EMG_{MVC} decreased the inactivity time considerably, and the threshold of 5 % EMG_{MVC} increased it. Therefore, our results support the suggestion from Klein et al. (2010) that even a small change in the threshold may result in a very large change in the daily EMG duration.

Maximal voluntary muscle force and EMG activity measurement. The measurement method of MVC needs to be considered when comparing different studies reporting inactivity and activity times of muscles. In addition to the between subject variability in MVC and EMG_{MVC} values, the maximal voluntary muscle force and muscle activity is a critical measurement as changes in the threshold (%EMG_{MVC}) affect the inactivity time and time spent in different activity levels. Klein et al. (2010) normalized their data with EMG_{MVC} values measured in 80° knee angle, while we used 140° knee angle (knee fully extended is 180°). Although 120° is reported to be optimal for maximal force production we wanted to use a knee angle that is closer to ones used commonly in normal daily life. Careful attention was paid to ensure that real maximum was achieved in MVC testing by doing enough trials and by using loud verbal encouragement.

6.2 Simulated activities of daily living (III and IV)

Thigh muscle activity of standing still was shown to be 2.5 times higher than that of sitting. Therefore, from the perspective of muscle activity, standing can be considered as physical activity. Slow walking elicits 3 times higher muscle activity than standing. For some subjects fast walking elicit activity as high as 42 % EMG_{MVC} and squatting 63 % of EMG_{MVC} therefore indicating that normal daily tasks can be physically rather demanding for some individuals. In all simulated activities of daily living standard deviations of muscle activity were relatively high indicating large inter-individual differences. This is probably mostly explained by differences in maximal force production capabilities and varying body masses between individuals. In all tasks muscle activities were significantly higher in older than in younger people (except in the squatting which did not reach the level of significance) indicating that daily tasks are physically more demanding for the older people. This probably also explains why, in daily measurements, burst amplitudes were higher in the older people compared to younger.

6.3 Active vs. passive transport (IV)

In active and passive transport tests our older subjects were in relatively good physical condition (VO_{2max} = 26.9 ± 5.6 ml · kg^{-1} · min^{-1}) the peak muscle activity level reached 123.9 ± 35 % of EMG_{MVC} during stair ascending as compared to 71.2 ± 16.9 % of VO_{2max}. The subjects that were able to ascend five flights of stairs did not reach their MVC during the performance. In contrast, those who failed to reach the highest floor reached or exceeded their EMG_{MVC}. Thus it seems that neuromuscular activity is the limiting factor during stair ascending. Since none of the subjects where close to their maximal oxygen consumption during unloaded or loaded ascending it seems that the limiting factor was capacity to produce force and power. Thus the limiting factor was not the cardiovascular but neuromuscular system. Indeed, it seems that those subjects who climbed more flight of stairs had better muscle performance. This observation is in line with previous studies (Valtonen et al. 2009, Larsen et al. 2009) which have reported that the power generated around the knee joint is related to the stair climbing velocity among older women. It has also been shown that the performance in counter-movement-jump largely explains the variation in stair climbing velocity among older people (Larsen et al. 2009).

Muscle activity was higher during ascending than descending, which is natural as more external work is done in ascending than in descending. Although the mean value during ascending in the current study was approximately only one third of EMG_{MVC}, the peak values reached almost 1.25 times EMG_{MVC}. Supramaximal EMG values are possible as MVC values were measured during the isometric tasks and stair negotiation consists of dynamic muscle actions. Furthermore, the EMG_{MVC} value is mean of one second time window and peak values are maximum values of 10 ms time frame.

These results highlight the importance of muscle strength in maintaining the physical independence of older people. As climbing stairs and rising up from a chair are important components of independent living, compromised ability (Hortobagyi et al. 2003) in those tasks limits the scale of independent living of older people. In addition, it has been previously shown that descending stairs is one of the most dangerous tasks for older people (Roys 2001). Furthermore, older people have shorter gait length, stance phase (Monaco et al. 2009), lower muscle strength and decreased RFD (Häkkinen et al. 1998) (than young) which all has been associated with increased risk of falling (Wolfson et al. 1995). Often sudden stumbling causes loss of balance and fall possibly because there is no strength capacity left to regain balance (Larsen et al. 2009). Decreased rate of force development and strength cause considerable loss in produced power (Paterson, Jones & Rice 2007). By improving force and power performance a considerable amount of bone fractures and related deaths could be prevented, although this theory has been questioned (American Geriatrics Society and British Geriatrics Society 2011, Pizzigalli et al. 2011). Studies have shown that older people can attain remarkable gains both in strength and power with strength training (Häkkinen et al. 2000). As peak values of EMG were mostly over 80 % of EMG_{MVC}, stair climbing can be seen as a good way to enhance muscle strength and it is also recommended in Physical Activity Recommendations as a possible method to perform resistance training (Haskell et al. 2007). In addition, it has been shown with sedentary young women that stair ascending can improve VO_{2max} (Boreham et al. 2005). Training at 60-80 % of VO_{2max} corresponds to training intensity zone of basic endurance training, which is shown to improve fat utilization capacity and increase capillary density of trained muscles (Rusko et al. 1986).

The results confirm beneficial effects of active transport over passive transport. Since 1 kilometre of walking requires 3.3 times more oxygen and yields 3.5 times higher mean muscle activity level than when transport by bus. VO_2 and EMG in stair ascent was about 12 times that of using elevator. Converting these values to calories burned (1 litre of oxygen equalling ~5 kcal (Thompson 2010)), walking 1 km consumed 0.7 $kcal \cdot kg^{-1}$ (~50 kcal for person weighing 70 kg) more than using bus and using stairs consumed 0.4 $kcal \cdot kg^{-1}$ (~28 kcal for person weighing 70 kg) more than using elevator. The difference in a single bout may not seem substantial, but accumulation of similar bouts of activities throughout the day, additional energy expenditure could contribute considerably to weight management (Hamilton, Hamilton & Zderic 2007). People in sedentary occupations may have their muscles inactive (below 1.7 % of EMG_{MVC}) nearly 90 % of the waking hours (Klein et al. 2010). By adding walking and stair ascents to daily routines, inactivity times could be decreased and energy expenditure increased considerably. It has also been shown that low intensity activities are needed (in addition to higher intensities) to maintain normal fat metabolism (Hamilton, Hamilton & Zderic 2004).

6.4 Daily muscle inactivity

6.4.1 Normal population (III)

A very large variability between subjects in total inactivity times ranging from 40 to 91 % of total time were found (Figure 19). Also light activity (3-45 % of total time) has much higher between-subjects variability than moderate (2-21 % of total time) or vigorous (1-23 % of total time) activity indicating that individual differences in light physical activity have greater influence on inactivity time than moderate or vigorous physical activity. It is important to measure also short periods of physical activity accurately as even 15 min of physical activity per day provides a reduction in all-cause mortality and extends an individual's lifespan for an average of 3 years (Wen et al. 2011). There was a very large variation between subjects in continuous inactivity periods. One subject did not have inactivity periods longer than 3 minutes and in the other extreme one subject had the longest inactivity period lasting almost 40 minutes and even his 5th longest inactivity period was over 15 minutes. It should be reminded that activity burst as short as 0.1 second breaks the inactivity period reported in this paper. Therefore, it is possible that a long inactivity period is stopped by very short activity that could be done during sitting followed by another long inactivity period. As our inactivity threshold was individually determined based on a functional task it is highly likely that these values represent the true behaviour of the subjects. Short inactivity periods may reflect a behaviour where person is rarely sitting or sitting but fidgeting legs very often. At this point we do not know how long the activity period should be to be physiologically significant or how long inactivity can be sustained without consequences to health although a recent report shows adverse effects of 1 day sitting on metabolism (Stephens et al. 2011).

6.4.2 Older people (IV)

Older people spent less time being inactive than younger ones (50 % vs. 68 % of measurement time, respectively). Consequently activity times were higher in all activity intensity categories for older subjects (activity times for light (11 % vs. 9 %), moderate (30 % vs. 17 %) and vigorous activity (9 % vs. 7 %), respectively). In contrast to higher activity times, the longest continuous inactivity periods were all longer in older people than in younger lasting for 21 min vs. 14 min; 15 min vs. 10 min; 12 min vs. 8 min; 10 min vs. 7 min; 9 min vs. 6 min for 1st, 2nd, 3rd, 4th and 5th longest inactivity periods (old vs. younger), respectively. It is possible that older subjects who were all on pension had more freedom during the day to choose their daily routines. The younger subjects were likely to have more predetermined tasks during the day and many of the tasks might increase inactivity (e.g. commute by car, office work). Higher activity times could be related to longer burst lengths and, on practical level, also to slower walking speed of older people (Kang & Dingwell 2008) because same distances takes longer time for the older and many daily tasks require a certain distance of locomotion to be covered.

6.5 Daily muscle activity

6.5.1 Normal population (III)

One of the main findings of this study was that thigh muscles are inactive over 65 % of the measurement time and only a fraction of muscle's maximal voluntary strength capacity is used during normal daily life. Average EMG amplitude was 4 % EMG_{MVC} which is below the mean EMG level required for walking (Fig 3). In the present study, quadriceps and hamstring muscles were active on average 34 % of total time (3.6 hours from 11 hour recordings), while other studies have reported lower values for EMG duration for vastus lateralis during 8 to 15-h recordings, including 13% , 12 % , 10 % , and 9 % (Klein et al. 2010). One factor possibly explaining differences in activity times is that in the present study, with a comprehensive sample size, we also measured hamstrings in addition to quadriceps, and instead of single muscles, whole muscle groups were measured. Also many other factors such as differing subject group, measurement systems, thresholds employed and analysis procedures used, probably contribute to the differences in activity times between the studies.

In Study III the mean EMG burst amplitude of quadriceps and hamstring muscles was 5.8 % of EMG_{MVC} that is comparable to that found by Klein et al. (2010) where mean vastus lateralis EMG was 6.9 % EMG_{MVC}. On the other hand, Kern et al. (2001) reported mean burst amplitude of 17 % MVC (for vastus lateralis) and 18 % MVC (for vastus medialis) but these subjects were moderately active college students who are likely to be more active than the present group with large age range. In addition, Kern et al. (2001) used the burst threshold of 2 % of MVC which may have left some smaller bursts out of the analysis whereas the numbers by Klein et al. (2010) are based on values above a baseline, which may explain the smaller mean amplitudes. As average EMG amplitude was only 4 % EMG_{MVC}, the daily muscle activity could be cumulated by walking at 7 $km \cdot h^{-1}$ for 3 hours or ascending stairs for less than 2 hours. Fifteen subjects had the average daily EMG amplitude under 2 % of EMG_{MVC} which could be achieved by less than 1 hour of stair climbing or about 1.5 hours of walking at 7 $km \cdot h^{-1}$. These subjects could have increased their thigh muscle activity 50 % by standing 3.5 hours more during the day.

On average, the subjects had muscle activity over 90 % of EMG_{MVC} only for 56 seconds (Table 9). Thirty-six subjects had less than 10 seconds of muscle activity over 90 % EMG_{MVC} and 39 subjects had less than on minute of muscle activity over 60 % EMG_{MVC}. Larger muscles, such as those in leg or arm are reported to recruit motor units at least up to 90 % of MVC. Specifically, in isometric conditions vastus lateralis muscle maximum recruitment threshold has been shown to be 95 % of MVC although in rapid contractions the threshold is lower (Desmedt & Godaux 1977). Therefore, some motor units may have very little if any activity during the daily life in these subjects. Long-term consequences of limited activity of the highest threshold motor units are uncertain, but it is conceivable that such a condition for many years could contribute to age-related weakness and muscle atrophy. To express the activity times from another perspective, in hypertrophic strength training a typical activity duration for one single exercise is about 60-220 seconds (4-6 sets with 8-12 repetitions each lasting 2-3 seconds) and the intensity level varies between 70–85 % of one repetition maximum. This kind of hypertrophic training usually includes 2-3 different exercises for one muscle group leading to increase in muscle mass. While the maintenance of the acquired muscle mass and strength after an intensive training period requires 1-1.5 training sessions per week, it is not quite clear how much and what type of muscle activity is needed to maintain muscle mass in normal subjects during daily life.

Differences between males and females. Women had more activity time at intensity of 40-100 % of EMG_{MVC} and more activity bursts than men. Kern et al. (2001) reported that women had 70 % higher summed duration of bursts in biceps brachii than males and their small sample size might have hindered differences in other muscles. Finnish women have been reported to take more steps during the day than Finnish men (Hirvensalo et al. 2011). Shorter stature of females could affect to higher burst count as shorter persons need to take more steps to cover the same distance in walking or running. Women had significantly lower MVC meaning that they need to use higher relative force for the same absolute tasks than men, possibly explaining women having more activities at higher intensity.

6.5.2 Older people (IV)

In the present study with older subjects the mean muscle activity burst amplitude of quadriceps and hamstring muscles was 10 % of EMG_{MVC} which is higher than in study of Klein et al. (2010) with 20-48 year old men and women whose mean vastus lateralis EMG was 6.9 % EMG_{MVC}. On contrary, Kern et al. (2001) reported mean burst amplitude of 17 % MVC (for vastus lateralis) and 18 % of EMG_{MVC} (for vastus medialis) but these subjects were moderately active college students. More detailed comparisons to these studies are not rational due to differing methodology (different muscles assessed, burst thresholds used and analysis methods utilized).

In this study mean muscle activity and burst amplitude were significantly higher in the older compared to younger subjects. As many of daily tasks demand a certain level of force output, and since muscle strength of older people is lower (young 107 ± 44 kg; 52 ± 14 kg in knee extension), older people need to use higher percentage of their maximum capacity to get same daily tasks accomplished. There was no difference in body mass (69.6 ± 11.6 vs. 70.1 ± 10.2 kg for old and younger, respectively), which therefore does not explain difference in the EMG amplitudes. Also probably daily routines differ to some extent between younger and older especially as all of the older subjects were already on pension. Thus, for older people, daily life seems to be more demanding probably due to lower maximum strength levels. In addition, it has been shown that old people compensate plantar flexor weakness by using more hamstrings and gluteus maximus for production of propulsion in walking (Schmitz et al. 2009, DeVita & Hortobagyi 2000, Cofre et al. 2011, Savelberg et al. 2007), which could also be related to higher hamstring activity in the older.

Older subjects had less muscle activity bursts and burst duration was considerably longer in older subjects than in younger. The longer burst duration could be related to slower speed of locomotion and longer stance phase (Kang & Dingwell 2008). Also as the rate of force development has in some studies reported to be lower in older people reaching a certain absolute level of force output takes longer for old compared to younger people (Häkkinen et al. 2001).

6.6 Limitations of the study

6.6.1 EMG measurements

In this thesis all the studies were done using the novel EMG technology which has textile electrodes embedded into sportswear. This technology differs rather much from the methodological point of view from the traditional EMG measurements and therefore some considerations needs to be addressed. In the module of the shorts, the EMG-signal is collected in its raw form with a sampling frequency of 1000 Hz and a frequency band 50 Hz – 200 Hz (-3 dB). Such a bandwidth differs from the SENIAM recommendations and is used in the equipment to reduce possible large amplitude movement artefacts which mostly occur at frequencies below 50 Hz. These artefacts are difficult to detect and remove automatically from the averaged data. The chosen bandwidth together with pre-processing of the data makes the EMG shorts applicable to use in challenging conditions where the use of conventional EMG devices would not be convenient or possible. Even with the restricted bandwidth, it has been shown that the signals from the textile electrodes are in good agreement with the traditionally measured surface EMG signal (Finni et al. 2007). The relationship between muscle strength and EMG has been shown to be similar for both traditional and textile electrodes, therefore suggesting that the EMG shorts are a valid and feasible method for assessing muscle activity (Finni et al. 2007). The considerably larger surface area of the textile electrodes used in the EMG shorts compared to traditional bipolar electrodes results that EMG is measured from muscle groups rather than from individual muscles. In addition, it has to be noted that shorts need to be correctly chosen to be tight enough to achieve minimal movement artefact from skin-electrode interface. Although as the measuring area of the textile electrodes is considerably larger than typical bipolar electrodes, small movements of the electrodes in relation to the skin and muscles have probably a smaller effect on the magnitude of the EMG signal.

6.6.2 Other muscles not assessed in this study

Several other muscles, not assessed in this study are also activated in locomotion and daily tasks. Activity of muscles not assessed in this study can create error in EE estimations, but in theory only in those instances, in which activity of muscles not assessed increases in different proportion than activity of measured thigh muscles. Sousa and Tavares have shown that gait speed influence not only activity levels but also relative activity patterns of leg muscles (Sousa & Tavares 2012). Activity of rectus femoris, gluteus maximus, gastrocnemius medialis and biceps femoris increase (in decreasing order) during stance below and above the preferred walking speed of individuals. However, it can be assumed that most of the time during non-exercise activities people walk close to their preferred speed. Plantar flexor activity increases at faster walking speeds (Bartlett & Kram 2008) and have been shown to contribute greatly to mechanical energetic demands of walking and are the primary contributors to propulsive ground reaction forces in walking (Neptune, Sasaki & Kautz 2008).

With increases in uphill grade hip, knee and ankle extensor muscle activities increase progressively in the stance phase (Franz & Kram 2012). In downhill walking only knee extensor activities increase with steeper downhill grade and ankle extensor muscles activities decrease with the increasing downhill slope (Franz & Kram 2012). As thigh muscles are important in either deceleration or acceleration in uphill and downhill locomotion, EMG of thigh muscles seems a relatively good way to estimate EE also in those activities, signified by observed relatively high correlations at all loads. Because thigh muscles constitute a relatively large portion of muscle mass activated during walking, they give relatively good estimate of EE in gait.

6.6.3 Measurement errors

Since all main variables were measured simultaneously in the treadmill test of Study I, any systematic error in the EE measurement affect all predictions similarly and 1 minute average of all variables was used to minimize the effect of small artefacts or irregularities in the data. Only part of the subjects did the running loads but any bias created by this is the same for all measurement methods. Test-retest repeatability of EE, EMG and accelerometer were good, but test-retest correlation values of HR were low and typical error values were considerably high indicating low reliability of the HR measurements, which could be related to psychological factors, for example.

As all the EMG results are presented relative to MVC results are incorrect if maximum is not reached during MVC testing. Especially with the older subjects it might be difficult to obtain real MVC as they often are not accustomed to maximal performance and might be cautious to exert maximal force. In fact, Harridge et al. (1999) have shown that in very elderly people (85-97 years) muscle activation during a maximal voluntary isometric contraction to be incomplete (ranging from 69% to 93%). To obtain as real maximum as possible practise trials were done before the actual test trials and loud verbal encouragement was used to encourage maximal performance. A minimum of 3 actual test trials were performed and if MVC value improved more than 5 % in the last trial more trials were performed. Although the possibility of incorrect MVC values cannot be ruled out fully, the best attempt was done to obtain maximal values during the testing.

6.6.4 Unconventional treadmill protocols (I and II)

The unconventional treadmill protocol of Study I consisting mainly of walking loads (and last loads having rather steep incline), has its shortcomings. Although the test protocol might underestimate the VO_{2max} values measured in the study (as local muscle fatigue might terminate the test prematurely), VO_{2max} values were of secondary importance in this study. This unconventional test protocol relates more closely to normal daily locomotion as extra stress of locomotion usually comes from ascent rather than higher speed.

In Study II, the discontinuous incremental exercise protocol was utilized in contrast to the continuous incremental protocol used in many previous EMG threshold studies. The advantage of the continuous protocol is that thresholds can be determined more accurately as incremental steps in exercise intensity are smaller than in the discontinuous protocol. However, all previous studies using the continuous protocols have been conducted with bicycle ergometers e.g. (Lucia et al. 1999) while the discontinuous protocols are commonly used in performance testing of runners on a treadmill e.g.(Taylor & Bronks 1994).

6.6.5 Treadmill locomotion vs. over ground locomotion (I)

Naturally, because the goal of Study I was to validate EE estimations for over ground locomotion rather than for the treadmill, it needs to be considered whether treadmill walking is a valid testing method of validity for over ground locomotion. In fact, Lee and Hidler (2008) have shown that when walking on treadmill individuals modify their muscle activation patterns and subsequent joint moments and powers while limb kinematics and spatiotemporal gait parameters remain relatively constant (Lee & Hidler 2008). Despite of the observed differences, overall patterns have been shown to be quite similar (Lee & Hidler 2008), therefore treadmill locomotion seems not to deviate that much from over ground locomotion. In addition, Cronin & Finni have found calf muscle function to be comparable in over ground and treadmill walking and running (Cronin & Finni 2013). To more accurately assess whether EMG shorts can be used to estimate EE of normal daily life doubly labelled water or metabolic chamber measurements should be used.

6.6.6 Exclusion of data

Rather large amount of subjects had to be excluded from the final analysis (14%, 25%, 31% and 10% of subjects, respectively in Studies I, II, III and IV) which represents an obvious limitation to the study. This was due to the first generation of the EMG shorts and due to fact that at the time of Study II we did not have shorts of optimal size for some very lean subjects. Also, in daily measurements subjects spent the measurement time in their normal daily environments and researchers could not check quality of the data and did not have any control of the measurement equipment during that time. In Study IV one subject was excluded because of corrupted data and 6 subjects did not provide complete series of measurements due to varying reasons (e.g. ventilation face mask feeling uncomfortable, tests demanding quite a lot of extra time). In addition to the excluded subjects some erroneous EMG data from included subjects had to be left out of analysis. Since EMG measurements were done for both left and right side of hamstrings and quadriceps, effect of exclusion of single EMG channel is rather small, as the majority of the activities of daily living are bilateral. For example, in Study I more than one channel was excluded only from 4 % of the subjects. Despite a rather large percentage of excluded subjects and data, we feel that results give valuable information as sample sizes (except in Study IV) and recording time (over 10 hours / day) remained relatively good.

6.6.7 Representativeness of subject groups

In Studies I, III and IV subjects were recruited through advertisements in public places and different workplaces and therefore do not represent a randomly selected sample. Often more active people are more interested taking part in research projects which include physical activity assessments and although this bias cannot be excluded, our results do show that we also had inactive and sedentary subjects in our study. The measurements were conducted with Finnish people living in a rather small city with good possibilities to walk or bicycle to work. However, the nature of office work does not differ considerably between cultures and therefore our data gives insight into inactivity of modern societies. Despite the limitations we feel that results of studies III and IV provide useful and valuable information of physical activity patterns of people of different ages, although results of Study IV need to interpreted cautiously as the sample size (n=9) was small.

Because subjects of Study II were active young men and some of the results were significant only for the endurance athletes group (VO_{2max} 64 ± 8 $mL \cdot kg^{-1} \cdot min^{-1}$), results can be safely generalized only for endurance athletes. In inexperienced runners the variability in running technique and muscle activation patterns may be distracting factors in the threshold determination while more stable and constant running technique of experienced runners provided more consistent results. For example, at some running speeds the inexperienced runners might not be able to relax their muscles enough in the recovery part of the stride cycle, therefore, eliciting a higher EMG value than what is needed to achieve a given running speed. Therefore the present study may suggest that EMG is not a viable method to detect ventilatory thresholds in inexperienced runners.

6.7 Implications and future directions

Obesity and diabetes have reached epidemic -like proportions in the world (Naser, Gruber & Thomson 2006). Although the reasons for this are multifaceted, modern lifestyles that allow and even encourage to the avoidance of physical activity are believed to have played a major role (Zimmet, Alberti & Shaw 2001). In response, public health recommendations have been used in attempt to increase participation in moderate-to-high intensity physical activity (Pate et al. 1995). However, emerging evidence is showing that absence of whole body movement and prolonged periods of inactivity are related to risk of chronic diseases (Hamilton, Hamilton & Zderic 2007) and all-cause and cardiovascular mortality (Matthews et al. 2012) independent of physical activity. Accurate and valid assessment methods and detailed information of physical activity are of great importance when exercise prescriptions are outlined. The novel wearable EMG measurement and developed analysis methods can be used for objective inactivity and activity quantifications in free-living conditions and it is possible to examine dose-response relationship of inactivity more accurately. Besides the total inactivity time, the way in which it is accumulated may be also be important and there is a real need to understand how the patterns by which sedentary time is accumulated is associated with metabolic risks (Healy et al. 2008). The novel measurement and analysis methods developed within this project are able to distinguish also the shortest activity bursts occurring during sitting and standing. This is important since each activity burst of a muscle initiates the metabolic processes that are important for our health.

The results of Study I showed that EMG provides an alternative for accelerometer based measurement methods and can yield distinct and valuable information of physical inactivity and activity, which other measurement methods cannot provide. An important aspect of physical activity measurements with EMG is that, it can accurately measure also the lowest level physical activities (standing, fidgeting slow walking etc.). Further, Study II showed that in experienced runners EMG shorts can provide a convenient way for V_{T2} determination during running and underline the importance to measure EMG_T from large muscle groups rather than from individual muscles. In practice, EMG shorts could be used to detect the ventilatory threshold and guide training intensity during running in typical training conditions. In addition, the transition from aerobic to anaerobic metabolism has important implications, as well for occupational, preventive, and rehabilitative medicine (Moritani, Takaishi & Matsumoto 1993).

Study III introduced new ways to report activity and inactivity measured with EMG. Individually determined task specific inactivity thresholds avoid many of the pitfalls other inactivity thresholds do possess. Study III also validated and provided concise guidelines for data analysis, how inactivity time could be determined and reported in long-term EMG studies. This enables comparisons between individuals with varying backgrounds, which are of great importance when increasing the body of literature of long-term EMG measurements starts to emerge. Also the novel method of calculating thresholds for low, moderate and vigorous exercise intensities from EMG data were presented and it enables the use of established and widely used physical activity categorization classes also for EMG data. This makes it possible to compare results, at least to some extent, between studies made with different measurement methods.

The muscle activity patterns reported in Study III are significant for understanding the intensity, amount and distribution of physical activity which is typical in healthy adults and older people. These data can be used as a reference point for recommendations of avoidance of inactivity in normal daily life and of activity levels and patterns that maintain or can recover normal muscle properties. Further, the data can be valuable for future interpretations of activity patterns in different disorders affecting motor dysfunctions, locomotor abilities, or overall physical activity. Studies III and IV underline the importance of ubiquitous physical activity since daily physical activity accumulates mainly from low levels of activity and exercise have only little impact on the total daily activity, total daily energy expenditure and weight maintenance against overweight and obesity (Hamilton, Hamilton & Zderic 2007).

The results of Study IV show that, for older people, daily life is physically more demanding than for younger people. Probably this is due to lower maximum strength levels and highlights the importance of muscle strength in maintaining the physical independence of older people. These results further stress importance of strength training also in older people. Studies have shown that also older people can attain considerable gains both in strength and power with strength training (Häkkinen et al. 2000). Also stair climbing was confirmed as a good alternative to enhance leg muscle strength and VO_{2max} in older people indicated by high EMG and VO_2 values measured in our study during the stair ascending task. In addition the results of Study IV confirm beneficial effects of active transport over passive transport.

Studies III and IV report typical daily muscle activity patterns, but there is a clear need to gain deeper understanding of the effects and mechanisms of avoidance of inactivity and breaking of continuous inactivity periods as data from experimental, interventional inactivity studies are still scarce. For example, current physical activity recommendations provide guidance only for 150 minutes of moderate to vigorous physical activity per week, but gives no guidelines how the other almost 10 000 minutes of the week should be spent. There is a need to use strict definitions of terms like ‘sedentary’, ’inactivity’, ‘active’, ‘sports’ and ‘exercise’ (Pate, O'Neill & Lobelo 2008, Ekblom-Bak, Hellenius & Ekblom 2010). With respect to health ‘being sedentary’ does not necessarily have an identical effect as ‘not participating in exercise or sports’, and vice versa ‘to exercise daily’ does not exclude a ‘sedentary lifestyle’. This is not only important for scientists to able to communicate accurately but also for general public to understand the distinction between different behaviours of activity and inactivity and their effects on health.

7 MAIN FINDINGS AND CONCLUSIONS

The main findings and conclusions of the present study can be summarized as follows:

1. EMG shorts can be used in EE estimations in a wide range of physical activity intensities in a heterogeneous subject group. In general, EMG of hamstrings provides more accurate EE estimations than EMG of quadriceps during gait (I). EMG shorts can also be used to study daily inactivity and activity and individually determined inactivity and activity threshold provide objective way to calculate and report results (III).

2. EMG_T can be detected from the combined quadriceps and hamstrings muscle activity during treadmill running and the estimation of V_{T2} using EMG electrodes embedded into sportswear is possible. Threshold estimation seems to be more valid in experienced runners (II).

3. During normal daily life thigh muscles were inactive over 65 % of the measurement time and the longest continuous inactivity periods lasted approximately for 14 min (range 2.5–38.3 min). Only a fraction of muscle's maximal voluntary strength capacity is used during normal daily life. Average EMG amplitude was 4 % of EMG_{MVC} which is below the mean EMG level required for walking. On average, subjects had muscle activity above 70% of EMG_{MVC} for less than 2 minutes per day (III).

4. In daily life older people seem to have less muscle inactivity, but longer continuous inactivity periods than younger. Daily life was physically more demanding for older people, therefore highlighting the importance of maintaining strength level with aging (IV).

YHTEENVETO (FINNISH SUMMARY)

Fysiologinen kuormittuminen normaalissa päivittäisessä elämässä ja liikunnassa elektromyografialla mitattuna.

Tutkimustulokset osoittavat, että inaktiivisuus ja istuminen ovat haitallisia terveydelle liikunnan harrastamisesta huolimatta. Fyysisen inaktiivisuuden on tähän mennessä havaittu olevan yhteydessä lukuisiin kroonisiin tauteihin kuten sydän- ja verisuonitauteihin ja tyypin II diabetekseen. Tämä on hälyttävää, koska istumisen määrä on lisääntynyt yhteiskunnallisten muutosten seurauksena huomattavasti. Koska fyysisen aktiivisuuden jatkumon eri kohdat (täydellisestä inaktiivisuudesta maksimaaliseen aktiivisuuteen) aiheuttavat erillisiä fysiologisia vasteita, tulee optimaaliseen terveyteen luultavasti saavuttaa tietty taso kaikissa aktiivisuusjatkumon osissa. Tämänhetkisen tieteellisen tietämyksen perusteella ei voida määritellä terveyden kannalta optimaalista fyysisen aktiivisuuden mallia, eikä vielä tiedetä terveyden edistämisen kannalta fyysisen aktiivisuuden minimitasoa. Tämänhetkiset liikuntasuositukset ohjeistavat kuinka 150 minuuttia viikossa kannattaa käyttää kohtuulliseen tai kovatehoiseen liikuntaan, mutta eivät anna minkäänlaista ohjeistusta siitä, millainen toiminta olisi terveellistä muina 9 930 minuuttina viikossa.

Arkiaktiivisuuden lisäämiseen ja inaktiivisuuden välttämiseen liittyvien ohjeistuksien määrittämiseen tarvitaan tarkkaa tietoa inaktiivisuudesta ja matalan intensiteetin aktiivisuuksista. Ongelmana kuitenkin on, että monet fyysisen aktiivisuuden mittausmenetelmät mittaavat kohtuullisen ja korkean intensiteetin aktiivisuutta hyvin, mutta toisaalta huonosti matalan intensiteetin aktiivisuutta. Lihasaktiivisuusmittaus voi mahdollisesti tarjota matalan intensiteetin fyysisten aktiivisuuksien mittaamiseen uuden ratkaisun. Lihasaktiivisuutta voidaan mitata noninvasiivisesti ihon pinnalta elektromyografialla (EMG), mutta menetelmää ei ole juurikaan käytetty fyysisen aktiivisuuden mittaamiseen päivittäisessä elämässä. Tähän mennessä päivittäistä lihasaktiivisuutta on lähinnä mitattu eläimiltä. Ihmisillä tehdyissä EMG:n pitkäaikaismittauksissa on pääosin keskitytty ergonomiaan, lihasongelmien riskitekijöihin, painottomuuden vaikutuksiin sekä vertailemaan terveitä henkilöitä potilaisiin. Lisäksi ylä- ja alavartalon lihasten aktiivisuuksia on vertailtu terveillä ja on havaittu, että aktiivisuuden määrä voi vaihdella suuresti yksilöiden ja lihasten välillä.

EMG:tä mittaavien vaatteiden kehitys on tehnyt pitkäaikaisen EMG:n mittaamisen kenttäolosuhteissa suhteellisen vaivattomaksi. Tämän tutkimuksen tarkoituksena oli validoida EMG vaatteiden käyttö energiankulutuksen ja aerobisen suorituskyvyn arvioinnissa sekä määrittää reisilihasten inaktiivisuus ja aktiivisuustasot normaalissa päivittäisessä elämässä aikuisilla ja ikääntyneillä. Yksityiskohtaisemmin ensimmäisen artikkelin tavoitteena oli validoida vaatteisiin integroidun EMG menetelmän tarkkuus energiankuluksen arvioinnissa liikkumisen aikana, etenkin matalilla fyysisen aktiivisuuden intensiteettitasoilla. On nimittäin erittäin tärkeää, että myös matalan intensiteetin aktiivisuudet pystytään mittaamaan tarkasti, koska selkeästi suurempi osa valveillaoloajasta koostuu inaktiivisuudesta ja matalan tehon aktiivisuuksista kuin korkean ja kohtuullisen intensiteetin aktiivisuuksia. Toisen artikkelin tavoitteena oli puolestaan arvioida, voidaanko EMG menetelmällä havaita EMG kynnys juoksun aikana ja kuinka tarkasti se vastaa toista hengityskaasuista määritettyä hengitys- ja verenkiertoelimistön suorituskykyyn liittyvää kynnystä (V_{T2}), jota käytetään liikuntaintensiteetin määrittämiseen harjoitusohjelmia laadittaessa niin urheilijoilla, tavallisilla ihmisillä kuin potilaillakin. Kolmannen artikkelin tarkoitus oli kartoittaa lihasten kuormittumista tavallisen päivittäisen elämän aikana, jotta saataisiin tarkkaa tietoa tyypillisistä lihasten aktiivisuustasoista ja voimareserveistä. Sen lisäksi tutkimuksessa testattiin yksilöllisesti määriteltyjen inaktiivisuus- ja aktiivisuusrajojen vaikutusta aktiivisuusaikoihin. Neljännen artikkelin tarkoituksena oli puolestaan selvittää ikääntyneiden lihasten aktivaatioita päivittäisessä elämässä, simuloiduissa päivittäisen elämän toimissa ja aktiivisen ja passiviisen työmatkailun aikana.

Tutkimustavoitteiden saavuttamiseksi 122 tervettä vapaaehtoista rekrytoitiin mittauksiin, joissa mitattiin lihasaktiivisuutta normaalin päivittäisen elämän aikana EMG-shortseilla ja useita eri muuttujia (hengityskaasut, syke, kolmiakselinen kiihtyvyys, veren laktaattipitoisuus) laboratorio olosuhteissa. Laboratoriotestit sisälsivät antropometriset testit, juoksumattotestin, päivittäistä elämää simuloivat testit, maksimivoimatestit sekä aktiivista ja passiivista työmatkailua simuloivat testit. Alkuperäisestä koehenkilöjoukosta 63 koehenkilöä sisällytettiin lopulta tutkimukseen I, 84 koehenkilöä tutkimukseen III ja 9 vanhempaa koehenkilöä tutkimukseen IV (yli 65-vuotiaat). Tutkimuksen II mittaukset olivat erilliset muista mittauksista ja niihin rekrytoitiin nuoria miehiä, joista lopulta 21 koehenkilöä (8 kestävyysjuoksijaa ja 13 liikunnallisesti aktiivista henkilöä) sisällytettiin tutkimukseen.

Tutkimuksen I tulokset osoittavat, että EMG tarjoaa vaihtoehtoisen mittausmenetelmän kiihtyvyysantureille ja sykemittareille. EMG voi antaa erityisesti matalatehoisesta fyysisestä aktiivisuudesta ja inaktiivisuudesta sellaista informaatiota, mitä muut mittausmenetelmät eivät pysty tarjoamaan. EMG menetelmän avulla pystytään havaitsemaan monista muista mittalaitteista poiketen myös hyvin matalan intensiteetin fyysisiä aktiivisuuksia (esim. ero istumisen ja seisomisen välillä). Tähän liittyen tutkimus III esitteleekin uudet yksilölliset ja tehtäväspesifit määritelmät kuinka analysoida ja raportoida EMG:llä mitattua fyysistä inaktiivisuutta ja aktiivisuutta. Yksilöllisesti määritellyt tehtäväspesifit inaktiivisuus- ja aktiivisuuskynnyksillä voidaan välttää monet ongelmat ja heikkoudet, jotka liittyvät absoluuttisia aktiivisuustasoja käyttäviin menetelmiin. Tutkimuksessa II tarkasteltiin kestävyysharjoitteluun ja aerobiseen suorituskykyyn liittyviä kynnyksiä juoksun aikana ja tulokset osoittavat, että kokeneilla juoksijoilla EMG shortsit mahdollistavat V_{T2}:n määrittämisen juoksun aikana. Käytännössä EMG shortseja voi käyttää V_{T2} määrittämisessä ja harjoitusintensiteetin kontrolloinnissa tyypillisissä harjoitteluolosuhteissa. Siirtymäkohdalla aerobiselta aineenvaihdunnan alueelta anaerobiselle alueelle on tärkeitä sovelluksia työterveydelliseen, kuntouttavaan ja ennaltaehkäisevään lääketieteeseen.

Tutkimuksen III tulokset osoittavat, että päivittäisen elämän aikana vain pieni osa lihaskapasiteetista on käytössä ja keskimääräinen EMG:n taso oli 4 % maksimista, mikä on alhaisempi kuin keskimääräinen lihasaktiivisuus kävellessä. Päivän aikana aikuisilla oli keskimäärin noin 12 500 lihasaktiivisuuspursketta, jotka olivat keskimäärin noin 6 % maksimista ja joiden kesto oli keskimäärin 1,4 sekuntia. 97 % mittausajasta lihasaktiivisuus oli alle 30 % maksimista ja vain alle 2 minuuttia yli 70 % maksimista. Keskimäärin koehenkilöillä lihasaktiivisuus oli yli 90 % maksimista vain 56 sekuntia päivän aikana. Kevyt-, keski-, ja kovatehoista aktiivisuutta oli 16,7 %, 8,5 % ja 7,3 % mittausajasta, kyseisessä järjestyksessä. Reisilihakset olivat inaktiivisina 65% mittausajasta ja pisimmät yhtäjaksoiset inaktiivisuusjaksot kestivät keskimäärin noin 14 minuuttia. Tutkimuksen IV tulosten perusteella iäkkäämmillä ihmisillä vaikuttaisi olevan päivittäisessä elämässä vähemmän aktiivisuuspurskeita vaikkakin korkeammalla intensiteetillä. Iäkkäät olivat myös vähemmän aikaa inaktiivisia, mutta yksittäiset inaktiivisuusjaksot ovat pidempiä. Normaali päivittäinen elämä näyttääkin olevan fyysisesti haastavampaa iäkkäille korostaen lihasvoiman säilyttämisen tärkeää roolia ikäännyttäessä. Aktiivinen työmatkailu ja portaiden käyttäminen hissin sijasta voi parantaa verenkierto –ja hengityselimistön kuntoa sekä hermolihasjärjestelmän toimintakykyä.

Tutkimuksessa III raportoidut päivittäisen lihasaktiivisuuden mallit lisäävät ymmärrystä normaalien ihmisten tyypillisen fyysisen aktiivisuuden intensiteetistä, määrästä ja jakaumasta. Kyseistä informaatiota voidaan käyttää lähtökohtana inaktiivisuuden välttämiseen tähtäävien suositusten laatimisessa, sekä hahmottamaan aktiivisuustasot ja -mallit, joilla lihas säilyttää tai saa takaisin normaalit toiminnalliset ja rakenteelliset ominaisuutensa. Tutkimusten III ja IV tulokset korostavat matalatehoisen arkiaktiivisuuden tärkeyttä, koska fyysinen aktiivisuus kertyy pääosin arkiaktiivisuudesta ja korkean intensiteetin liikunnalla on vain pieni vaikutus päivän kokonaisaktiivisuuteen ja energiankulutukseen. Tutkimuksen IV tulokset osoittavat että päivittäinen elämä on fyysisesti vaativampaa vanhemmille kuin nuoremmille todennäköisesti alhaisempien maksimaalisten voimantuotto-ominaisuuksien vuoksi. Tulokset korostavat lihasvoiman säilyttämisen tärkeyttä, mihin voidaan merkittävästi vaikuttaa voimaharjoittelulla. Aiemmat tutkimukset nimittäin osoittavat, että myös iäkkäämmät ihmiset voivat saavuttaa merkittäviä parannuksia voimantuotto-ominaisuuksissa voima- ja tehoharjoittelun avulla.

Yhteenvetona voidaan todeta, että EMG menetelmä tarjoaa hyvän vaihtoehdon fyysisen inaktiivisuuden ja aktiivisuuden mittaamiselle ja antaa tarkkaa ja yksityiskohtaista informaatiota. Tässä tutkimuksessa raportoidut tulokset auttavat hahmottamaan millaisia lihasaktiivisuuksia esiintyy normaalissa elämässä ja millaisia aktiivisuuksia erilaiset päivittäiset toimet saavat aikaan. Tätä tietoa voidaan käyttää lähtökohtana nykyistä tarkempia liikunta ja arkiaktiivisuus ohjeistuksia laadittaessa.

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ORIGINAL PAPERS

I

EMG, HEART RATE AND ACCELEROMETRY AS ESTIMATORS OF ENERGY EXPENDITURE DURING LOCOMOTION.

by

Tikkanen O, Kärkkäinen S, Haakana P, Kallinen M, Pullinen T, Finni T. 2014

Medicine & Science in Sport & Exercise 46 (9): 1831-1839

II

VENTILATORY THRESHOLD DURING INCREMENTAL RUNNING CAN BE ESTIMATED USING EMG SHORTS.

by

Tikkanen O, Min H, Vilavuo T, Tolvanen P, Cheng S, Finni, T. 2012

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III

MUSCLE ACTIVITY AND INACTIVITY PERIODS DURING NORMAL DAILY LIFE.

by

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Muscle Activity and Inactivity Periods during Normal Daily Life

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Abstract

Recent findings suggest that not only the lack of physical activity, but also prolonged times of sedentary behaviour where major locomotor muscles are inactive, significantly increase the risk of chronic diseases. The purpose of this study was to provide details of quadriceps and hamstring muscle inactivity and activity during normal daily life of ordinary people. Eighty-four volunteers (44 females, 40 males, 44.1±17.3 years, 172.3±6.1 cm, 70.1±10.2 kg) were measured during normal daily life using shorts measuring muscle electromyographic (EMG) activity (recording time 11.3±2.0 hours). EMG was normalized to isometric MVC (EMG_{MVC}) during knee flexion and extension, and inactivity threshold of each muscle group was defined as 90% of EMG activity during standing (2.5±1.7% of EMG_{MVC}). During normal daily life the average EMG amplitude was 4.0±2.6% and average activity burst amplitude was 5.8±3.4% of EMG_{MVC} (mean duration of 1.4±1.4 s) which is below the EMG level required for walking (5 km/h corresponding to EMG level of about 10% of EMG_{MVC}). Using the proposed individual inactivity threshold, thigh muscles were inactive 67.5±11.9% of the total recording time and the longest inactivity periods lasted for 13.9±7.3 min (2.5–38.3 min). Women had more activity bursts and spent more time at intensities above 40% EMG_{MVC} than men ($p<0.05$). In conclusion, during normal daily life the locomotor muscles are inactive about 7.5 hours, and only a small fraction of muscle's maximal voluntary activation capacity is used averaging only 4% of the maximal recruitment of the thigh muscles. Some daily non-exercise activities such as stair climbing produce much higher muscle activity levels than brisk walking, and replacing sitting by standing can considerably increase cumulative daily muscle activity.

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Introduction

Recent epidemiological findings suggest that not only the lack of physical activity, but also prolonged times of sedentary behaviour, particularly sitting, increase significantly the risk of chronic diseases. This association persists even if people participate in moderate-to-vigorous intensity physical activities [1–9]. Since the continuum from total inactivity to vigorous-intensity training contains different physiological actions, one probably needs to meet a certain portion of different parts of this continuum for optimal health and fitness [10].

In the normal physical activity level (PAL) range, the distribution of time spent on activities with low and moderate intensity determines the daily activity level. High activity does not have much impact on PAL in the normal population because people spend more time sleeping and performing sedentary and light activities and hence the contribution from short term high intensity activity is small [11]. Consequently, an accurate estimation of time spent at low intensities is especially important during long term physical activity measurements [12]. It is also important to measure even short periods of physical activity accurately as even 15 min per day or 90 min a week provides a reduction in all-cause and all-cancer mortality [13].

Accelerometers and heart rate monitors are used extensively in research and can estimate energy expenditure, but cannot give any specific information about muscle activity. A major reason for limited data about the time spent in activities at different intensities is the difficulty to measure sitting time and patterns of spontaneous non-exercise movements [14]. Because every movement is generated by the muscle, the most direct approach to characterize daily physical activity is to measure electromyographic (EMG) activity. EMG can instantaneously detect the muscle activity burst durations and intensities. The muscle activity measurements present a novel avenue in physical activity measurements and some reports of daily EMG recordings have been published in humans (e.g., [15–19]). However, traditional EMG measurement devices set limitations to long ambulatory measurements in out-of-laboratory settings due to the fact that electrode placement and skin preparation require careful handling, and measurement systems include wires that need to be secured in order to avoid movement artefacts.

The development of clothes with embedded textile electrodes has made surface EMG measurements convenient even for whole day field measurements [16,20–21]. For example, main locomotor muscle activity can be reliably measured using "EMG shorts" without skin preparation and problem of wires around the body, if one is only interested in the signal presence or absence and its relative amplitude [20].

In the present study the EMG shorts were used to assess muscle inactivity and activity periods during normal daily life of ordinary people. Muscle inactivity and different activity levels were categorized according to individually measured thresholds that were identified during functional tasks. From the methodological perspective the effect of different thresholds on inactivity and activity durations was tested.

Methods

This study was part of a project "*Muscle loading during physical activity and normal daily life: correlates with health and well-being (EMG 24)*" that uses novel textile EMG electrodes embedded into shorts [20]. The study was approved by the ethics committee of the University of Jyväskylä and the subjects signed an informed consent prior to any measurements.

Subjects

Subjects were recruited by advertisements to public places and different workplaces. We received a total of 245 contacts of which 122 were measured and meeting the inclusion criteria of being healthy with no major disorders or illnesses. Sufficient data was obtained from 84 subjects (20–76 years). Subject anthropometrics are presented in Table 1.

Protocol

The protocol included assessments in the laboratory and physical activity measurements during normal daily life in the normal living environment of each individual. In laboratory, anthropometrics, questionnaires of physical activity and medical history were collected and subjects over 40 yrs were screened by a medical doctor. Further, the subjects performed the following tasks while hamstring and quadriceps muscle activity using EMG shorts was measured: lying down, standing, sitting, squatting, stair negotiation, walking, running and maximal isometric voluntary contraction (MVC).

Laboratory measurements. Body composition including fat percentage and visceral fat was measured with bioimpedance device (InBody 720, Biospace Ltd, Soul, Korea) in a fasting state. Resting metabolic rate (RMR) was measured for calculation of metabolic equivalent (MET). Subjects filled in activity and health questionnaires in which, for instance, their habitual physical activity, percentage of time spent sitting during working hours and health status were asked.

Subjects wore the shorts with textile electrodes (Myontec Ltd, Kuopio, Finland) during the activity laboratory test and performed bilateral maximal voluntary isometric contractions (MVC) in knee extension/flexion machine (David 220, David Health Solutions, Helsinki, Finland) with 140° knee angle in both flexion and extension. The EMG values from MVC were used to normalize all EMG data. In all MVC tests subjects were first familiarized with the testing actions. At least 3 trials of 3–5 seconds were performed (with 1 minute rest period between trials) in each test and if torque improved more than 5% in the last trial more trials were done. In all performances loud verbal encouragement was used to push subjects to their best.

On another day the subjects performed a special treadmill (OJK-1, Telineyhtymä, Kotka, Finland) test with 3 minute steps. All subjects started the test by walking at 4, 5, 6 and 7 km/h. The 5 km/h load was performed both at level and with 4° decline and incline. From this onwards, subjects who were under 29 years and also older subjects who were accustomed to run, performed one running load (10 km*h^{-1} for females and 12 km*h^{-1} for males). The next step for all participants was walking 5 km*h^{-1} with 8° ascent. After walking for 3 minutes with this load it was estimated how close participants were to their maximal oxygen consumption (VO_{2max}). If two out of three of the following criteria were fulfilled participants continued with the same load until exhaustion: 1) VO_{2max} over 85% of estimated maximum, 2) heart rate over 90% of age estimated maximum, 3) Borg rating of perceived exertion over 16. If two out of three criteria were not fulfilled, participants continued the test by walking 7 km*h^{-1} with 10° ascent until exhaustion. This special protocol provided a possibility to measure heart rate and EMG in conditions that can occur during normal daily life (walking in different terrains).

Daily measurements. Measurements during normal daily life were performed either after the laboratory assessments or on separate days but not after the treadmill test. In the morning of each measurement day, the subjects came to the laboratory where the EMG recording devices were put on and set to record. Then they left for their normal living environments with instructions to live normal daily life as usual. To control the reliability of the EMG signal, the subjects were asked to perform and mark down to a diary special reference tests (15 seconds each) including lying down, standing and squatting preferably every 3 hours. The subjects were told to remove the equipment when taking a shower or swimming, or at latest before bedtime. When going to toilet, the subjects were instructed to carefully roll the shorts down and then roll the shorts back on. Measurement days were assigned for the subjects depending on their schedules, and some measurements were also done during weekends. During the measurement days, the subjects marked down the activities they have performed in ½ hour blocks, including sitting, standing, walking, bicycling and exercise for fitness, if any.

Table 1. Basic characteristics of the subjects.

Characteristics	Women (n = 44)		Men (n = 40)		All (n = 84)	
	Mean	SD	Mean	SD	Mean	SD
Age (years)	44.1	18.0	44.2	16.5	44.1	17.3
Height (cm)	166.0 ***	5.6	178.5 ***	6.6	172.3	6.1
Weight (kg)	62.3 ***	8.6	78.0 ***	11.9	70.1	10.2
BMI (kg/m^2)	22.6 **	2.8	24.4 **	2.8	23.5	2.8
Knee extension MVC (kg)	93.0 **	36.2	123.5 **	47.2	107.0	44.0
Knee flexion MVC (kg)	59.9 ***	23.4	87.5 ***	33.6	73.0	32.0
VO_2max (ml/kg/min)	41.0	10.9	44.3	12.5	42.4	11.6

Significant difference between genders are expressed as
**$p<0.01$;
***$p<0.001$.
doi:10.1371/journal.pone.0052228.t001

EMG recordings

EMG was measured with shorts made of knitted fabric similar to elastic clothes used for sport activities or as functional underwear with the exception of capability to measure EMG from the skin surface of the quadriceps and hamstring muscles (Myontec Ltd, Kuopio and Suunto Ltd, Vantaa, Finland). To obtain the average rectified value of EMG (aEMG), the shorts were equipped with conductive electrodes and wires integrated into the fabric, which transfer the EMG signals from the electrodes to the electronics module. The textile electrodes are sewn onto the internal surface of shorts and consist of conductive yarns including silver fibres and non-conductive synthetic yarns woven together to form a fabric band. The electrodes are located such that the bipolar electrode pair lies on the distal part of the quadriceps and hamstrings, and the reference electrodes longitudinally at lateral sides (over tractus iliotibialis) on left and right side. Sizes of the electrodes were 2.5×9.5–14 cm for quadriceps muscles, 1.5×7.5–8 cm for hamstrings muscles and 2×29–33 cm for lateral grounding electrodes depending on the size of the shorts. In this study, five pairs of shorts (three different sizes) were used. Shorts were equipped with adjustable zipper in the waist and hems, and elastic Velcro straps in the hem for improved fit. Electrode paste (Redux Electrolyte Crème, Parker Inc., USA) was added on the electrode surfaces prior to every measurement day to improve and stabilize conductivity between the skin and electrodes. The subjects were also given a small bottle of the paste with them and instructed to add more paste after shower, for example. After every measurement day the shorts (electronics module detached) were washed with washing powder either by hand or in the washing machine.

The recording electronic module contains signal amplifiers, microprocessor with firmware, data memory and PC interface. In the module, the EMG signal is measured in its raw form with a sampling frequency of 1000 Hz and a frequency band 50 Hz–200 Hz (−3 dB). The raw EMG signal was first rectified and then averaged over non-overlapping 100 ms intervals. The averaged data was stored in the memory of the module from which the data was downloaded to a PC using the specifically designed HeiMo PC-software (Myontec Ltd, Kuopio, Finland) and then analyzed in MegaWin software (Mega Electronics Ltd., Kuopio, Finland).

EMG analysis

Artefact correction. The entire EMG data was first visually assessed and corrected for artefacts. Use of automated algorithms was considered unreliable and difficult as data was not recorded in raw format but averaged over 100 ms intervals due to limited memory capacity of the module. Artefact removal and correction procedures were developed and refined with use of EMG shorts with online measurements possibility (Myontec Ltd, Kuopio, Finland). In separate laboratory testing session, different intentionally induced artefacts (i.e. movement of electrodes, module and lead wires; applying different degrees of pressure on electrode locations, placing shorts very close to electrical devices etc.) were compared to normal activities of daily living, and data was simultaneously screened on computer in real-time. With this procedure it was possible to educate research personnel responsible for artefact correction to differentiate between real muscle activity and artefacts with good degree of accuracy. The activity diaries and aEMG values during MVC (EMG_{MVC}, see below) were compared to the signal and if non-physiological signals were observed the data were operated with four possible methods:

1) Brief high amplitude ($>100\%EMG_{MVC}$, <1 s) artefacts or ones which were identical and seen simultaneous on several channels. These artefacts seemed to be caused by electrical interference due to sharp movements of measurement module, lead wires or electrodes. These artefacts were replaced with mathematical interpolation from values prior to and after the artefact.
2) Continuing artefact occurring during obvious bilateral movement (i.e. walking) was corrected by copying the data from contralateral channel. These artefacts were noticed as considerably higher peak activities or considerably increased 'baseline' activity than on contralateral side which could not be explained by physiological factors. These artefacts seemed to be caused by extraneous movement of electrodes in relation to skin, or movement of tissues between electrodes and muscle (i.e. skin and fat tissue) due to impact forces of locomotion.
3) In case the artefact was longer than 30 min, the signal was removed from that particular channel; therefore the recording time can vary between the four channels.
4) In case the signal was consistently abnormal throughout the measurement day(s) the particular channel was removed fully from the analysis. These cases were probably caused by improper function of the measurement device, improper size of the shorts or impedance problems between skin and electrodes.

A total of 222 days were measured equalling 888 channels of daily data (4 channels per measured day; right quadriceps, right hamstring, left quadriceps, left hamstring), from those channels 23% were not included in the analysis because of non-usable data, leaving 684 channels of daily data for analysis. On those channels recording time was on average 11.3±2.0 hours and on average 22.9±50.4 min (4.1±9.9%) was corrected for artefacts with the methods explained above. On average correction method 1 was used for 1.3±5.5 min (0.2±1.5%) per channel, method 2 for 3.3±8.6 min (0.7±2.6%), and method 3 for 18.4±49.5 min (3.1±9.3%)

Baseline correction. Signal baseline was determined as moving 5 minute minimum. The minimum of the following 5 minute data window was subtracted from each data point. The 5 min window was tested to be the best one to correct for minor baseline fluctuations without affecting the actual signal amplitude, inactivity times or activity burst durations.

Data normalization. Maximal EMG values (EMG_{MVC}) were taken as an average from a 1 s period during MVC. The EMG signal from each of the four muscles (right quadriceps, right hamstring, left quadriceps, left hamstring) was normalized to the EMG_{MVC} value in a given muscle, and the mean of the four channels is presented in the results as % of EMG_{MVC}. Also the thresholds for light, moderate and vigorous intensities were determined channel-by-channel from normalized EMG before averaging the four channels.

Threshold level determinations. Threshold levels between different muscle activity intensities during normal daily life were based on the standing reference test and an incremental treadmill walking test. The threshold between inactivity and light-intensity activity was set as an EMG value corresponding to 90% of the EMG value of standing on each individual and each channel. Thus, inactivity in this report represents the true individual behaviour below standing activity. The thresholds between light and moderate, and moderate and vigorous intensity were defined as 3 METs (metabolic equivalent) and 6 METs, respectively. These thresholds were assessed from the incremental treadmill walking test in the following way: From each load EMG was taken as one minute average from the middle of the load and VO_2 as an average from two last minutes of the load. VO_2 values were transformed to METs by division with resting metabolic rate (RMR) [22]. EMG values from each load were plotted against the corresponding MET values, and the EMG values corresponding to 3 METs (threshold for moderate intensity) and 6 METs (threshold for vigorous intensity) were calculated by regression analysis and used as individual threshold values. In the regression, additional point was added for 1 MET = 0 EMG representing the resting state and the highest VO_2 value was excluded since the normal daily activities are lower and the highest value could have biased the regression equation.

The artefact corrected and normalized EMG data was run through a custom made Matlab script (MATLAB, MathWorks, Massachusetts) where the following EMG variables were calculated:

Burst, inactivity and activity calculations. Determination of burst variables is shown in Figure 1. The following variables were calculated:

- average EMG from the entire recording period (% of EMG_{MVC})
- total inactivity duration (min)
- durations of five longest continuous inactivity periods (min)
- light intensity activity time (min)
- moderate intensity activity time (min)
- vigorous intensity activity time (min)
- number of bursts (#)
- average duration of bursts (s)
- average amplitude of all bursts (% of EMG_{MVC})
- burst rate (bps)
- total area of bursts (% of EMG_{MVC} * s)

Activity histograms. The distribution of muscle activity for different levels was calculated for different percentages of EMG_{MVC}: 0–1, 1–2, 2–3, 3–4, 4–5, 0–5, 5–10, 10–20, 20–30, 30–40, 40–50, 50–60, 60–70, 70–80, 80–90, 90–100 and >100. After that the calculations were completed with the individual threshold levels for inactivity, light-, moderate- and vigorous-intensity activity.

Averaging of variables. After the variables (e.g. inactivity time, burst amplitude) were extracted from each four channels, they were averaged across different days within individual. Then, the different variables from the four muscle groups were averaged to get one descriptive variable for each subject, and these averaged values were used for further analysis.

Repeatability of data. Repeatability of the EMG data was assessed using the reference tests from 20 subjects during 1–3 days. The reference test consisted of lying down quietly for 15 s, standing quietly for 15 s and remaining in half-squat position for 15 s. From each task average EMG values from a 10 s period were analyzed. Intraclass correlation was calculated between aEMG values of two tests within the same day. The mean intraclass correlation of all four channels was 0.73±0.19 in lying down, 0.75±0.16 during standing and 0.73±0.09 during half-squat. Day-to-day intraclass correlations of all four channels were 0.80±0.37 in lying down, 0.97±0.03 during standing and 0.90±0.07 during half-squat. It should be noted that these analyses were done before signal baseline correction, which can explain the higher day-to-day than within-day repeatability

Statistical analyses. Statistical analyses were performed with PASW Statistics v.18.0 (SPSS inc. Chicago, Illinois, US). Data is presented as mean ± standard deviation. The differences between the genders were studied with independent samples Mann-Whitney U-test after checking distribution of the data with Saphiro-Wilk test. Significance level was set at $P<0.05$.

Results

Examples of raw recordings during the reference tests (Fig. 2A) and during normal daily life (Fig. 2B, 2C) are shown in Figure 2. Muscle activities during the different functional tasks in the laboratory are shown in Figure 3. For example, muscle activity during standing is almost 2.5 times higher than during sitting. Downhill walking yields similar average muscle activation as walking on level ground and muscle activity is increased on average 30.8% in 4° uphill compared to level ground with same walking speed (5 km/h). While stairs ascend is typically considered as non-exercise activity it produces EMG amplitudes over 20% of EMG_{MVC} that are much higher than in brisk walking.

The individually defined inactivity, moderate activity (3 MET) and vigorous activity (6 MET) thresholds are shown in Table 2, while Table 3 compares total daily activity and inactivity times calculated using the individual inactivity thresholds and absolute thresholds of 1, 2 and 5% of EMG_{MVC}. On average, the 2% EMG_{MVC} threshold yields activity and inactivity times similar to the individually determined threshold.

During normal daily life, the average EMG amplitude was 4.0% of EMG_{MVC}, and average burst amplitude was 5.8% of EMG_{MVC} (Table 4). The subjects had 12,600±4,000 muscle activity bursts during a day and burst duration was 1.4±1.4 s. Women had significantly more (15.7%, $P<0.05$) activity bursts than men and

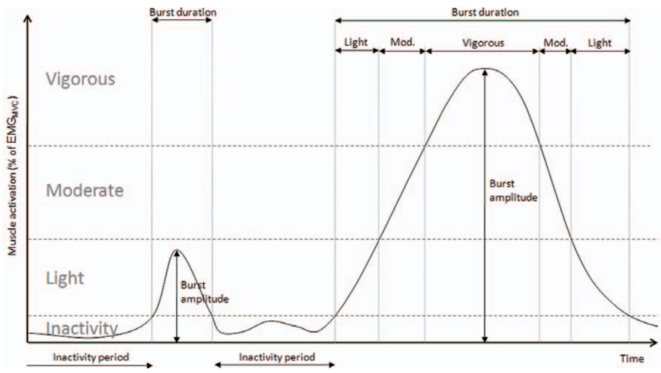

Figure 1. Analysis of burst characteristics and muscle activities. Schematic drawing depicting analysis of burst amplitude, duration, inactivity periods and differentiation to light, moderate and vigorous muscle activities. The thresholds for inactivity, light, moderate and vigorous activities were determined individually (see text).
doi:10.1371/journal.pone.0052228.g001

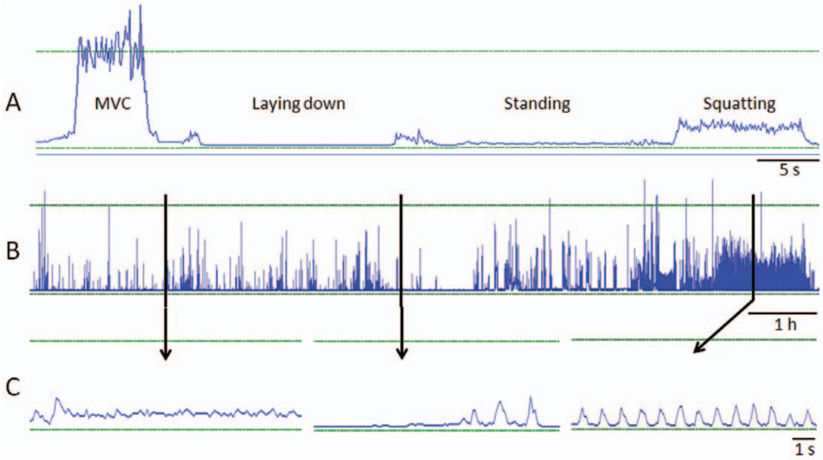

Figure 2. Example EMG data from laboratory and field measurements. Examples of averaged EMG data of left quadriceps femoris from one subject. Part A shows from the laboratory measurement session MVC of knee extension, lying down, standing still and squatting. Part B shows EMG activity during the entire day. Part C shows zoomed areas from daily EMG data (thick vertical lines show which parts of the data are zoomed). Horizontal lines represent baseline and 100% of EMG_{MVC}.
doi:10.1371/journal.pone.0052228.g002

time over 50% EMG_{MVC} was 73% longer than in men ($p<0.05$). Overall, women spent more time at intensities above 40% EMG_{MVC} compared to men ($p<0.05$) (Table 5).

Table 5 shows the time spent at different EMG intensities in detail. 97% of measurement time muscle activity was below 30% of EMG_{MVC} and less than 2 min was at intensities above 70% EMG_{MVC}. Accumulated time over 50% of EMG_{MVC} was only 5.1±6.4 min (range 0.0–21.2 min).

Thigh muscles were inactive for 67.5±11.9% of the measurement time (Fig. 4). Corresponding times for light, moderate and vigorous activity were 16.7±9.9%, 8.5±3.4% and 7.3±4.2%, respectively. Inactivity ranged from 39.9 to 90.9% of measurement time highlighting large inter-individual differences in physical

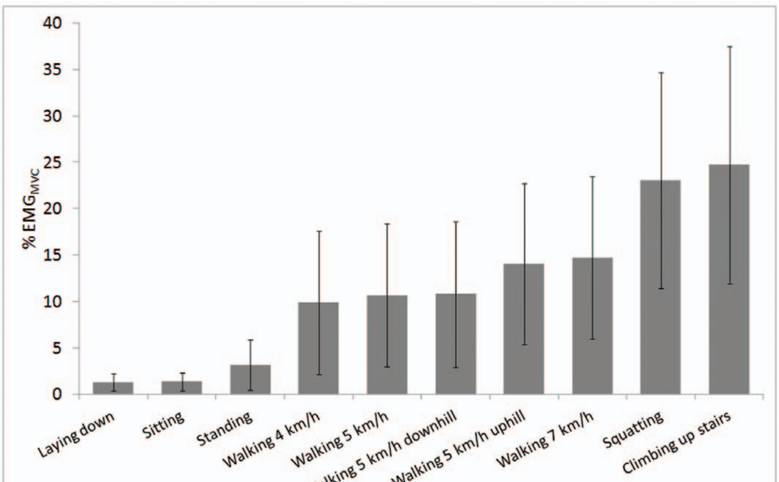

Figure 3. Average muscle activity in daily tasks. Average (±SD) quadriceps and hamstring muscle activity for different daily tasks measured in the laboratory (n = 63–84).
doi:10.1371/journal.pone.0052228.g003

Table 2. Average EMG activities at different thresholds that were defined from the standing and incremental treadmill walking test.

Laboratory tests	Women (n = 44)		Men (n = 40)		All (n = 84)	
	Mean	SD	Mean	SD	Mean	SD
Inactivity threshold = 0,9×standing (% EMG_{MVC})	2.5	2.0	2.4	1.4	2.5	1.7
Moderate activity threshold (% EMG_{MVC})	6.9	4.7	5.6	2.0	6.3	3.7
Vigorous activity threshold (% EMG_{MVC})	15.4	11.2	12.9	5.0	14.2	8.8

doi:10.1371/journal.pone.0052228.t002

activity behaviour. Inter-individual variance was considerably high also in light, moderate and vigorous activities ranging from 2.8 to 45.0%, 2.0 to 20.9% and from 0.5 to 22.8% of measurement time, respectively.

The longest continuous inactivity periods lasted for 13.9±7.3 min (range 2.5–38.3 min). 2nd, 3rd, 4th and 5th longest inactivity periods lasted 9.8±4.5 min, 8.0±3.4 min, 7.0±3.0 min, 6.3±2.7 min, respectively. Bivariate correlations revealed that the longest inactivity period was associated with the 2nd ($R^2 = 0.80$), 3rd ($R^2 = 0.72$), 4th ($R^2 = 0.70$) and 5th ($R^2 = 0.68$) longest inactivity periods ($P < .001$). Thus the longest inactivity period represents the trend of the lengths of other inactivity periods, too.

Discussion

This study reports EMG levels during normal daily living and provides reference points measured in the laboratory during simulated daily activities. The main finding of this study was that thigh muscles are inactive over 65% of the measurement time and only a fraction of muscle's maximal voluntary strength capacity is used during normal daily life. Average EMG amplitude was 4% EMG_{MVC} which is below the mean EMG level required for walking (Fig. 3). In our study, quadriceps and hamstring muscles were active on average 34% of total time (3.6 hours from 11 hour recordings), while others studies have reported lower values for EMG duration for vastus lateralis during 8 to 15-h recordings, including 13% [18], 12% [27], 10% [17], and 9% [28]. One factor possibly explaining differences in activity times is that in our study, with a comprehensive sample size, we also measured hamstrings in addition to quadriceps, and instead of single muscles whole muscle groups were measured. Also many other factors such as differing subject group, measurement systems, thresholds employed and analysis procedures used, probably contribute to the differences in activity times between the studies.

Table 3. Inactivity times during normal daily life based on different thresholds.

Inactivity threshold	Inactivity time (% of total time)	
	Mean	SD
90% of EMG of standing	67.5	11.9
1% EMG_{MVC}	54.5	17.1
2% EMG_{MVC}	68.2	15.4
5% EMG_{MVC}	81.4	11.9

The first row represents results using individually determined threshold below standing activity (mean of four muscle groups) that is compared to the absolute % levels of each individual's EMG amplitude during maximal voluntary contraction (EMG_{MVC}).

doi:10.1371/journal.pone.0052228.t003

Muscle activity during normal daily life

In the present study the mean EMG burst amplitude of quadriceps and hamstring muscles was 5.8% of EMG_{MVC} that is comparable to that found by Klein et al. [18] where mean vastus lateralis EMG was 6.9% EMG_{MVC}. On the other hand, Kern et al. [17] reported mean burst amplitude of 17% MVC (for vastus lateralis) and 18% MVC (for vastus medialis) but these subjects were moderately active college students who are likely to be more active than the present group with large age range. In addition, Kern et al. [17] used burst threshold of 2% of MVC which may have left some smaller bursts out of the analysis whereas the numbers by Klein et al. [18] are based on values above a baseline, which may explain the smaller mean amplitudes.

As average EMG amplitude was only 4% EMG_{MVC}, the daily muscle activity could be cumulated by walking at 7 km/h for 3 hours or ascending stairs for less than 2 hours. Fifteen subjects had average daily EMG amplitude under 2% of EMG_{MVC} which could be achieved by less than 1 hour of stair climbing or about 1.5 hours of walking at 7 km/h. These subjects could have increased their thigh muscle activity 50% by standing 3.5 hours more during the day.

On average, the present subjects had muscle activity over 90% of EMG_{MVC} only for 56 seconds (Table 5). Thirty-six subjects had less than 10 seconds of muscle activity over 90% EMG_{MVC} and 39 subjects had less than on minute of muscle activity over 60% EMG_{MVC}. Larger muscles, such as those in leg or arm are reported to recruit motor units at least up to 90% of MVC [23]. Specifically, in isometric conditions vastus lateralis muscle maximum recruitment threshold has been shown to be 95% of MVC [24] although in rapid contractions the threshold is lower [25]. Therefore, some motor units may have very little if any activity during the daily life in these subjects. Long-term consequences of limited activity of the highest threshold motor units is uncertain, but it is conceivable that such a condition for many years could contribute to age-related weakness and muscle atrophy [18]. To express the activity times from another perspective, in hypertrophic strength training typical activity duration for one single exercise is about 60–220 seconds (4–6 sets with 8–12 repetitions each lasting 2–3 seconds) and the intensity level varies between 70–85% of one repetition maximum. This kind of hypertrophic training usually includes 2–3 different exercises for one muscle group leading to increase in muscle mass. While the maintenance of the acquired muscle mass and strength after an intensive training period requires 1–1.5 training sessions per week, it is not quite clear how much and what type of muscle activity is needed to maintain muscle mass in normal subjects during daily life [26].

Table 4. EMG volume and rate indicators from normal daily life for women and men presented relative to isometric MVC (±SD).

	Women (n = 44)		Men (n = 40)		All (n = 84)	
	Mean	SD	Mean	SD	Mean	SD
EMG volume indicators						
Average amplitude (% EMG_{MVC})	4.4	3.0	3.5	2.0	4.0	2.6
Average burst amplitude (% EMG_{MVC})	5.9	3.7	5.7	3.1	5.8	3.4
Total area (% EMG_{MVC} * s)	148 885	89 116	116 089	73 100	133 268	83 046
Time over 50% EMG_{MVC} (min)	6.4*	7.1	3.7*	5.4	5.1	6.4
Activity time (min)	229	86	200	84	215	86
EMG rate indicators						
Number of bursts	13 410*	3 549	11 591*	4 331	12 544	4 021
Average burst duration (s)	1.4	1.3	1.5	1.5	1.4	1.4
Burst rate (bps)	0.41	0.15	0.37	0.14	0.39	0.15

Significant difference between genders are expressed as
*$p<0.05$.
doi:10.1371/journal.pone.0052228.t004

A very large variability between subjects in total inactivity times ranging from 40 to 91% of total time were found (Fig. 4). Also light activity (3–45% of total time) has much higher between-subjects variability than moderate (2–21% of total time) or vigorous (1–23% of total time) activity indicating that individual differences in light physical activity have greater influence on inactivity time than moderate or vigorous physical activity. It is important to measure also short periods of physical activity accurately as even 15 min of physical activity per day provides a reduction in all-cause mortality and extends an individual's lifespan for an average of 3 years [13].

Continuous inactivity periods

There was a very large variation between subjects in continuous inactivity periods. One subject did not have inactivity periods longer than 3 minutes and in the other extreme one subject had the longest inactivity period lasting almost 40 minutes and even his 5th longest inactivity period was over 15 minutes. It should be

Table 5. Time spent at different EMG intensities (relative to isometric MVC) in normal daily life for women and men.

	Women (n = 44)		Men (n = 40)		All (n = 84)		All (n = 84)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
EMG_{MVC}: time (%)							**Time (mm:ss)**	
0–1%	53.3	18.6	55.9	15.3	54.5	17.0	361:39	126:20
1–2%	13.0	6.1	14.3	8.6	13.6	7.3	91:11	51:32
2–3%	6.6	3.7	6.2	4.1	6.4	3.9	42:48	27:54
3–4%	4.4	2.8	3.6	2.2	4.0	2.5	26:37	17:15
4–5%	2.9	1.4	2.7	1.7	2.8	1.5	18:51	10:17
0–5%	80.2	13.1	82.8	10.5	81.4	11.9	541:06	120:08
5–10%	8.3	5.0	8.0	6.0	8.2	5.5	53:44	34:19
10–20%	6.1	3.6	5.4	3.1	5.8	3.4	38:10	21:53
20–30%	2.5	2.1	2.0	1.6	2.2	1.9	14:40	11:28
30–40%	1.3	1.3	0.9	0.8	1.1	1.1	07:01	06:30
40–50%	0.7*	0.7	0.4*	0.4	0.6	0.6	03:53	03:40
50–60%	0.4*	0.4	0.2*	0.2	0.3	0.4	01:59	02:14
60–70%	0.2*	0.3	0.1*	0.2	0.2	0.2	01:07	01:23
70–80%	0.1*	0.2	0.1*	0.1	0.1	0.1	00:40	00:53
80–90%	0.1*	0.1	0.0*	0.1	0.1	0.1	00:25	00:36
90–100%	0.1*	0.1	0.0*	0.1	0.0	0.1	00:16	00:25
≥100%	0.1*	0.2	0.1*	0.2	0.1	0.2	00:38	01:16

Time expressed as percentage from total measurement time and as minutes and seconds.
Significant difference between genders are expressed as
*$p<0.05$.
doi:10.1371/journal.pone.0052228.t005

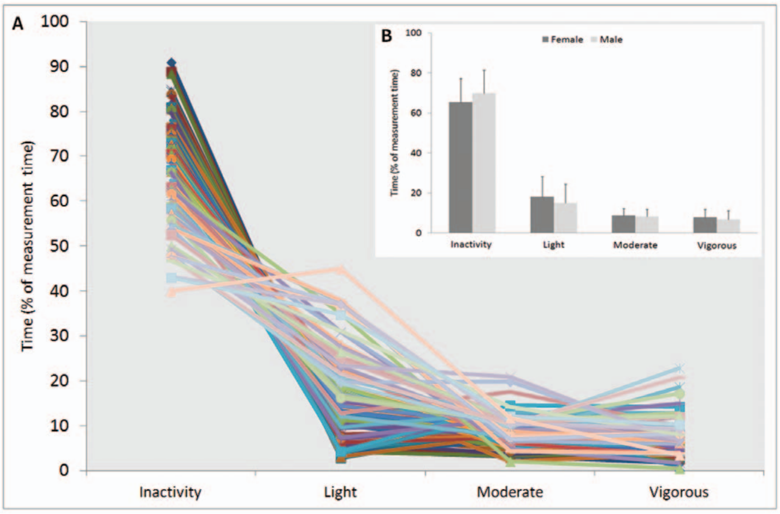

Figure 4. Muscle activity levels during normal daily life. A) Time spent at different muscle activity levels during normal daily life based on individual threshold values (2.5±1.7, 6.3±3.7 and 14.2±8.8% EMG_{MVC} for inactivity, moderate activity and vigorous activity thresholds, respectively). Each line represents one individual (n = 84). B) Duration of mean (±SD) quadriceps and hamstring muscle activity at different intensities did not differ between males (n = 40) and females (n = 44) during an 11 hour measurement.
doi:10.1371/journal.pone.0052228.g004

reminded that activity burst as short as 0.1 second breaks the inactivity period reported in this paper. Therefore, it is possible that a long inactivity period is stopped by very short activity that could be done during sitting followed by another long inactivity period. As our inactivity threshold was individually determined based on a functional task it is highly likely that these values represent the true behaviour of the subjects. Short inactivity periods may reflect a behaviour where person is rarely sitting or sitting but fidgeting legs very often. At this point we do not know how long the activity period should be to be physiologically significant or how long inactivity can be sustained without consequences to health although a recent report shows adverse effects of 1 day sitting on metabolism [29].

Differences between males and females

Women had more activity time 40–100 of EMG_{MVC}, over 50% EMG_{MVC} and more activity bursts than men. Kern et al. [17] reported that women had 70% higher summed duration of bursts in biceps brachii than males and their small sample size might have hindered differences in other muscles. Finnish women have been reported to take more steps during the day than Finnish men [30]. Shorter stature of females could affect to higher burst count as shorter persons need to take more steps to cover the same distance in walking or running. Women had significantly lower torques in MVC meaning that they need to use higher relative force for the same absolute tasks than men, possibly explaining women having more activities at higher intensity.

Inactivity threshold determination

We decided to use individual task-based threshold because of the large variability in MVC torques and EMG_{MVC} values. If we had, for example, used 1.7±0.2% of EMG_{MVC} (determined from the baseline) as inactivity threshold as used by Klein et al. [18], some of the strongest subjects would not have exceeded the threshold during standing, which would then had been mistakenly classified as inactivity. Indeed, we used quiet standing as a reference activity as it can be considered as the lowest level of activity in daily life. Inactivity threshold was set to 90% of activity of standing to ensure that standing would be classified as activity in all cases. Individual inactivity threshold is especially important when subjects differ largely in their force production capabilities, as in the present heterogeneous study group.

The individually determined threshold (2.5±1.7% EMG_{MVC}) yielded approximately the same inactivity times as 2% EMG_{MVC} threshold, but with smaller variation in inactivity times (SD 11.9 and 15.4, respectively). Inactivity threshold of 1% EMG_{MVC} decreased the inactivity time considerably, and threshold of 5% EMG_{MVC} increased it. Therefore, our results support the suggestion from Klein et al. [18] that even a small change in the threshold may result in a very large change in the daily EMG duration.

Maximal voluntary muscle force and EMG activity measurement

In addition to the between subject variability in MVC and EMG_{MVC} values, the method by which these values are measured is important when comparing different studies. The maximal voluntary muscle force and muscle activity is a critical measurement as changes in the threshold (%EMG_{MVC}) affect the inactivity time and time spent in different activity levels. Klein et al. [18] normalized their data with EMG_{MVC} values measured in 80° knee angle, while we used 140° knee angle (knee fully extended is 180°). Although 120° is reported to be optimal for maximal force production [31] we wanted to use a knee angle that is closer to ones used commonly in normal daily life. Careful attention was paid to ensure that real maximum was achieved in MVC testing by doing enough trials and by using loud verbal encouragement.

Methodological limitations

Even though considerable amount of data (23%) had to be excluded from the analysis, sample size (n = 84) and recording time (over 10 hours/day) remained relatively good. The cross-sectional design, however, adds variability to our study as people are likely to be more physically active in summer than in winter [32–34] and in weekends than weekdays [33]. On the other hand, light physical activities dominate over moderate activities on weekdays [30]. In our study we only measured muscle activity from thigh muscles. Probably thigh muscle activity gives a good indication of activity of other leg muscles also as a major portion of daily physical activity consists of standing and locomotion [11]. We have tested that thigh muscle activity correlates highly with energy expenditure in walking at different speeds in level and in uphill and downhill (unpublished results).

Representativeness of subject group

Subjects were recruited through advertisements in public places and different workplaces and therefore do not represent a randomly selected sample. Often more active people are more interested taking part in research projects which include physical activity assessments and although this bias cannot be excluded, our results do show that we also had inactive and sedentary subjects in our study. This study was conducted with Finnish people living in a rather small city with good possibilities to walk or bicycle to work. However, the nature of office work does not differ considerably between cultures and therefore our data gives insight into inactivity of modern societies.

Relevance of the study

Wearable electromyography enables measurement of details of muscle inactivity and activity during normal daily life. The muscle activity patterns reported in this paper are significant for understanding intensity, amount and distribution of physical activity which is typical in healthy adults. These data can be used as a reference point of activity levels and patterns that maintain or can recover normal muscle properties. Further, the data can be valuable for future interpretations of activity patterns in different disorders affecting locomotor abilities, motor dysfunctions, or overall physical activity.

Author Contributions

Conceived and designed the experiments: OT KH TP TF. Performed the experiments: OT PH AP. Analyzed the data: OT PH AP TR MH TF. Wrote the paper: OT AP TF.

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IV

MUSCLE ACTIVITY DURING DAILY LIFE IN THE OLDER PEOPLE.

by

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Muscle activity during daily life in the older people

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Running head: EMG during daily life in older people

Abstract

Introduction. The purpose of this study was to assess thigh muscle activity patterns during normal daily life and simulated daily tasks and to compare muscle activity and energy consumption during active and passive transport tasks in older people.

Methods. Nine volunteers (70±6 yrs) were measured for quadriceps and hamstring muscle activity (EMG) during normal daily life, treadmill walking, and during passive and active transport tasks. EMG was normalized to that recorded during maximal voluntary contraction (MVC). Oxygen uptake (VO_2) was measured during treadmill and transport tasks.

Results. During daily life the mean EMG amplitude was 5.9±2.4 % of EMG_{MVC} and the longest continuous inactivity periods were 20.9±10.0 min. During stair ascend the peak EMG activity was 120 % of EMG_{MVC} and the peak VO_2 values were only about 70 % of VO_{2MAX}. One kilometer walk consumed 3.5 times more energy than passive transport by bus, and using stairs consumed 11.7 times more energy than using an elevator.

Discussion. In daily life, older people use only a small fraction of muscle's maximal capacity and have long continuous inactivity periods. Active ways of transport produce significant load to neuromuscular but not to cardiovascular system thus providing an effective strength training stimulus.

Key words: physical activity, electromyography, independent living, energy expenditure

Introduction

Muscle mass and strength decrease gradually with advancing age (1) and changes in strength are not the same for all muscle groups or tasks (2). There is a growing evidence linking decreased strength to functional disability, decreased bone density, falls, glucose intolerance, and decreased cold and heat tolerance in older adults, but to which degree strength loss is due to decreased level of daily activity and thereby muscle activation, remains speculative. Since older individuals are forced to use almost their maximum effort in certain daily activities (e.g. stair ascending, descending and rising from a chair) (3), maintenance of strength and power reserves seems essential when considering unexpected stumbling or loss of balance.

Recent epidemiological findings suggest that not only the lack of physical activity, but also prolonged times of sedentary behavior, particularly sitting, increase significantly the risk of chronic diseases, such as type 2 diabetes (10) and insulin resistance (11). This association persists even if people participate in moderate-to-vigorous intensity physical activities (12-20). Consequently, it is important to measure also low the intensity activities and short bursts of activity accurately in long-term measurements. Shorts embedded with textile electromyographic (EMG) electrodes provide a convenient tool to examine the daily physical activity spectrum including the low intensity activities and muscle inactivity in the most precise way (21-23).

In the present study, shorts measuring quadriceps and hamstring muscle EMG were used to assess inactivity and activity periods during normal daily life and simulated tasks of laying down, sitting, standing and squatting in the older people. In addition, this study investigated the differences in muscle activity and energy expenditure in active and passive ways of transport among healthy community-dwelling older people.

METHODS

Participants

Healthy 66-76 year old community-dwelling men and women were recruited to the study through public advertisements and email lists of local companies and institutes in Central Finland. Exclusion criteria were any self-reported prevailing injuries in back or lower extremities, use of beta blockers or hormonal medication, diabetes, exercise induced asthma, angina pectoris and exercise induced arrhythmia and inability to perform maximal treadmill test or inability to perform test activities included in the study protocol. Sixteen older participants (9 females, 7 males) volunteered for the study and were approved for testing after medical examinations (28). Ten of the participants provided a complete series of measurements. One participant was excluded due to corrupted data. Finally, nine individuals (3 females, 6 males) were included into the analysis. Their basic characteristics of are given in Table 1. The ethics committee of the University of Jyväskylä approved the study and a written informed consent was obtained from all participants.

Protocol

Measurements consisted of the following parts: 1) Anthropometric tests, 2) Maximum voluntary contraction (MVC) tests, 3) Simulated daily tasks (laying down, standing, sitting and squatting), 4) Maximal VO_2 test, 5) Active and passive transport tasks (including 1 km commute and stair ascending and descending) and 6) EMG activity measurements during normal daily life. EMG from quadriceps and hamstring muscles was measured during all the tests (excluding anthropometric tests) using EMG shorts (23). During maximal VO_2 test and active and passive transport tests the participants also wore a portable device measuring respiratory gases.

Anthropometric and resting measurements. Anthropometrics including body composition (InBody 720, Soul, Korea) were measured in the laboratory after overnight fasting. Resting metabolic rate was determined as an average oxygen uptake over 10 minutes preceded by 20 minutes of quiet bed rest (Jaeger Oxycon Pro with LabManager 3.0 software, Viasys Healthcare Gmbh, Hoechberg, Germany). HR (Suunto T6, Vantaa, Finland) was recorded continuously and resting HR was determined as the lowest value within a five-second window.

MVC testing. Maximum isometric voluntary contraction (MVC) on a custom made leg press (University of Jyväskylä, Finland) and knee extension and flexion strength (DAVID 200, David Fitness and Medical, Ltd. Vantaa, Finland) with knee angle of 140° were measured. After warm up trials three maximal contractions with 1 minute break between the trials were recorded. If the force of the last trial was over 5 % higher than the best trial, additional trials were done. The best performance was analyzed and the mean EMG from 1 second period was considered as EMG_{MVC}.

Simulated daily tasks consisting of lying down, sitting, standing and squatting were performed in the laboratory. EMG was averaged over a 15 second period from each task.

VO_2 max test. Maximal VO_2 test, with 3 minute loads, was performed on a large treadmill (4m x 2m; model OJK-1, Telineyhtymä, Kotka, Finland) to enable unobstructed walking and running. Walking was performed with velocities of 4 km · h^{-1}, 5 km · h^{-1}, 5 km · h^{-1} (4 ° decline), 5 km · h^{-1} (4 ° incline), 6 km · h^{-1} and 7 km · h^{-1}. After one minute break for blood pressure measurement the test continued with velocity of 5 km · h^{-1} with incline of 8°. At the end of each three minutes load the VO_2, HR and RPE were evaluated. If two of the following three criteria were met 1) VO_2 was over 85% of estimated maximum 2) HR over 90% of maximum, 3) RPE over 16, the test was continued with the same load, if not, the velocity was increased the last load being 7 km · h^{-1} with inclination of 10°, and performed until exhaustion. Maximum VO_2 (VO_{2max}) was considered to be reached when VO_2 reached plateau and calculated as 30 s mean. The treadmill test was supervised by a medical doctor. Respiratory gases were measured with Jaeger Oxycon Pro which was calibrated before every participant. Nasal respiration was blocked with a nose clip (Nose Clip Disposable Series 9014, Hans Rudolph Inc., Shawnee, USA). Respiratory gases, heart rate and EMG were measured continuously during the test.

Active and passive transport tests. Four different tasks simulating passive and active ways of transport (Table 2) were performed on a different day than maximal VO_2 test. The first passive task consisted of a 50 m walk to a bus and sitting in it for two minutes (estimated as 1 km distance by bus in an urbanized area) and then another 50 m walk. During the second passive task the participants used an elevator to ascend and descend to the fourth floor. Subsequently, the first active task was a one kilometer walk at self-selected pace and the second active task was stair negotiation. Participants were told to ascend as many stairs as they can (maximum of five flight of stairs) and then after a sitting resting period (until respiratory rate and HR decreased close to the resting levels) to descend the same amount of stairs. The stair negotiations were first done with no additional load and on the second time carrying 5 kg bags in both hands. All tasks were performed with a self-selected pace wearing HR monitor, EMG shorts and portable gas analyzer (Oxycon Mobile, VIASYS Healthcare Gmbh, Hoechberg, Germany) with a face mask.

Muscle activity during normal daily life. Measurements during daily life in the normal living environment of each individual were performed either after the laboratory assessments or on separate days but not after the maximal VO_2 test. In the morning of each measurement day, EMG shorts were dressed on and set to record in the laboratory. Then the participants left for their normal living environments with instructions to live normal daily life as usual. The participants were told to remove the equipment when taking a shower or before bedtime at the latest. Each participant was measured for 1-3 days, some of them being weekend days.

Electromyography

Muscle activity was recorded using electromyography (EMG) from quadriceps and hamstrings muscles of both legs using elastic shorts with embedded textile electrodes and stored to a data logger attached to waistline (Myontec Ltd. Kuopio, Finland) (23). Electrode paste (Redux Electrolyte Créme, Parker Inc., USA) was used between the electrodes and skin to ensure proper conductance throughout the day.

EMG signal processing. EMG data was collected to the data logger with 1 000 Hz sampling rate and band pass filtered with 50-200 Hz. Before storing, the raw data was rectified and averaged in 100 ms non-overlapping window to allow long recording time. The rectified and averaged EMG-signal from the data logger was downloaded using HeiMo-software (Myontec Ltd, Kuopio, Finland) and inspected using MegaWin-software (Mega Electronics Ltd. Kuopio, Finland) for any untypical values (>> MVC) or interferences in the signal. If errors were found they were corrected with standard procedure of either extrapolation or removal. The EMG data was normalized to EMG_{MVC}. Thus, values higher than 100% of maximal EMG from MVC test (EMG_{MVC}) are possible especially during dynamic movements. Detailed description of the signal processing is given in (22).

Data analysis

Treadmill test and resting metabolic rate. Resting metabolic rate was determined as a mean oxygen uptake over 10 minutes preceded by 20 minutes of quiet bed rest. During the treadmill test the mean heart rate, EMG and respiratory gas data from the last 60 seconds of each load was further analyzed. Heart rate was calculated as % of maximum found during the treadmill test.

Active and passive transport tests. In active and passive transport tests mean muscle activity (aEMG) from the four channels were calculated during each task. The cumulative integrated EMG (iEMG) was calculated as the area under the EMG-time curve, expressed initially as µV·s and then normalized to EMG_{MVC}. Peak values during different tasks are the highest 100 ms mean value of all four channels during the given task. The measured VO_2 values of transport tests were first averaged in 5 second periods. Then the area under the VO_2 curve during each identified task was calculated. In addition, excess post oxygen consumption (EPOC) was calculated until level of $1.2 \cdot VO_{2\ rest}$ was achieved and added to the values measured during the actual tasks. This was done because the steady state was not reached during the stair ascend and other active tasks. Therefore, inclusion of EPOC allows comparison between the active and passive tasks. Ratios for comparing the magnitude of aEMG, iEMG and VO_2 in "*walking 1 km vs. transport by bus*" and "*using stairs vs. using* *elevator*" were calculated by dividing the values of the active task by corresponding values of the passive task. The absolute differences in aEMG, iEMG, mean VO_2 and cumulated VO_2 between the tasks were calculated by subtracting the passive values from the corresponding active values.

Daily measurements. In the daily measurements a total of 17 days were measured with an average recording time of 11.2 ± 0.8 hours. The EMG signal from each of the four muscles (right quadriceps, right hamstring, left quadriceps, and left hamstring) was normalized to the maximal EMG values (EMG_{MVC}) taken as an average from a 1 s period during MVC (knee extension or flexion test) for the given muscle. Threshold levels between different muscle activity intensities during normal daily life were based on the standing test and the incremental treadmill walking test. The threshold between inactivity and light-intensity activity was set as an EMG value corresponding to 90% of the EMG value of standing on each individual and each channel. The thresholds between light and moderate, and moderate and vigorous intensity were defined from the treadmill test as 3 METs (metabolic equivalent of task) and 6 METs, respectively. The artefact corrected and normalized EMG data was run through a custom made Matlab script (MATLAB, MathWorks, Massachusetts) where the following EMG variables were calculated for each channel: mean muscle activity (% of EMG_{MVC}), number of bursts (#), mean duration of bursts (s), mean amplitude of all bursts (% of EMG_{MVC}), burst rate (bps), total area of bursts (% of $EMG_{MVC} \cdot s$), total inactivity duration (min), durations of five longest continuous inactivity periods (min), light intensity activity time (min), moderate intensity activity time (min), vigorous intensity activity time (min). In addition, the distribution of muscle activity for different levels was calculated for different percentages of EMG_{MVC}: 0-1, 1-2, 2-3, 3-4, 4-5, 0-5, 5-10, 10-20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-80, 80-90, 90-100 and >100. After the variables (e.g. inactivity time, burst amplitude) were extracted from each four channels, they were averaged across different days within individual. Then, the different variables from the four muscle groups were averaged to get one descriptive variable for each participant, and these values were used for further analysis (22). Daily energy expenditure based on EMG recordings was calculated using the following equation (21):

$$EE\ (kcal \cdot min^{-1}) = 0.627 + 0.254 \cdot Sex + 0.015 \cdot Age + (0.968 + 0.179 \cdot Sex - 0.011 \cdot Age) \cdot aEMG(QH)$$

Mean muscle activity value (aEMG in % of EMG_{MVC}), age (in years) and sex (1 for men, 0 for women) of each participant were inserted in the equation to get daily EE. Then this EE value was multiplied by 1 440 (minutes in 24 h) to get a total 24 hour EE (to enable comparisons with other studies).

Statistical analysis. Statistical analyses were performed with PASW Statistics v.18.0 (SPSS Inc. Chicago, Illinois, U.S.A.). Data is presented as mean ± standard deviation, except for transport tests, which are presented in median ± standard deviation (because all tests performed for those results are based on median values). Nonparametric analyses were used due to non-Gaussian distribution with high skewness and kurtosis. To reveal differences between passive and active tasks the Wilcoxon Signed Ranks Test (2-tailed) was used and Kendall's Tau-b (2-tailed) was applied for correlations. To distinguish differences between the sexes, Mann-Whitney U-test was used. Significance level was set at $P<0.05$.

RESULTS

The basic characteristics of the participants are given in Table 1. Muscle activities during lying down, sitting, standing, squatting and walking on treadmill with different speeds on the treadmill are shown in Figure 1. For example, muscle activity during standing was on average 6 % of EMG_{MVC} ranging from 3 to 10 % of EMG_{MVC}. Walking at 6 km · h^{-1} was performed with an intensity corresponding to a mean of 21 % of EMG_{MVC} but in one participant muscle activity reached almost 50% of $EMG_{MVC.}$ Large inter-individual differences were prominent as indicated by large standard deviations.

Active and passive transport. Muscle activity and oxygen consumption during transport tasks is shown in Figure 2. The mean muscle activity was the lowest when using an elevator (5 % of EMG_{MVC}) followed by passive transport which included sitting and walking (13 % of EMG_{MVC}). Mean muscle activity was the highest during unloaded and loaded ascent reaching 29 and 32 % of EMG_{MVC}, respectively. During unloaded and loaded stair descent the mean muscle activity was of similar magnitude as during 1 km walking (Figure 2).

Oxygen consumption did not follow the trend of muscle activation being significantly lower ($P < 0.01$) during unloaded and loaded ascending than during walking. Oxygen consumption during elevator use (7 ml · kg^{-1} · min^{-1}) was comparable to the energy requirement of unloaded (6 ml · kg^{-1} · min^{-1}) and loaded descent (8 ml · kg^{-1} · min^{-1}).

The mean muscle activity during walking was 1.8 ± 0.3 times the amount of transport passively. Cumulated muscle activity of walking 1 km was 3.5 ± 2.7 times that of passive transport. The corresponding values for mean VO_2 and cumulated VO_2 were 2.2 ± 0.4 and 3.3 ± 2.5, respectively. Cumulated VO_2 was 140 ± 25 ml · kg^{-1} higher in active than in passive transport. One km walking time was negatively correlated with mean muscle activity during walking ($\tau b= - 0.556$, $P= 0.037$) and mean VO_2 during walking ($\tau b= - 0.667$, $p= 0.012$).

Insert Figure 2

Stair negotiations. All participants were able to climb at least three flights of stairs without load and at least two flights of stairs with the extra load. The peak muscle activity during stair ascent was 123.9 ± 35.0 % of EMG_{MVC} and 120.7 ± 31.8 % of EMG_{MVC} during loaded ascent. Corresponding values for stair descent were 87.2 ± 23.5 % of EMG_{MVC} for unloaded and 89.1 ± 34.2 % of EMG_{MVC} for loaded descent. Two of the male participants were able to ascend five flights of stairs without load and one of them also with 5 kg load. Peak muscle activity of these participants did not reach 100 % of EMG_{MVC} during the ascents (Figure 3), whereas in other participants muscle activity exceeded 100 % of EMG_{MVC} momentarily during the stair ascent. Figure 4 shows examples of muscle activity and oxygen consumption from two participants during the stair negotiation. During unloaded and loaded ascent the difference in the numbers of flights climbed was considerably different between those who reached their EMG_{MVC} during the unloaded ascent and those who did not.

Insert Figure 3

The peak VO_2 values were 71.2 ± 16.9 % of VO_{2max} during unloaded ascent and 55.1 ± 16.2 % of VO_{2max} during loaded ascent when fewer floors were climbed. Corresponding peak values for descent were 39.1 ± 6.1 and 46.3 ± 9.8 % of VO_{2max}, respectively. None of the nine participants reached their VO_{2max} during the stair negotiation. Figure 4A shows data during stair negotiating of a participant who was able to climb all the five flights of stairs. The mean muscle activity during stair negotiation was 11.4 ± 5.3 times that of during using an elevator and for cumulated muscle activity the corresponding ratio was 12.1 ± 7.4. The mean and cumulated VO_2 consumption during stair negotiation were 5.1 ± 1.2 and 11.7 ± 6.1, respectively, times than using an elevator. Mean difference in VO_2 consumption was 72.8 ±10.6 ml · kg^{-1} between elevator and stair negotiation.

Insert Figures 4 and 5.

Daily life. Figure 5 shows examples of muscle activity data during daily life and table 3 shows the time spent at different EMG intensities in detail. During normal daily life, the mean muscle activity amplitude was 5.9 % of EMG_{MVC}, and mean burst amplitude was 10.3 % of EMG_{MVC} (Table 3). It is notable that the daily life in some participants did not require muscle activities even close to the maximum capacity while some participants exceeded 100% of EMG_{MVC} multiple times. Longer gaps representing inactivity periods in muscle activity can be seen in figure 5 in some participants, although the total inactivity time was rather similar in all participants.

During normal daily life quadriceps and hamstring muscles were inactive for 49.6 ± 3.9 % of the measurement time (Fig. 6). Corresponding times for light, moderate and vigorous activity were 30.2 ± 7.6 %, 11.4 ± 6.0 % and 8.8 ± 5.2 %, respectively. 99 % of measurement time the muscle activity was below 50 % of EMG_{MVC} and less than 2.5 min in total was at intensities above 70 % of EMG_{MVC}. The longest continuous inactivity periods lasted for 20.9 ± 10.0 min (range 7.9–38.3 min). Second, 3rd, 4th and 5th longest inactivity periods lasted 14.6 ± 5.6 min, 11.6 ± 4.5 min, 9.7 ± 3.5 min, 8.8 ± 3.1 min, respectively. In total, inactivity ranged from 43.1 to 54.7 % of measurement time. Inter-individual variance was considerably high in light (range: 19.6 to 37.9 % of measurement time), moderate (4.3 to 20.9 %) and vigorous activities (3.5 to 20.8 %). Energy expenditure during daily life calculated based on EMG was 1.26 ± 0.26 kcal · min^{-1} (equaling 1 810 ± 375 kcal · min^{-1}) for men and 0.94 ± 0.15 kcal · min^{-1} (equaling 1 354 ± 215 kcal · min^{-1}) for women.

Insert Figure 6

Discussion

This study showed that the active ways of transport that can be incorporated into normal daily life provide an effective way to train cardiovascular and neuromuscular performance. When comparing active and passive modes of transport we found that 1 kilometer walk consumes over 3 times the amount of oxygen or muscle activity than when using a bus to commute. Similarly, cumulated oxygen consumption and mean muscle activity during stair ascent is 11 times higher than when using an elevator. Overall, the mean muscle activity bursts were about 10 % of EMG_{MVC} and inactivity time was 50 % of the measurement time during normal daily life in older adults.

Mobility, referring to ability to move and be engaged in basic daily activities is very important for older adults because it enables independency and social interaction (29). Stair climbing represents in many cases a major challenge to older adults and although participants of the present study were in relatively good physical condition for their age having VO_{2max} about 27 ml · kg^{-1} · min^{-1}, the peak muscle activity level exceeded 120 % of EMG_{MVC} during stair ascending while oxygen consumption remained submaximal (71.2 ± 16.9 % of VO_{2max}). It is notable that those participants who exceeded 100% EMG_{MVC} during stair climbing were not able to complete five flights of stairs (Fig. 3).

In this context it is important to note that the two used methods, EMG for assessing muscle electrical activity and oxygen consumption, have distinct differences. While EMG shows momentary and instantaneous activity, VO_2 measured from respiratory gases takes a certain time to reach the level demanded by physical activity. The participants who were able to ascend five flights of stairs did not reach their MVC during the performance. In contrast, those who failed to reach the fifth floor reached or exceeded their EMG_{MVC}. Thus, it seems that muscle activity rather than cardiovascular performance is the limiting factor during stair ascending since none of the participants where close to their maximal oxygen consumption. Indeed, it seems that those participants who performed more flight of stairs had better muscle performance. This observation is in line with previous studies reporting that the power generated around the knee joint is related to the stair climbing velocity among older women (30, 31). It has also been shown that the performance in counter-movement-jump largely explains the variation in stair climbing velocity among older people (31).

Muscle activity was higher during ascending than descending, which is natural as more external work is done in ascending than in descending and since it has been shown that EMG is generally lower in eccentric as compared to concentric muscle actions (32). Although the mean value during ascending in the current study was approximately only one third of EMG_{MVC}, the peak values reached almost 1.25 times EMG_{MVC}. Supramaximal EMG values are possible because MVC values were measured during isometric tasks and stair negotiation consists of dynamic muscle actions (33). Further explanation for EMG values over 100 % EMG_{MVC} come from the shorter time window that was used to define the peak EMG during the tasks as compared to a mean of one second time window during MVC.

These results highlight importance of muscle strength in maintaining the physical independence of older people. Climbing stairs and rising up from a chair are important components of independent living and compromised ability in those tasks limits the scale of independent living of older people (3). In addition, it has been shown that descending stairs is one of the most dangerous tasks for older people (34). Furthermore, older people have shorter gait length, stance phase (35), lower muscle strength and decreased rate of force development (36) than younger adults and all those factors have been associated with an increased risk of falling (37). Often sudden stumbling causes loss of balance and fall possibly because there is no strength capacity left to regain balance (31). Decreased rate of force development and strength cause considerable loss in produced power (38). It has been suggested that by improving force and power performance a considerable amount of bone fractures and related deaths could be prevented although this theory has been questioned (39, 40).

Studies have shown that older people can attain remarkable gains both in strength and power with strength training (41). Because the peak values of EMG were mostly over 80 % of EMG_{MVC}, stair climbing can be considered as a good way to enhance muscle strength and it is also recommended in the Physical Activity Recommendations as a possible method to perform resistance training (42). In addition, it has been shown that stair ascending can improve VO_{2max} in young sedentary women (43). Training at 60-80 % of VO_{2max} corresponds to training intensity zone of basic endurance training, which is shown to improve fat utilization capacity and increase capillar density of the trained muscles (44).

The results confirm the beneficial effects of active transport over passive transport. One kilometer of walking required 3.3 times more oxygen and yielded 3.5 times higher mean muscle activity level than when transport by bus. VO_2 and EMG in stair ascent was about 11 times that of using elevator. Converting these values to calories burned (1 liter of oxygen equaling ~5 kcal (45)), walking 1 km consumed 0.7 $kcal \cdot kg^{-1}$ (~50 kcal for person weighing 70 kg) more than using bus and using stairs consumed 0.4 $kcal \cdot kg^{-1}$ (~28 kcal for person weighing 70 kg) more than using elevator. Difference in a single bout may not seem substantial, but when similar bouts of activities accumulate throughout the day, additional energy expenditure could contribute considerably to metabolism (7) and weight management (46).

Only handful of studies have measured EMG of leg muscles in normal daily life (22, 24-27, 47). In the present study with older adults the mean muscle activity burst amplitude of quadriceps and hamstring muscles was 10 % of EMG_{MVC} which is higher than in the study of Klein et al. (26) with 20-48 year participants whose mean vastus lateralis EMG was 7 % EMG_{MVC}. On the contrary, Kern et al. (25) reported mean burst amplitude of 17 % EMG_{MVC} for vastus lateralis and 18 % of EMG_{MVC} for vastus medialis but those participants were moderately active college students. More detailed comparisons to these studies are not rational because the muscles assessed were not the same and different thresholds and analysis methods were utilized.

When compared to our earlier study, younger adults (aged 44.1 ± 17.3 years) had a considerably lower mean burst amplitude during normal daily life than the older adults in the present study (5.8 % vs. 10.3 % of EMG_{MVC}) (22). Burst duration was longer in older participants compared to younger (2.2 ± 2.5 vs. 1.4 ± 1.4 s, respectively) and could be related to slower speed of locomotion and longer stance phase (48) and to the fact that reaching a certain absolute level of force output takes longer for the older participants (36). Older participants had less muscle activity bursts when compared to younger participants (10,563 ± 4,694 vs. 12,600 ± 4,000 /day), but spent less time being inactive than younger ones (50 % vs. 68 % of measurement time, respectively) (22). Consequently the activity times were higher in all activity intensity categories for older participants (activity times for light (11.4 ± 6.0 % vs. 8.5 ± 3.4 %), moderate (30.2 ± 7.6 % vs. 16.7 ± 9.9 %) and vigorous activity (8.8 ± 5.2 % vs. 7.3 ± 4.2 %), respectively). As inactivity and activity thresholds were individually determined it seems that, at least comparing our studies, older people were more active than younger adults. It is possible that because all older participants were on pension they had more freedom during the day to choose their daily routines. Younger participants probably have more predetermined tasks that needs to be done and many of the tasks are rather inactive increasing inactivity (e.g. commute by car, office work). The higher activity times could be related to longer burst lengths and, on practical level, also to slower walking speed of older people (48) as the same distance takes longer time for the older. In contrast to higher activity times, the longest continuous inactivity periods were all longer in older people than in younger lasting for 20.9 ± 10.0 min vs. 13.9 ± 7.3 min; 14.6 ± 5.6 min vs. 9.8 ± 4.5 min; 11.6 ± 4.5 min vs. 8.0 ± 3.4 min; 9.7 ± 3.5 min vs. 7.0 ± 3.0 min; 8.8 ± 3.1 min vs. 6.3 ± 2.7 min for 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} longest inactivity periods (old vs. younger), respectively.

Since many of the daily tasks demand a certain level of force output and as muscle strength of older people is lower (52 ± 14 kg vs. 107 ± 44 kg in young in knee extension), they need to use a higher percentage of their maximum capacity to get the same daily tasks accomplished as younger do with less effort. This difference is not explained by differences in body mass (69.6 ± 11.6 vs. 70.1 ± 10.2 kg for old in the present study and younger in (22)). It has been shown that old people compensate plantar flexor weakness by using more hamstrings and gluteus maximus for production of propulsion in walking (49-52), which could increase hamstring activity and partly explain the differences between older and younger. Although the daily routines probably differ between these age groups the older adults being on pension, results probably reflect also physiological differences such as lower muscle mass and maximum strength (1) and lower rate of force development of the older people (36). Overall, the daily EE estimations from EMG were in a same range as reported earlier for older people (53, 54).

Methodological limitations. The present measurements were done during summer when people are likely to be more physically active and therefore the reported activity patterns may differ from wintertime. Furthermore, we only measured muscle activity from quadriceps and hamstring muscles, and while the activity of other muscles is of importance in many ways, quadriceps and hamstring muscle activity have high correlation with the energy expenditure during walking at different speeds in level and in uphill and downhill (21). As all the EMG results are presented relative to MVC it is possible that results are incorrect if maximum is not reached during MVC testing. However, older participants can reach maximal activation if enough attempts are given (Jakobi & Rice 2002). Therefore, a number of practice trials were done before actual test trials and loud verbal encouragement was used to encourage maximal performance. Although possibility of incorrect MVC values cannot be ruled out fully, the best attempt was done to obtain maximal values during the testing.

Representativeness of group. Participants were recruited through advertisements in public places and different workplaces and therefore do not represent a randomly selected sample. Also as participants of the study had already reached an advanced age of approximately 70 years they probably are, on mean, healthier than their peers. Nevertheless we feel that the results of this study provide valuable information of physical activity patterns of the older people.

*Conclusions***.** In normal daily life, older people use only a small fraction of muscle's maximal capacity and have long continuous inactivity periods. Daily life was shown to be physically demanding for the older adults due to low maximum strength thereby emphasizing the need for preservation of strength level with aging. Daily tasks such as stair ascent can result in muscle activities greater than isometric maximum which, in this study, was related to the limited ability to climb stairs. Overall, stair ascent was shown to place high stress on both cardiovascular and neuromuscular systems demonstrating that stair negotiations are effective and easily accessible way to maintain or improve physical performance.

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TABLE 1. Basic characteristics of participants.

	Men (n=6)		Women (n=3)		All (n=9)	
	Median	SD	Median	SD	Median	SD
Age (years)	72.0	2.6	71.0	3.6	71.0	2.9
Height (cm)	174.0	2.1	161.0	5.8	172.0	7.4
Weight (kg)	70.9	10.1	51.9	13.0	69.6	11.6
BMI ($kg \cdot m^{-2}$)	23.1	3.6	21.9	3.7	22.5	3.4
Fat %	19.7	7.5	31.9	16.7	21.0	10.5
Skeletal muscle mass (kg)	30.7	2.8	24.7	3.6	3.6	4.6
RMR ($kcal \cdot d^{-1}$)	1090	171	1027	194	1037	168
Resting HR (bpm)	57.5	8.5	64.0	4.2	4.2	7.5
VO_{2peak} ($ml \cdot kg^{-1} \cdot min^{-1}$)	28.1	5.0	23.0	7.9	7.9	5.6
Squat jump height (cm)	9.7	7.3	4.4	3.1	3.1	6.8
Leg press MVC (kg)	412	112	239	129.3	129.3	132

RMR= Resting metabolic rate, HR= Heart rate, bpm= Beats per minute.

TABLE 2. Active and passive transport tests.

1. Transport by bus
- Walking to bus
- Sitting in the bus for a duration corresponding to 1 km travel
- Walking from bus
2. Using elevator
- Up to and down from the fourth floor
3. Walking
- Walking 1 km with self-selected pace
4. Negotiating stairs (no additional load)
- Ascending stairs until exhaustion (max. 5 flights of stairs)
- Descending stairs (same amount of floors as ascending)
5. Negotiating stairs (5kg bag in each hand)
- Ascending stairs until exhaustion (max. 5 flights of stairs)
- Descending stairs (same amount of floors as ascending)

TABLE 3. Time spent at different EMG intensities (relative to isometric MVC) in normal daily life (time expressed as percentage from total measurement time and as minutes and seconds).

	Time (%)		Time (min:sec)	
	Mean	**SD**	**Mean**	**SD**
% EMG_{MVC}:				
0–1 %	41.1	16.7	280:00	127:42
1–2 %	12.7	9.2	83:00	56:50
2–3 %	6.4	3.7	42:12	21:42
3–4 %	5.1	4.2	34:36	28:42
4–5 %	3.4	1.5	23:00	10:18
0–5 %	68.8	13.0	462:54	97:42
5–10 %	14.3	10.5	96:48	69:24
10–20 %	9.3	3.1	62:12	21:48
20–30 %	3.7	1.9	24:36	12:08
30–40 %	1.8	1.1	12:10	7:30
40–50 %	0.9	0.6	6:00	4:05
50–60 %	0.5	0.4	3:20	2:25
60–70 %	0.3	0.2	1:45	1:24
70–80 %	0.1	0.1	0:57	0:48
80–90 %	0.1	0.1	0:33	0:31
90–100 %	0.0	0.0	0:19	0:19
≥100 %	0.1	0.1	0:41	0:57

TABLE 4. EMG volume and rate indicators from normal daily life presented relative to isometric MVC (mean ± SD).

	Mean	**SD**
EMG volume indicators		
Mean amplitude (% of EMG_{MVC})	5.9	2.4
Mean burst amplitude (% of EMG_{MVC})	10.3	3.9
Total area (% of EMG_{MVC} • s)	186 931	76 121
Time over 50 % of EMG_{MVC} (min)	7.4	6.2
Activity time (min)	187	43
EMG rate indicators		
Number of bursts	10 563	4 694
Mean burst duration (s)	2.2	2.5
Burst rate (bps)	0.28	0.11

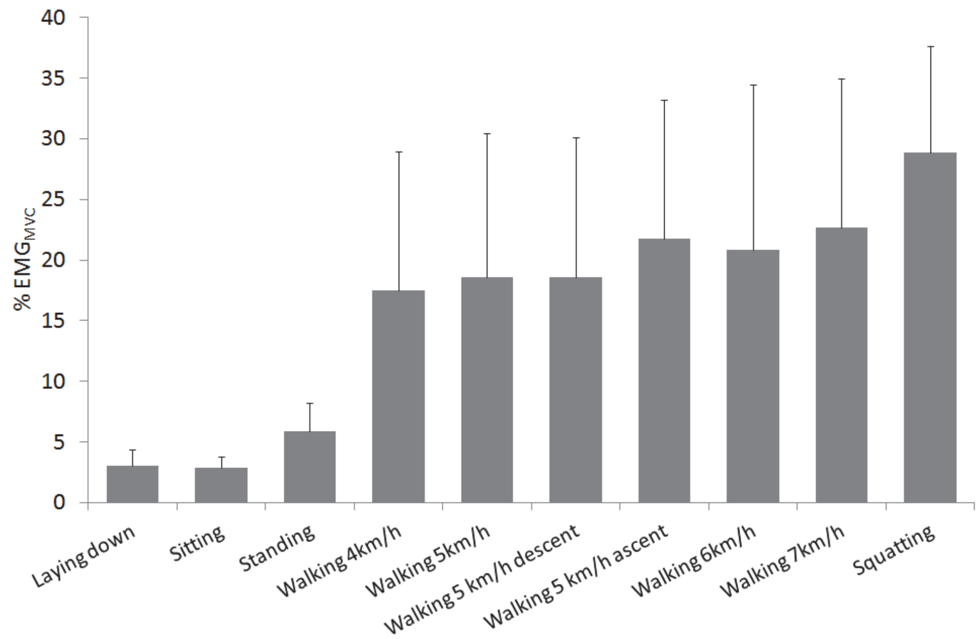

FIGURE 1. Mean (±SD) quadriceps and hamstring muscle activity (% of EMG during maximal voluntary contraction ($_{MVC}$) for different simulated daily tasks measured in the laboratory (n=8-9).

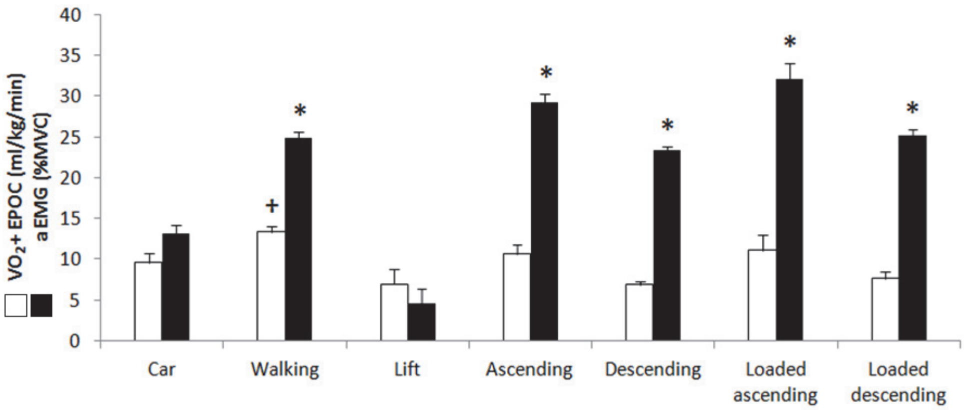

FIGURE 2. Mean muscle activity and VO_2 during different tasks. The VO_2 value has been calculated by summing VO_2 during the actual task and excessive post exercise oxygen consumption (EPOC) (until level of 1.2• $VO_{2\ rest}$).

* p<0.01 in aEMG between passive and corresponding active tasks

† p<0.01 difference in VO_2+EPOC between walking and using car.

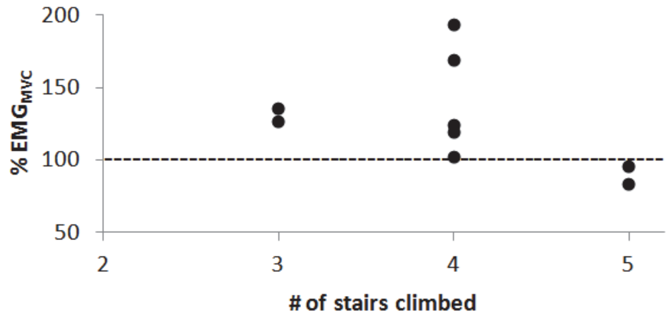

FIGURE 3. Relationship between peak muscle activity during stair ascending expressed as percentage of MVC and number of flights climbed.

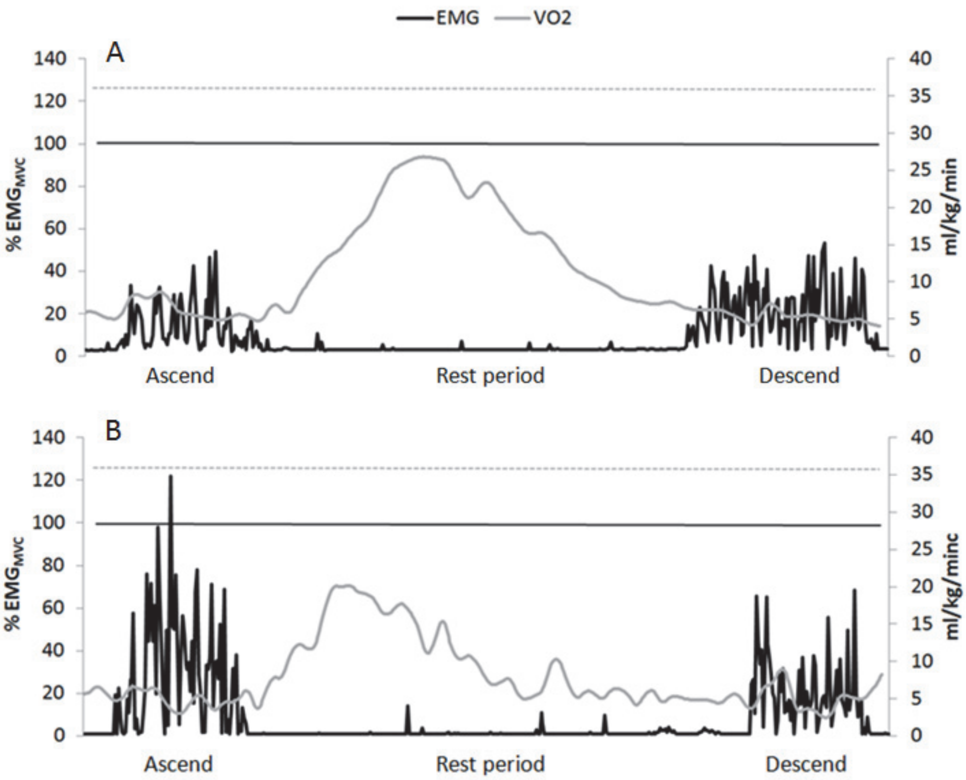

FIGURE 4. Example of EMG and VO_2 recordings during stair negotiation of two individuals. Solid horizontal black line represents EMG_{MVC} and dashed horizontal grey line represents VO_{2max}. Participant in panel A has high maximal force level (leg press 4 256 Nm) and used less of his muscle capacity during stair climbing than participant in panel B with lower maximal force (leg press 932 Nm). Participant A was able to ascend all 5 floors and participant B only 4 floors.

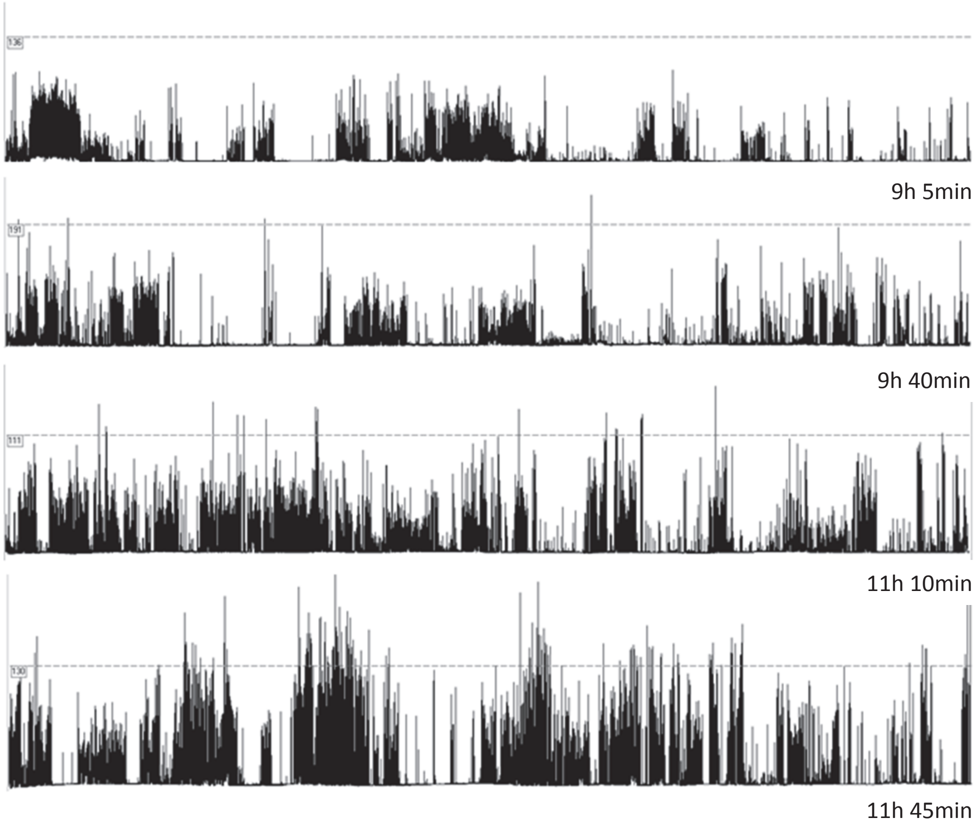

FIGURE 5. Examples of daily muscle activity patterns from four participants. Each signal represents an activity pattern of mean right quadriceps and hamstrings muscles. Maximum leg press results for participants were 3 461 Nm, 4286 Nm, 932 Nm and 1706 Nm from top to down. Dashed horizontal line represents 100 % of EMG_{MVC}.

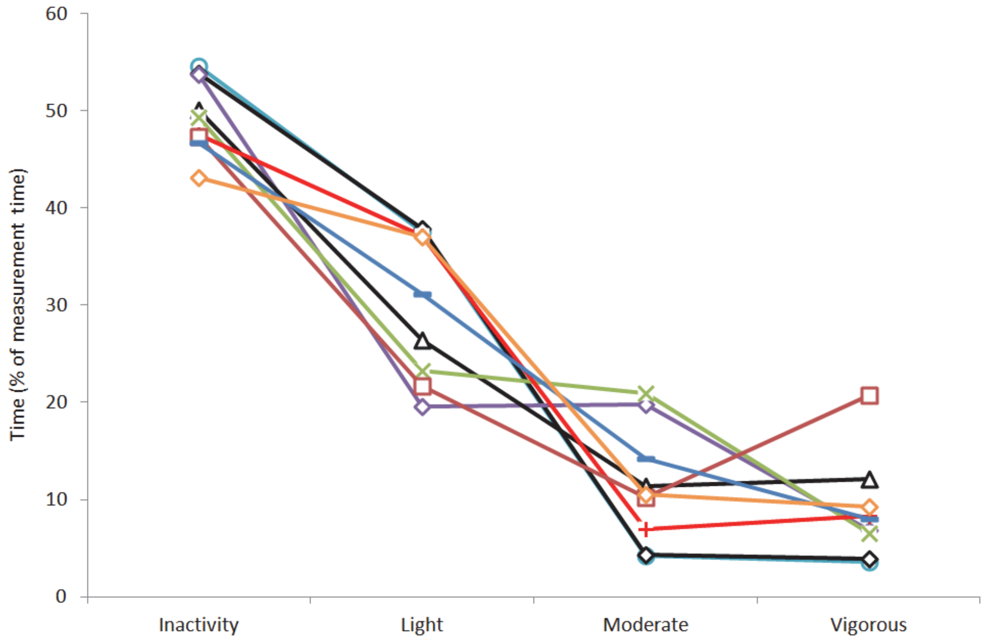

FIGURE 6. Time spent at different muscle activity levels during normal daily life based on individual threshold values (5.1 ± 2.6, 10.6 ± 4.6 and 24.9 ± 11.5 % EMG_{MVC} for light activity, moderate activity and vigorous activity thresholds, respectively). Each line represents one individual (n=9).

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