Author(s): Pesola, Arto; Laukkanen, Arto; Haakana, Piia; Havu, Marko; Sääkslahti, Arja; Sipilä, Sarianna; Finni Juutinen, Taija

Title: Muscle Inactivity and Activity Patterns after Sedentary-Time Targeted Randomized Controlled Trial

Year: 2014

Version:

Please cite the original version:

Pesola, A., Laukkanen, A., Haakana, P., Havu, M., Sääkslahti, A., Sipilä, S., & Finni Juutinen, T. (2014). Muscle Inactivity and Activity Patterns after Sedentary-Time Targeted Randomized Controlled Trial. Medicine and Science in Sports and Exercise, 46(11), 2122-2131. https://doi.org/10.1249/MSS.0000000000000335

Medicine & Science in Sports & Exercise
The Official Journal of the American College of Sports Medicine
www.acsm-msse.org

. . . Published ahead of Print

Muscle Inactivity and Activity Patterns after Sedentary-Time Targeted RCT

Arto J. Pesola[1], Arto Laukkanen[1,3], Piia Haakana[1], Marko Havu[1],
Arja Sääkslahti[3], Sarianna Sipilä[2], and Taija Finni[1]

[1]Neuromuscular Research Center, Department of Biology of Physical Activity;
[2]Gerontology Research Center, Department of Health Sciences; [3]Department of Sport Sciences, University of Jyväskylä, Finland

Accepted for Publication: 5 March 2014

Medicine & Science in Sports & Exercise, Publish Ahead of Print
DOI: 10.1249/MSS.0000000000000335

Muscle Inactivity and Activity Patterns after Sedentary-Time Targeted RCT

Arto J. Pesola[1], Arto Laukkanen[1,3], Piia Haakana[1], Marko Havu[1],
Arja Sääkslahti[3], Sarianna Sipilä[2], and Taija Finni[1]

[1]Neuromuscular Research Center, Department of Biology of Physical Activity;
[2]Gerontology Research Center, Department of Health Sciences; [3]Department of Sport Sciences,
University of Jyväskylä, Finland

Corresponding author information:

Arto J. Pesola

Department of Biology of Physical Activity

P.O: Box 35

FI-40014 University of Jyväskylä

Finland

Tel. +358 400 475 955

Fax. +358 14 260 2071

E-mail. arto.j.pesola@jyu.fi

Running title: Muscle inactivity patterns after RCT

Conflict of interest statement: Myontec Ltd and Suunto Ltd are acknowledged for their technical support. The study was funded by Finnish Ministry of Education and Culture (DNRO42/627/2010) and the Juho Vainio foundation. The authors have no financial conflict of interest to declare.

ABSTRACT

Purpose: Interventions targeting sedentary time are needed. We used detailed EMG recordings to study the short-term effectiveness of simple sedentary-time targeted tailored counseling on the total physical activity spectrum. **Methods:** This cluster RCT was conducted between 2011-2013 (InPact, ISRCTN28668090) and short-term effectiveness of counseling is reported in the present study. 133 office workers volunteered to participate, from which muscle activity data were analyzed from 48 (intervention n=24, control n=24). Following a lecture, face-to-face tailored counseling was used to set contractually binding goals regarding breaking up sitting periods and increasing family-based physical activity. Primary outcome measures were assessed 11.8±1.1 hours before and a maximum of two weeks after counseling including quadriceps and hamstring muscle inactivity time, sum of the five longest muscle inactivity periods and light muscle activity time during work, commute and leisure time. **Results:** Compared to the controls, counseling decreased the intervention group's muscle inactivity time by 32.6±71.8 min from 69.1±8.5% to 64.6±10.9% (whole day $p<.05$, work $p<.05$, leisure $p<.05$), and the sum of the 5 longest inactivity periods from 35.6±14.8 min to 29.7±10.1 min (whole day $p<.05$, leisure $p<.01$). Concomitantly, light muscle activity time increased by 20.6±52.6 min, from 22.2±7.9% to 25.0±9.7% (whole day $p<.05$, work $p<.01$, leisure $p<.05$), and during work time average EMG amplitude (%EMG_{MVC}) increased from 1.6±0.9% to 1.8±1.0% ($p<.05$) in the intervention group compared to controls. **Conclusion:** A simple tailored counseling was able to reduce muscle inactivity time by 33 min which was reallocated to 21 min of light muscle activity. During work time, average EMG amplitude increased by 13% reaching an average of 1.8% of EMG_{MVC}. If maintained, this observed short term effect may have health benefitting consequences. **Key words:** sedentary time, non-exercise physical activity, electromyography, textile electrodes, intervention

INTRODUCTION

Physical activity patterns illustrating typical daily life of modern people include a large proportion of sitting with relatively idle muscles, while the other dominant part consists of non-exercise physical activity, and only a fraction of the day can be categorized as more intense exercise (18). The sedentary part of this pattern has been recognized as an independent predictor of adverse health outcomes (11) even in people doing regular moderate to vigorous physical activity (25). The underlying cause of the independence of exercise and inactivity may be the different metabolic pathways that have been identified to convey the effects of inactivity compared to exercise (5). Similarly, muscle activities required for standing and walking slowly have been found to improve postprandial glucose and insulin responses (12), as well as to prevent the effects of complete inactivity (5, 35, 40), which emphasizes the importance of non-exercise activities. The driving concept behind these findings is the so called inactivity physiology paradigm, which states that "the brief, yet frequent, muscular contraction throughout the day may be necessary to short-circuit unhealthy molecular signals causing metabolic diseases" (18). Therefore, understanding and improving this typical physical activity pattern of modern people requires quantification of the whole physical activity continuum with careful evaluation of the balance between the two most dominant components: non-exercise physical activity and sedentary time, which in this paper is defined as a lack of any muscular activity in the locomotor muscles.

n addition to different metabolic pathways, exercise and inactivity have been shown to be independent factors of behavior (6, 14, 27), which highlights the need for promotion of reduced sitting in addition to traditional exercise guidelines. Despite a promising hypothesis, there is a paucity of randomized controlled trials (RCT) that have assessed sedentary time instead of physical activity as a primary outcome. In addition, workplace interventions promoting increased physical activity through mixed behavioral approaches have been shown to be ineffective at decreasing self-reported sitting time

(7). Because of the potential health benefits of replacing sitting with light intensity activities, promotion of this small change as a primary intervention goal could be an accessible, viable and effective method for busy and sedentary target groups including people in sedentary occupations (38) and parents of young children (31).

In order to gain further insight into interventions targeting sedentary time, the effect of behavioral change needs to be studied across the whole physical activity spectrum with objective measures. Given that the key mechanism proposed for the associations of sedentary time with health is lack of muscular activity, it is important to measure the changes in this outcome. By using novel wearable textile electrodes it is possible to measure muscle activity from the main locomotor muscles with similar or even better repeatability compared to traditional bipolar electrodes (15) across the whole physical activity spectrum (36).

The purpose of this study was to examine whether tailored counseling designed to reduce and break up sedentary time decreases muscle inactivity and increases muscle activity as measured by EMG from the quadriceps and hamstring muscles, which are some of the main locomotor muscles. We hypothesized that this specific counseling would decrease muscle inactivity time without increasing moderate-to-vigorous muscle activity.

METHODS

As a part of a year-long randomized controlled trial "A family based tailored counseling to increase non-exercise physical activity in adults with a sedentary job and physical activity in their young children" (InPact-project, (16)), this study investigated the short-term (within two weeks of the counseling) main outcomes of the RCT. The study was approved by the ethics committee of the Central

Hospital District of Central Finland on March 25, 2011 (Dnro 6U/2011) and the participants signed an informed consent prior to measurements.

Recruitment and study sample. Sampling was performed in the Jyväskylä region located in central Finland with a population of 133 000. Jyväskylä has a surface area of 1171 km^2 with a relatively small city centre, proximity of lakes and forests, and numerous opportunities for active commuting with an extensive network of bike-paths and sidewalks in the city region. Homogenous regions around the city were identified in terms of socioeconomic status and environmental possibilities for outdoor physical activities, and cluster randomization was done within these regions. These 7 regions included a total of 8 schools and 20 kindergartens (2-5 schools or kindergartens per region). The recruitment was done in three phases, where recruitment forms asking profession, % sitting time at work, health status and contact information, were delivered to parents via kindergartens and primary schools in spring 2011, autumn 2011 and spring 2012. In total, 1055 recruitment forms were delivered including information about the study, inclusion and exclusion criteria, and an incentive to get diverse information about personal health, diet and physical activity and motor skills of their children. Inclusion criteria were: healthy men and women with children 3–8 years old, parental occupation where they self-reportedly sit more than 50% of their work time, and children in all-day day-care in kindergarten or in the first grade of primary school. Exclusion criteria were: body mass index > 35 kg/m^2, self-reported chronic, long-term diseases, families with pregnant mother at baseline, children with disorders that delay motor development, and concurrent participation in another study. No monetary incentive was offered to the participants.

We received 300 responses. People fulfilling the criteria were contacted by phone and invited to an information lecture, where the procedures were explained in detail. If people were unable to attend the lecture, details of the project were explained on the phone. Finally, a total of 133 participants were measured at baseline. Figure 1 summarizes the recruitment and randomization process.

Of the 133 participants, 48 were selected for the EMG analysis based on the following criteria: 1) measured days were self-reportedly typical and identical in terms of occupational tasks, workday duration and leisure time activities (31 excluded), 2) both days included artifact-free EMG signal from the same muscles recorded with the same electrodes (34 excluded), 3) length of measurement > 9 hours (10 excluded), and 4) diaries were returned properly filled (3 excluded). In addition, 7 participants dropped out before the second measurement day. The final study sample included 24 participants in the intervention group and 24 in the control group.

Study protocol. Muscle activity from quadriceps and hamstring muscles was recorded during a structured laboratory test protocol and during daily measurements from two workdays before and after the counseling intervention. The participants were asked to select two measurement days that were as similar and typical as possible in terms of working schedule and duties. On the first day the participants' height and weight were measured after arriving to the laboratory in the morning. Subsequently EMG-shorts (Myontec Ltd, Kuopio, Finland) were put on. In order to measure the minimum level of EMG, the laboratory test protocol began by asking the participants to sit in front of a table while informing them about the diaries and questionnaires to be filled in. After the sitting period, a treadmill (OJK-1, Telineyhtymä, Kotka, Finland) protocol including walking at 5, 6 and 7 km/h and running at 10 km/h with one minute steps was performed. Next, muscle activity was measured while standing still, standing on each leg individually, and while walking up and down stairs twice. Standing in different positions was measured for 15 seconds per task, and participants were asked to stand still as they usually do, except that the weight was first supported by both, and then by one leg at a time. For the stair walking, the participants were instructed to step on every step, and to use their normal pace.

EMG amplitudes from these tests are presented in Figure 2. Participants then performed bilateral maximal voluntary isometric contractions (MVC) in a knee extension/flexion machine (David 220, David Health Solutions, Helsinki, Finland) with a 140° knee angle in both flexion and extension. After thorough familiarization and warm-up, at least three 3-5 s maximal efforts with strong verbal encouragement were performed with 1 minute rest periods between trials. If torque improved by more than 5 % in the last trial, more trials were performed.

After the laboratory experiments the participants left for work and were expected to continue normal living while wearing the shorts and keeping a diary of commuting, working and leisure time. Any abnormal tasks and behaviors (e.g. abnormal working tasks, working time or leisure activities) were to be reported in order to include only structurally similar days for analysis. After baseline measurements the intervention group received tailored counseling. The post-intervention measurements were performed within two weeks of the counseling session.

Description of intervention. The intervention was designed based on previous knowledge of effective interventions (9) and theory of planned behaviour (1). Briefly, the intervention consisted of a common 30 min lecture for a maximum of six participants at a time followed by face-to-face discussions with the researchers (16). The lecture included research-based information about health hazards of prolonged sitting, and encouragement to incorporate even the smallest physical activities into everyday routines in order to overcome these health problems. In the face-to-face discussions the participants were first asked to describe their normal daily routines during commuting, working hours and leisure time. Regarding leisure time, routines of the entire family were discussed because they are relevant to the individual's behavior. During the discussion, participants were encouraged to think of feasible ways to reduce long sitting periods, to increase non-exercise physical activity, and to increase family-based activities from their personal premises, accompanied by ideas from the researcher. The participants set small-step goals which were written into a contract signed by the researcher and the participant. An example from the contract from one participant is as follows:

"My goals to decrease sitting time and to increase non-exercise physical activity during working time are:

- *I stand up from my chair every half an hour*
- *When answering the phone I stand up from the chair*
- *Instead of calling I walk to my colleague's room*
- *I take the stairs instead of the elevator*
- *I walk for lunch and once a week choose a restaurant that is further away"*

"Mine and my family's goals to decrease sitting time and to increase physical activity during leisure time are:

- *At least once a day we go out as a family in order to replace family sitting activity*
- *We cycle to work whenever the weather permits us to do so*
- *Instead of taking the car, we walk or bicycle to the grocery shop more often as a family*
- *We organize family dancing sessions*
- *We will work hard with snow removal, using child labour together with us ☺"*

The goals related to occupational tasks and leisure time activities were printed for participants to place them in a visible location at home and at work. In addition, participants were given material about simple break exercises, local outdoor activities and simple games suitable for the whole family. The materials were gathered to a project web-page (perheliikunta.nettisivu.org), from which the participants were encouraged to find the relevant information.

Assessment of outcomes.

The primary study outcomes were EMG derived muscle inactivity time, duration of the 5 longest inactivity periods, and light muscle activity time assessed during working time, commute and leisure time. The domains were separated based on diaries. Since differences in EMG wear time may affect the time spent at different physical activity intensities (20), an equal recording time was analysed for both measurements based on the shorter measurement.

EMG recordings. EMG was measured with shorts made of knitted fabric similar to elastic clothes used for sport activities or functional underwear, with the exception of the capability to measure EMG from the skin surface of the quadriceps and hamstring muscles (Myontec Ltd, Kuopio and Suunto Ltd, Vantaa, Finland). Bipolar electrode pairs are located on the distal part of the quadriceps and hamstrings, and the reference electrodes are located longitudinally along the left and right lateral sides (over tractus iliotibialis). The EMG signal was stored to a 50 g electronic module attached to the waist. In this study, eight pairs of shorts (four different sizes) were used. Electrode paste (Redux Electrolyte Crème, Parker Inc., USA) was used on the electrode surfaces to improve and stabilize conductivity between the skin and electrodes. After every measurement day the shorts were washed after detaching the electronics module. The EMG shorts have been tested for validity, repeatability and feasibility in our laboratory and detailed descriptions of the recording devices and analysis software have been reported previously (15, 36).

Signal processing and categorizing. The individual channels from right and left quadriceps and hamstring muscles were normalized to EMG amplitudes measured during bilateral MVC contractions. The repetition with the highest force level was chosen, from which the most consistent one second mean EMG amplitude was used for each channel. In order to reflect the overall inactivity or activity of thigh muscles, the normalized channels from quadriceps and hamstring muscles were averaged. The threshold between inactivity and light activity was set individually at 90% of the mean EMG amplitude measured during standing still for 15 seconds in the laboratory (Figure 2). This approach enabled determination of inactivity periods in the main locomotor muscles. The thresholds between light and moderate, and moderate and vigorous muscle activity intensities were defined individually as a one minute mean EMG value when walking at 5 km/h and running at 10 km/h, respectively. Because some of the participants reported being unfamiliar with walking and running on a treadmill and MVC increased on the second laboratory test ($p<.001$), the values from the second measurement were used for both days to minimize the effect of learning on the thresholds. Adequate repeatability of the EMG/force -relationship ($0.74 \leq ICC \leq 0.93$, see table, Supplemental Digital Content 1, http://links.lww.com/MSS/A387: supplemental table 4—repeatability of maximal voluntary contraction) ensured the consistency of EMG signals between days. Detailed description of signal processing, artefact removal and Matlab analysis procedures are presented in Supplemental Digital Content 1, http://links.lww.com/MSS/A387, and 2, http://links.lww.com/MSS/A388 (additional details of EMG analysis procedures, and EMG channel averaging and baseline correction, respectively).

Statistical analyses. The initial sample size calculations for the entire intervention have been reported previously (16) and for this particular sample of EMG study, the calculated post hoc statistical powers and effect sizes (Eta Squared, η^2) for the outcomes are reported. Effect sizes can be interpreted as follows: small >0.01, medium >0.06, large >0.14. Statistical analyses were performed with PASW Statistics v.18.0 (SPSS inc. Chicago, Illinois, US). Data are presented as mean ± standard deviation. The Shaphiro-Wilk -test was used to evaluate whether the data were normally distributed. Where data were not normally distributed, log-transformation was used and normality was re-tested. Differences between the groups at baseline were tested with independent samples T-test, the Mann-Whitney test or

Chi-Squared test. The effect of the intervention on EMG variables was assessed using repeated measures ANOVA with measurement time and baseline values of variables as covariates. Not normally distributed variables (total and leisure time average EMG and leisure time vigorous muscle activity time) were tested with the Mann-Whitney test by comparing within-group changes (post-values - pre-values) between the groups, after which within-group changes were tested with the Wilcoxon test. The differences between % inactivity and activity time before and after the intervention were calculated as the arithmetic difference (% of measurement time post - % of measurement time pre) yielding a percentage point (pp). Significance level was set at P<0.05.

RESULTS

Participants. The study groups were comparable in terms of anthropometry, profession, weekly work time and self-reported sitting at work (Table 1). There were no significant differences between the participants in the EMG study as compared with the rest InPact study sample (females EMG study 58%/InPact study 54%, age 38.0±5.5y/37.9±5.3y, BMI 24.6±3.7 kg/m^2/24.4±3.8kg/m^2, managerial employees 54%/41%, work time/week 37.6±5.6h/38.0±14.7h, self-reported sitting at work 82.7±13.4%/85.8±12.5%). As compared to the recruitment region's mean, a higher proportion of InPact study participants had university education (35% vs. 71%, respectively).

Recording time. Total recording time was 11.8±1.1 hours on both days. The duration of work time increased from 5.9±1.2 h to 6.7±1.0 h (p<.001) while the duration of leisure time decreased from 5.0±1.3 h to 4.2±1.2 h (p<.001) with no differences between the groups. The commuting time was 0.9±0.4 h on both days.

Baseline observations. At baseline there were no differences between the groups in any of the muscle inactivity variables. Detailed group, gender and domain -specific baseline values are presented at Supplemental Digital content 1, http://links.lww.com/MSS/A387: supplemental table 1. Both groups were inactive for an average of 69.1±11.1% of the whole day, and the sum of the 5 longest inactivity periods was on average 36.7±16.0 minutes. During working hours, on average 78.6±10.8% of signals fell below the inactivity threshold and the duration of the five longest inactivity periods averaged 31.7±16.0 minutes. During commuting and leisure time, muscle inactivity time was on average 44.3±21.6% and 61.6±15.6% of measurement time and the duration of the 5 longest inactivity periods was on average 7.8±6.8 minutes and 25.6±12.0 minutes, respectively.

At baseline, light muscle activity covered 21.9±10.0% of the whole day with values of 16.2±9.3% during work, 32.8±14.0% during commuting and 27.5±13.6% during leisure time. Less than eight percent (7.4±3.2%) of the whole day involved moderate muscle activity, consisting of 4.5±2.7%, 19.1±12.8% and 8.7±4.5% during work, commuting and leisure time, respectively. On average, only 1.5±2.6% of the whole day included vigorous muscle activity. The lowest value, 0.7±1.0%, was measured during work time, while during commuting and leisure time the vigorous muscle activity times were 3.9±5.4% and 2.2±5.1 %, respectively. The only difference between the groups at baseline was the greater amount of moderate muscle activity during commuting time among the controls (24.1±14.5 %) compared to the participants in the intervention group (14.1±8.4 %, $p<.05$).

At baseline EMG amplitude was on average 2.4±1.6% of EMG_{MVC} during the whole day, with a value of only 1.5±0.8% of EMG_{MVC} measured during working hours. During commuting and leisure time the EMG amplitudes were 4.7±2.9% and 3.0±3.1% of EMG_{MVC}, respectively. Both groups had on average 23.4±14.9 muscle activity bursts per minute during the whole day. During work time, commuting and leisure time, the number of bursts per minute was 19.4±14.3, 31.3±25.1 and 27.2±17.7, respectively. At baseline there were no differences between the groups in either EMG amplitude or the number of bursts per minute.

Intervention effects. Table 2 and figures 3 and 4 summarize the effects of intervention on EMG inactivity and EMG activity variables in the intervention group compared to the control group. During the whole day, muscle inactivity time ($p<.05$, power=.54, $\eta^2=.09$) and the sum of the 5 longest muscle inactivity periods ($p<.05$, power=.61, $\eta^2=.11$) decreased with concomitant increases in light muscle activity time ($p<.05$, power=.63, $\eta^2=.11$) and the number of bursts per minute ($p<.05$, power=.61, $\eta^2=.11$) in the intervention group compared to the controls. Despite the significant group*time –interaction, the number of bursts per min did not change significantly within the intervention group (table 2). During work time, a decrease in muscle inactivity time ($p<.05$, power=.63, $\eta^2=.11$) was accompanied by an increase in light muscle activity time ($p<.01$, power=.77, $\eta^2=.15$) and average EMG amplitude ($p<.05$ power=.52, $\eta^2=.09$) in the intervention group compared to the controls. Compared to the control group, muscle inactivity time ($p<.05$, power=.70, $\eta^2=.13$) and the sum of the 5 longest muscle inactivity periods ($p<.01$, power=.83, $\eta^2=.17$) decreased and light muscle activity time ($p<.05$, power=.64, $\eta^2=.11$) increased in the intervention group during leisure time. Compared to the intervention group the sum of the 5 longest muscle inactivity periods decreased during commuting in the control group ($p<.01$, power=.83, $\eta^2=.17$).

DISCUSSION

In this intervention, a onetime lecture and face-to-face tailored counseling aimed at reducing and breaking up sitting time and increasing non-exercise physical activity time led to decreases in muscle inactivity time and long inactivity periods with concomitant increases in light muscle activity time. The effects were achieved partly during work time and more profoundly during leisure time. However, given the minimal use of muscle maximal voluntary contractile capacity (1.5% of EMG_{MVC} during working hours), these changes resulted in a significant increase in average EMG amplitude during working hours of office workers. In other activity variables, there were no significant group*time changes during the whole day, suggesting that this specific counseling changed muscle inactivity and activity patterns as hypothesized. Reallocation of muscle inactivity to ambulatory activity of the observed magnitude (~30 min) have been shown to decrease metabolic risk factors in short term interventions (12, 30).

According to a previous review (7), strategies aimed at promoting physical activity are often not able to reduce self-reported sitting time despite increasing physical activity in various workplace interventions. However, behavioral interventions targeted specifically at reducing sedentary behavior in overweight office workers (23) and in the elderly (17) showed similar results as the present study, i.e. reductions of sedentary time with simultaneous increases in light intensity physical activity time. In addition, a lecture and a specific prompt program for normal weight office workers (13), a TV-lockout system for overweight and obese individuals (26), and the implementation of sit-stand workstations (2, 19) were able to reduce sedentary behavior by changing the physical environment resulting mostly in more substantial changes as compared to behavioural intervention alone. These results illustrate that to reduce sedentary time, the specific physical and social contexts that modify participation in sedentary activities must be modified, and these factors are likely different to factors related to physical activity (28).

In the present study, both the intervention instructions and data analysis were classified into commute, work time and leisure time in order to emphasize the effect of the intervention within these domains. The changes during leisure time were ~twofold bigger as compared to the work time, while no intervention effects were observed during commuting. The specific contexts affecting sedentary behavior are likely various and present throughout the day. Specifically, a potential to decrease sedentariness through behavioral intervention is different between these domains. Even though workplace settings include challenges for behavioral interventions in terms of structured time-use, social norms and environment among others, the present behavioral intervention was effective in participants from various professional backgrounds. We also tested the potential confounding effect of occupational status by using it as a covariate in the statistical tests but the results remained largely unchanged suggesting that the intervention was independent of professional background within our study population. On average, the magnitude of the change induced by this simple intervention is rather modest and may benefit from environmental support and a multilevel approach at the workplace. In addition, given the high education level of the study participants these results may not be fully generalizable. However, because sedentary work seems to be most prevalent in highly educated people (8) there might be need for sedentary-time targeted intervention within this particular group.

Leisure time, on the other hand, offers a more flexible environment for behavioral changes as evidenced by a twofold bigger decrease in sedentary time as compared to the work time. In particular, the family-based approach, which incorporates educational and parental aspects in addition to individual priorities, may have exposed the motivation towards non-exercise activity through the desire for activities that are important for children. About 40% of Finnish families have children, from which 50% have children under the age of 6 (34). The findings of this study show the potential of family-based intervention in a population representing busy stage of life and low daily physical activity level (31). To increase the effectiveness of future interventions targeting sedentary time, workplace settings might benefit from environmental support and commuting time may require a more powerful and wide-ranging intervention (28).

In addition to different domains, it is also important to consider changes in behavior across the entire physical activity spectrum. For example, an increase in high intensity physical activity may occur independent of inactivity (10, 14) or may even be paralleled by a decrease in light intensity physical activity (32) changing the interpretation of findings. From the perspective of sedentary time, laboratory studies have revealed different metabolic pathways that are activated by physical inactivity and by reallocation of inactivity to light or to more intense activities (4, 18, 24). Due to these differences it is important to consider not only the change, but also the reallocation of sedentary time. In the present study the intervention achieved the stated goals, since the only significant group*time -interactions during the whole day were seen in muscle inactivity time, sum of the 5 longest muscle inactivity periods and light muscle activity time, which were the primary outcome variables. The main intervention message of reducing prolonged sedentary time and increasing non-exercise physical activity was thus well transferred to the muscle level.

The beneficial effects of reduced sedentary time have been suggested by cross-sectional and prospective studies, but evidence from long-term interventions is lacking. However, short-term experimental studies have induced a positive change on postprandial glucose and insulin responses with regular 1 min 40s to 2 min activity breaks totaling ~30 min reallocation of sitting to ambulatory activity a day (12, 30), a change of similar magnitude as seen in this study. In long-term, a 2-hr reduction in objectively measured sedentary time was associated with a favorable change in cardio-metabolic biomarkers reflecting a 7% lower risk of cardiovascular events (21, 39). When adjusted to similar wear time, 21% of the participants in the present study achieved a change of this magnitude. Although the results of this study show potential in terms of clinical significance, more research is needed to confirm what is the required minimum reduction in sedentary time yielding clinically significant end point in long term.

The limitations of the present study include one-day measurement periods and a systematic increase in the working time between the measurement days. This is likely due to longer duration of laboratory measurements on the first day, while on the second day the participants had fewer questionnaires to fill in and instruction time was shorter. By having a control group and selecting only self-reportedly typical workdays in the analysis the effect of between-days variability on the results was minimized. On the other hand, many participants were excluded based on this criterion. These "non-typical" days included e.g. organized exercise-evenings at workplace, giving visitors a grand tour of the workplace or staying at home because kids were sick. Because of device availability and study schedule we were not able to replicate these measurements resulting in reduced sample and limited power in some variables. During commuting, the control group showed a decrease in the longest inactivity periods compared to the intervention group. This may be explained by their more active commute habits at baseline in combination with participation in a study entitled "Daily activity" that included informed consent, which potentially provided a cognitive intervention to the participants. On the other hand, there were no differences in the change in total muscle inactivity or activity parameters during commuting between the groups.

The main strength of this study was the use of EMG, which shows both the duration and intensity of muscle activity with high precision (36, 37). Classifying the EMG signal, as well as accelerometer counts (22), merely by threshold values makes it impossible to determine whether the participants were actually sitting, standing or moving. However, because the inactivity threshold was set individually to be between the values of sitting and standing, it is likely that the inactivity time presented in this study reflects the actual sitting time accompanied with complete inactivity periods from quadriceps and hamstring muscles. Concerning associations between physical activity and health, the underlying enzymatic processes related to insulin resistance and substrate utilization are initiated by muscle activity, not physical impact measured by accelerometer counts or the posture itself. The definition of sedentary behavior has gained wide attention, but consensus is yet to be reached (3, 27, 29, 33). With these considerations in mind, the present study focused on complete inactivity and activity periods measured directly from locomotor muscles, which we believe is the most insightful method for the measurement of physical inactivity and activity.

Only a small fraction (2.4%) of muscle's maximal voluntary strength capacity is used in normal daily life and the main locomotor muscles are inactive almost 70% of the day. Tailored counseling was effective in decreasing muscle inactivity time by 33 min (4.5pp) with concomitant increases in light muscle activity by 21 min (2.8 pp). This resulted in 13% increase in work time average EMG amplitude without increases in high intensity EMG. These results reveal the potential of behavioral interventions targeting decreased sedentary time, rather than merely increased physical activity time, to decrease muscle inactivity time.

Acknowledgements.

We are grateful to Marko Tanskanen, MSc for his assistance in data analysis, to Olli Tikkanen, MSc for his contribution to EMG analysis methods and to Neil Cronin, PhD for revising language. Myontec Ltd and Suunto Ltd are acknowledged for their technical support. This study was funded by Finnish Ministry of Education and Culture (DNRO42/627/2010) and the Juho Vainio foundation. The authors have no financial conflict of interest to declare.

The results of the present study do not constitute endorsement by the American College of Sports Medicine.

REFERENCES

1. Ajzen I. From intentions to actions: A theory of planned behavior. In: Kuhl J, Beckmann J, editors. *Action-control: From cognition to behavior*. Berlin, Heidelberg: Springer Berlin Heidelberg; 1985 p. 11–39.

2. Alkhajah TA, Reeves MM, Eakin EG, Winkler EAH, Owen N, Healy GN. Sit-stand workstations: a pilot intervention to reduce office sitting time. *Am J Prev Med* 2012;43(3):298–303.

3. Bennett JA, Winters-Stone K, Nail LM, Scherer J. Definitions of sedentary in physical-activity-intervention trials: a summary of the literature. *J Aging Phys Act* 2006;14:456–77.

4. Bey L, Akunuri N, Zhao P, Hoffman EP, Hamilton DG, Hamilton MT. Patterns of global gene expression in rat skeletal muscle during unloading and low-intensity ambulatory activity. *Physiol Genomics* 2003;13(2):157–67.

5. Bey L, Hamilton MT. Suppression of skeletal muscle lipoprotein lipase activity during physical inactivity: a molecular reason to maintain daily low-intensity activity. *J Physiol* 2003;551(Pt 2):673–82.

6. Burton NW, Khan A, Brown WJ, Turrell G. The association between sedentary leisure and physical activity in middle-aged adults. *Br J Sports Med* 2012;46(10):747–52.

7. Chau JY, van der Ploeg HP, van Uffelen JGZ, et al. Are workplace interventions to reduce sitting effective? A systematic review. *Prev Med* 2010;51(5):352–6.

8. Choi B, Schnall PL, Yang H, et al. Sedentary work, low physical job demand, and obesity in US workers. *Am J Ind Med* 2010;53:1088–101.

9. Conn VS, Hafdahl AR, Mehr DR. Interventions to increase physical activity among healthy adults: meta-analysis of outcomes. *Am J Public Health* 2011;101(4):751–8.

10. Craft LL, Zderic TW, Gapstur SM, et al. Evidence that women meeting physical activity guidelines do not sit less: an observational inclinometry study. *Int J Behav Nutr Phys Act* 2012;9:122.

11. Dunstan DW, Barr ELM, Healy GN, et al. Television viewing time and mortality: the Australian Diabetes, Obesity and Lifestyle Study (AusDiab). *Circulation* 2010;121(3):384–91.

12. Dunstan DW, Kingwell BA, Larsen R, et al. Breaking up prolonged sitting reduces postprandial glucose and insulin responses. *Diabetes Care* 2012;35(5):976–83.

13. Evans RE, Fawole HO, Sheriff SA, Dall PM, Grant PM, Ryan CG. Point-of-choice prompts to reduce sitting time at work: a randomized trial. *Am J Prev Med* 2012;43(3):293–7.

14. Finni T, Haakana P, Pesola a J, Pullinen T. Exercise for fitness does not decrease the muscular inactivity time during normal daily life. *Scand J Med Sci Sports* 2012;1–9.

15. Finni T, Hu M, Kettunen P, Vilavuo T, Cheng S. Measurement of EMG activity with textile electrodes embedded into clothing. *Physiol Meas* 2007;28(11):1405–19.

16. Finni T, Sääkslahti A, Laukkanen A, Pesola A, Sipilä S. A family based tailored counselling to increase non-exercise physical activity in adults with a sedentary job and physical activity in their young children: design and methods of a year-long randomized controlled trial. [Internet]. *BMC Public Health* 2011;11:944. doi:10.1186/1471–2458–11–944.[cited 2013 Mar 4] Available from: http://www.biomedcentral.com/1471-2458/11/944

17. Gardiner PA, Eakin EG, Healy GN, Owen N. Feasibility of reducing older adults' sedentary time. *Am J Prev Med* 2011;41(2):174–7.

18. Hamilton MT, Hamilton DG, Zderic TW. Role of low energy expenditure and sitting in obesity, metabolic syndrome, type 2 diabetes, and cardiovascular disease. *Diabetes* 2007;56(11):2655–67.

19. Healy GN, Eakin EG, Lamontagne AD, et al. Reducing sitting time in office workers: short-term efficacy of a multicomponent intervention. *Prev Med* 2013;57(1):43–8.

20. Herrmann SD, Barreira T V, Kang M, Ainsworth BE. Impact of accelerometer wear time on physical activity data: a NHANES semisimulation data approach. *Br J Sports Med* 2014;48:278–82.

21. Hokanson JE, Austin MA. Plasma Triglyceride Level is a Risk Factor for Cardiovascular Disease Independent of High-Density Lipoprotein Cholesterol Level: A Metaanalysis of Population-Based Prospective Studies. *Eur J Cardiovasc Prev Rehabil* 1996;3(2):213–9.

22. Kerr J, Marshall SJ, Godbole S, et al. Using the SenseCam to Improve Classifications of Sedentary Behavior in Free-Living Settings. *Am J Prev Med* 2013;44(3):290–6.

23. Kozey-Keadle S, Libertine A, Staudenmayer J, Freedson P. The feasibility of reducing and measuring sedentary time among overweight, non-exercising office workers. *J Obes* 2012;2012:282303.

24. Latouche C, Jowett JB, Carey AL, et al. Effects of breaking up prolonged sitting on skeletal muscle gene expression. *J Appl Physiol* 2013;114(4):453–60.

25. Matthews CE, George SM, Moore SC, et al. Amount of time spent in sedentary behaviors and cause-specific mortality in US adults. *Am J Clin Nutr* 2012;95(2):437–45.

26. Otten JJ, Jones KE, Littenberg B, Harvey-Berino J. Effects of Television Viewing Reduction on Energy Intake and Expenditure in Overweight and Obese Adults. *Arch Intern Med* 2009;169(22):2109–15.

27. Owen N, Leslie E, Salmon J, Fotheringham MJ. Environmental determinants of physical activity and sedentary behavior. *Exerc Sport Sci Rev* 2000;28(4):153–8.

28. Owen N, Sugiyama T, Eakin EE, Gardiner PA, Tremblay MS, Sallis JF. Adults' sedentary behavior determinants and interventions. *Am J Prev Med* 2011;41(2):189–96.

29. Pate RR, O'Neill JR, Lobelo F. The evolving definition of "sedentary". *Exerc Sport Sci Rev* 2008;36(4):173–8.

30. Peddie MC, Bone JL, Rehrer NJ, Skeaff CM, Gray AR, Perry TL. Breaking prolonged sitting reduces postprandial glycemia in healthy, normal-weight adults: a randomized crossover trial. *Am J Clin Nutr* 2013;98:358–66.

31. Rovio E, Hakonen H, Kankaanpää A, et al. Physically inactive adults in Finland-Identification of the subgroups. *Liik T* 2009;46(6):26–33.

32. Rowland TW. The biological basis of physical activity. *Med Sci Sports Exerc* 1998;30(3):392–9.

33. Sedentary Behaviour Research Network. Letter to the Editor: Standardized use of the terms "sedentary" and "sedentary behaviours."*Appl Physiol Nutr Metab* 2012;37(3):540–2.

34. Statistics Finland Web site. Families, 2011 [Internet]. 2012;[cited 2014 Jan 15] Available from: http://www.stat.fi/tup/suoluk/suoluk_vaesto_en.html

35. Sun B, Zhang LF, Gao F, et al. Daily short-period gravitation can prevent functional and structural changes in arteries of simulated microgravity rats. *J Appl Physiol* 2004;97(3):1022–31.

36. Tikkanen O, Haakana P, Pesola AJ, et al. Muscle Activity and Inactivity Periods during Normal Daily Life. [Internet]. *PLoS One* 2013;8(1):e52228.[cited 2013 Mar 4] Available from: http://www.plosone.org/article/info%253Adoi%252F10.1371%252Fjournal.pone.0052228 doi: 10.1371/journal.pone.0052228

37. Tikkanen O, Hu M, Vilavuo T, Tolvanen P, Cheng S, Finni T. Ventilatory threshold during incremental running can be estimated using EMG shorts. *Physiol Meas* 2012;33(4):603–14.

38. Tudor-Locke C, Leonardi C, Johnson WD, Katzmarzyk PT. Time spent in physical activity and sedentary behaviors on the working day: the American time use survey. *J Occup Environ Med* 2011;53(12):1382–7.

39. Wijndaele K, Orrow G, Ekelund U, et al. Increasing objectively measured sedentary time increases clustered cardiometabolic risk: a 6 year analysis of the ProActive study. *Diabetologia* 2014;57(2):305–12.

40. Zhang LF, Sun B, Cao XS, et al. Effectiveness of intermittent -Gx gravitation in preventing deconditioning due to simulated microgravity. *J Appl Physiol* 2003;95(1):207–18.

List of figures

FIGURE 1. Randomization and recruitment procedure for EMG analysis in the present InPact-project.

FIGURE 2. Mean and standard deviations of EMG amplitude (%EMG_{MVC}) measured during various laboratory tests. The horizontal lines show thresholds for intensity classification, which was done individually for each participant.

FIGURE 3. EMG-derived muscle inactivity time in intervention (Int.) and control (Cont.) groups across different domains in pre and post measurements.

Footnote: * denotes significance at $p<.05$ and ** to $p<.01$.

FIGURE 4. EMG-derived muscle inactivity and activity variables in the intervention and control groups during the whole day in pre and post measurements. Units for each variable are presented after the variable names.

Footnote: * denotes significance at $p<.05$.

List of Supplemental Digital Content

Supplemental digital content 1: Additional results and further details of EMG analysis procedures

Supplemental digital content 2: Supplement figures 1A and B illustrate EMG channel averaging and baseline correction

Figure 1

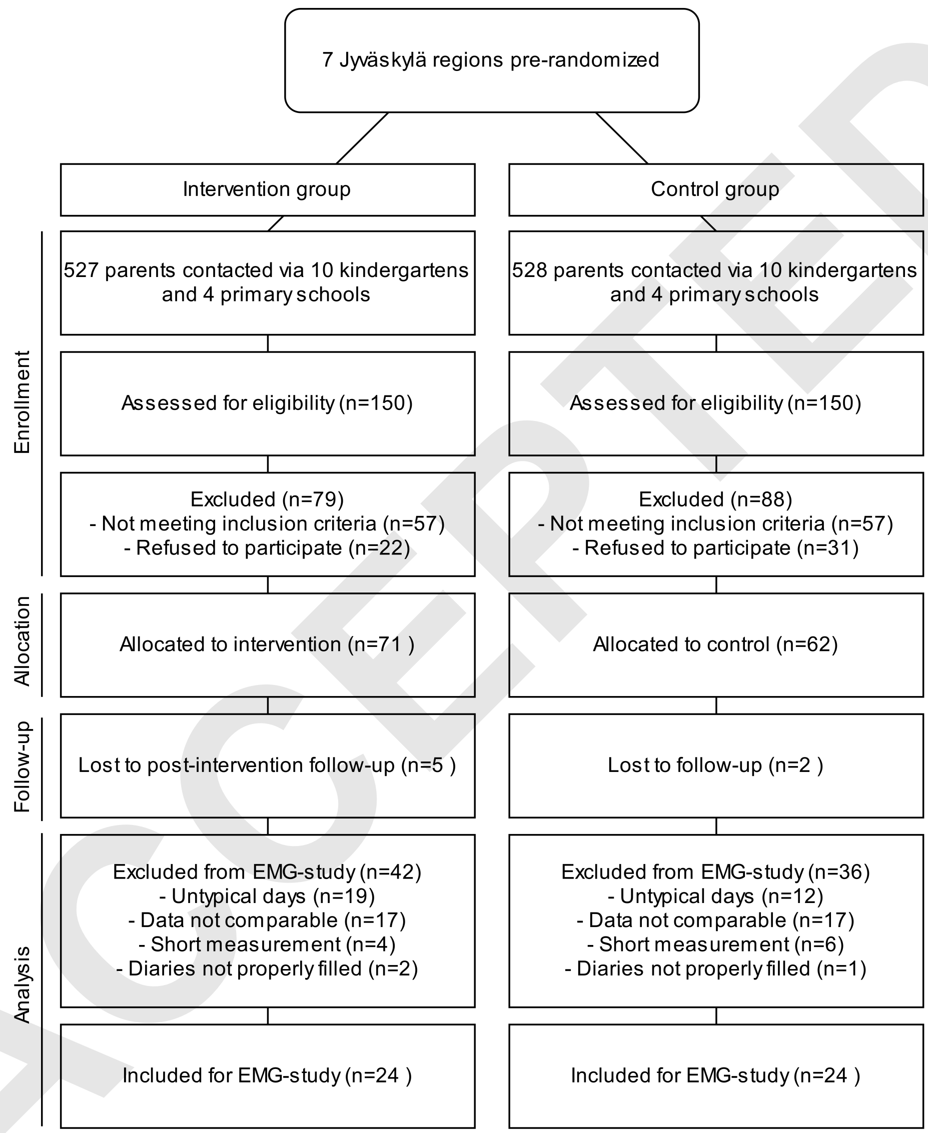
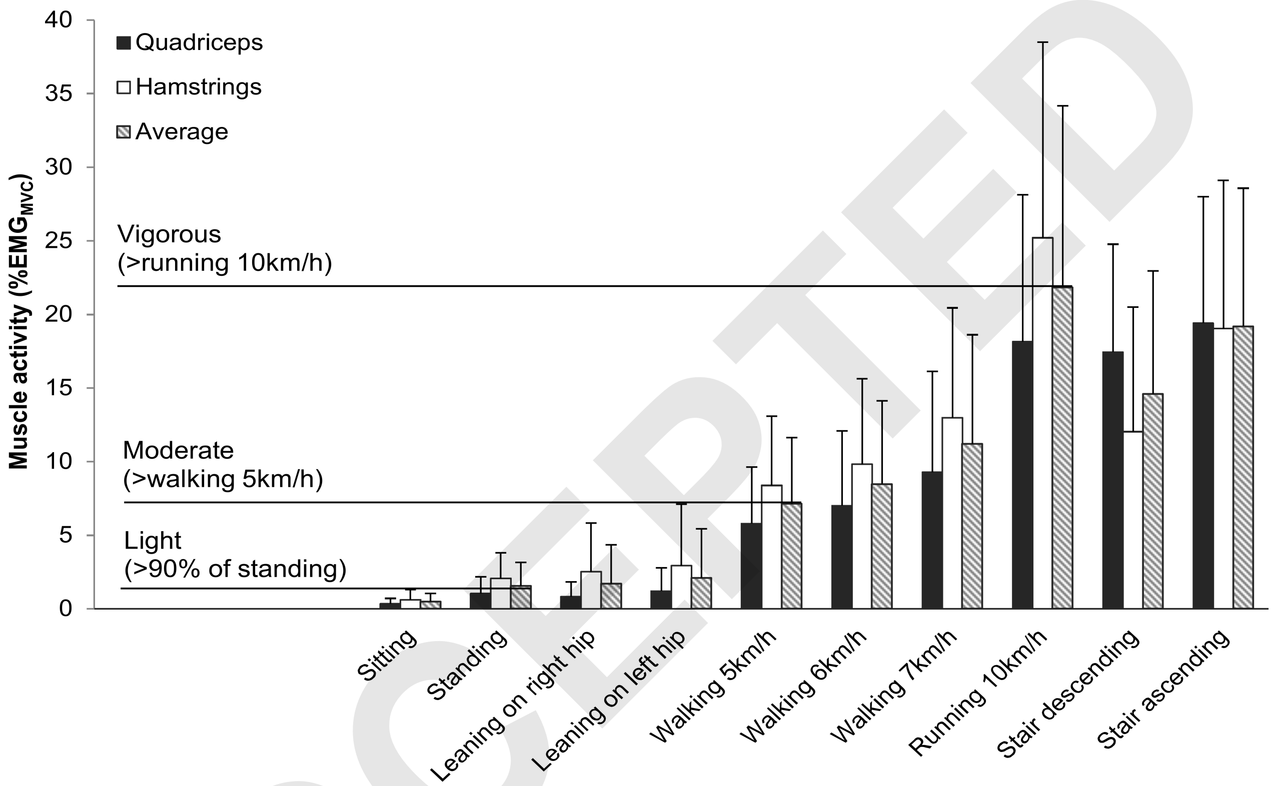
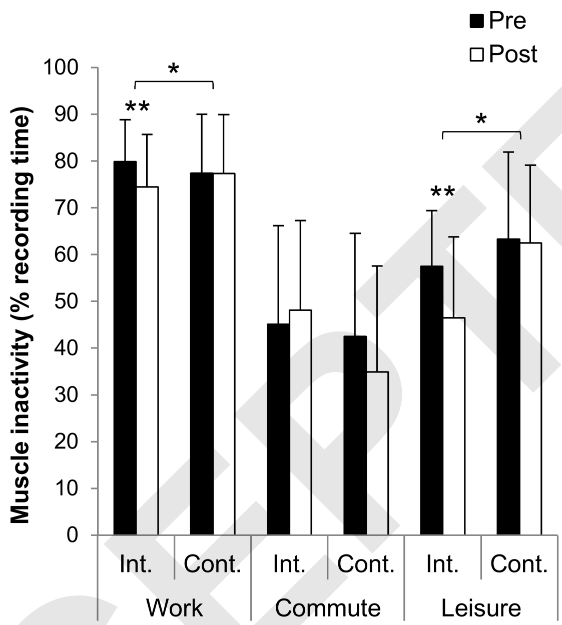

7 Jyväskylä regions pre-randomized
Intervention group
Control group
Enrollment
Allocation
Follow-up
Analysis
527 parents contacted via 10 kindergartens and 4 primary schools
528 parents contacted via 10 kindergartens and 4 primary schools
Assessed for eligibility (n=150)
Assessed for eligibility (n=150)
Excluded (n=79)
- Not meeting inclusion criteria (n=57)
- Refused to participate (n=22)
Excluded (n=88)
- Not meeting inclusion criteria (n=57)
- Refused to participate (n=31)
Allocated to intervention (n=71)
Allocated to control (n=62)
Lost to post-intervention follow-up (n=5)
Lost to follow-up (n=2)
Excluded from EMG-study (n=42)
- Untypical days (n=19)
- Data not comparable (n=17)
- Short measurement (n=4)
- Diaries not properly filled (n=2)
Excluded from EMG-study (n=36)
- Untypical days (n=12)
- Data not comparable (n=17)
- Short measurement (n=6)
- Diaries not properly filled (n=1)
Included for EMG-study (n=24)
Included for EMG-study (n=24)

Figure 2



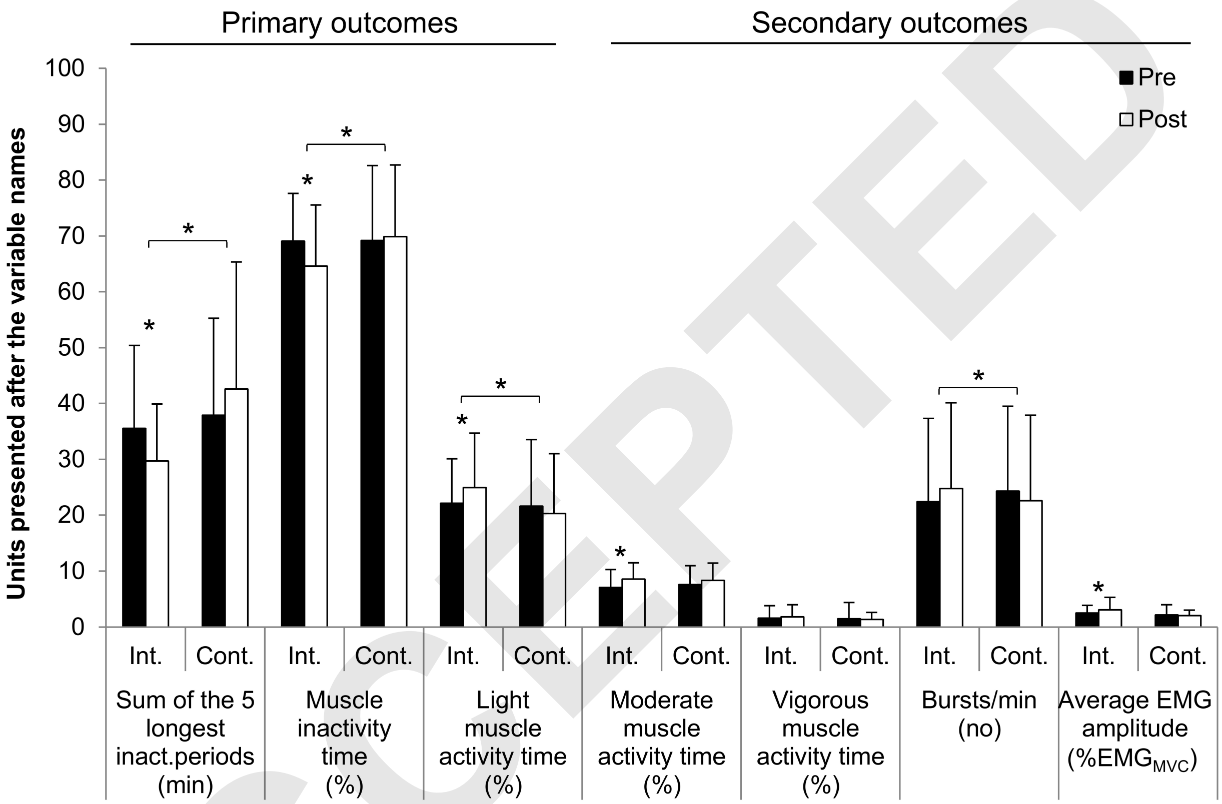
Quadriceps
Hamstrings
Average
Muscle activity (%EMG$_{MVC}$)
Vigorous
(>running 10km/h)
Moderate
(>walking 5km/h)
Light
(>90% of standing)
0
5
10
15
20
25
30
35
40
Sitting
Standing
Leaning on right hip
Leaning on left hip
Walking 5km/h
Walking 6km/h
Walking 7km/h
Running 10km/h
Stair descending
Stair ascending

Figure 3



Pre
Post
Muscle inactivity (% recording time)
100
90
80
70
60
50
40
30
20
10
0
*
**
*
**
Int.
Cont.
Int.
Cont.
Int.
Cont.
Work
Commute
Leisure

Figure 4



Primary outcomes
Secondary outcomes
Units presented after the variable names
100
90
80
70
60
50
40
30
20
10
0
Pre
Post
*
Int.
Cont.
Sum of the 5 longest inact.periods (min)
Muscle inactivity time (%)
Light muscle activity time (%)
Moderate muscle activity time (%)
Vigorous muscle activity time (%)
Bursts/min (no)
Average EMG amplitude ($\%EMG_{MVC}$)

Tables

TABLE 1. Basic characteristics of the subjects. There were no significant differences within the genders between the groups and neither between the group means.

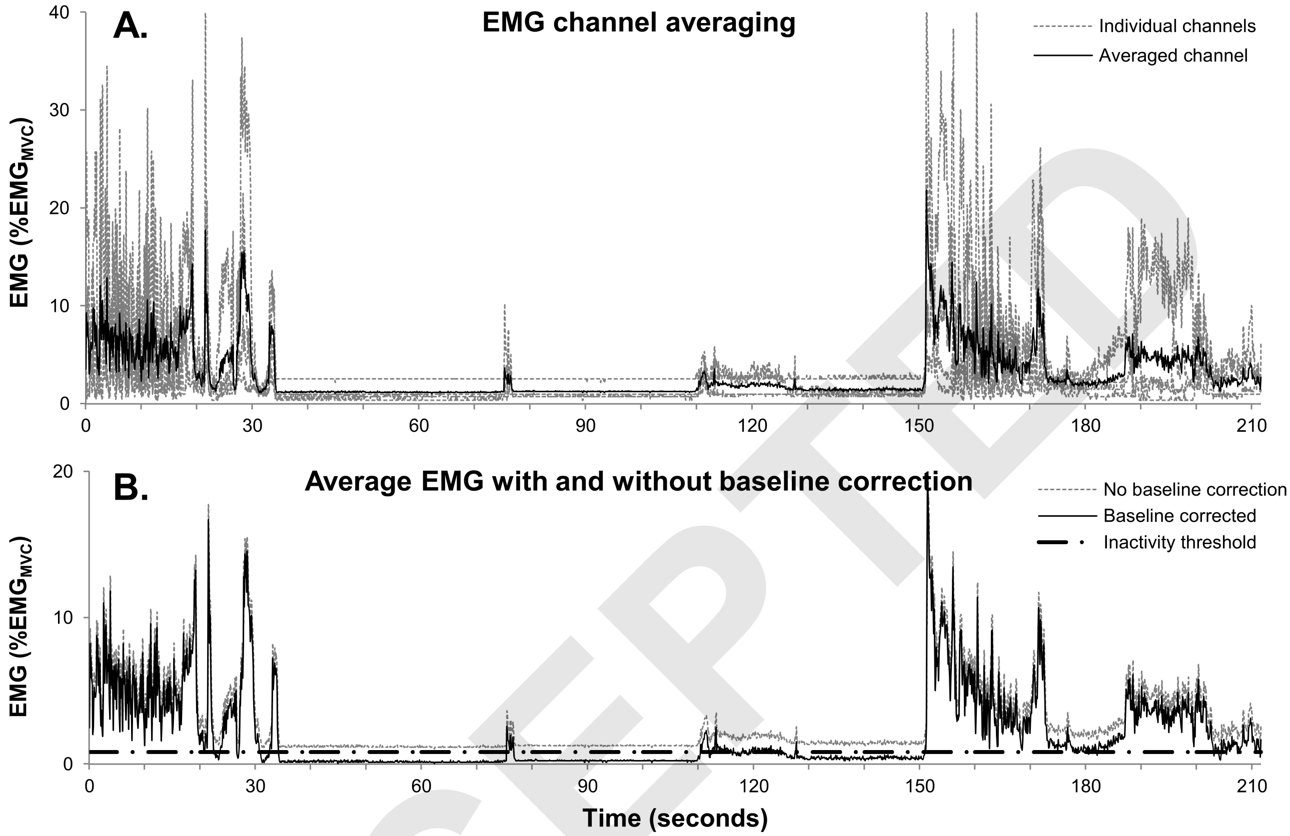
	Intervention			Control			All
	All (n=24)	Female (n=15)	Male (n=9)	All (n=24)	Female (n=13)	Male (n=11)	n=48
Anthropometrics							
Age (years)	37.0±5.5	34.8±4.0	40.7±6.2	39.0±5.4	38.2±5.9	40.1±4.8	38.0±5.5
Height (cm)	171.1±10.3	165.3±7.0	180.8±7.1	171.1±9.0	165.2±6.1	178.2±6.3	171.1±9.5
Weight (kg)	73.2±17.6	63.2±8.3	90.0±16.4	71.9±13.8	64.6±9.3	80.4±13.5	72.6±15.7
BMI (kg/m^2)	24.7±3.7	23.1±3.0	27.4±3.4	24.5±3.9	23.6±2.6	25.4±4.9	24.6±3.7
MVC extension (kg)	78.0±25.5	63.9±14.7	101.6±22.4	77.9±22.6	65.4±14.9	92.6±21.5	77.9±23.8
Professional group n (%)							
Employee	6 (25)	6 (40)	0 (0)	5 (21)	3 (23)	2 (18)	11 (23)
Official	1 (4)	0 (0)	1 (11)	4 (17)	3 (23)	1 (9)	5 (10)
Managerial employee	13 (54)	7 (47)	6 (67)	13 (54)	5 (38)	8 (73)	26 (54)
Entrepreneur	2 (8)	1 (7)	1 (11)	0 (0)	0 (0)	0 (0)	2 (4)
Non-defined	2 (8)	1 (7)	1 (11)	2 (8)	2 (15)	0 (0)	4 (8)
Work time/week n (%)							
<34h	4 (17)	4 (27)	0 (0)	1 (4)	1 (8)	0 (0)	5 (10)
35-39h	12 (50)	8 (53)	4 (44)	11 (46)	5 (38)	6 (55)	23 (48)
≥40h	8 (33)	3 (20)	5 (56)	12 (50)	7 (54)	5 (45)	20 (42)
Self-reported sitting at work (%)	80.8±14.4	80.2±15.4	82.1±12.9	84.5±12.4	82.4±10.6	86.7±14.3	82.7±13.4

TABLE 2. Changes of EMG inactivity and activity variables in intervention (Int.) and control (Cont.) groups in different domains.

		Total		Work		Commute		Leisure	
EMG inactivity		Difference	Group* time P	Difference	Group* time P	Difference	Group* time P	Difference	Group* time P
Muscle inactivity time (pp)	Int.	**-4.5±9.7***	**.042**	**-4.6±6.9****	**.023**	1.5±17.4	.08	**-9.3±18.5****	**.015**
	Cont.	0.7±8.0		0.3±7.1		-4.6±16.4		-0.7±17.6	
Sum of the 5 longest muscle inactivity periods (min)	Int.	**-5.8±9.9***	**.027**	-3.7±9.1	.12	-0.7±5.1	**.005**	**-8.2±11.8*****	**.005**
	Cont.	4.7±17.7		0.5±11.7		**-3.1±5.6*****		5.9±15.3	
EMG activity									
Light muscle activity time (pp)	Int.	**2.8±7.2***	**.023**	**3.7±6.0*****	**.008**	-3.0±11.8	.12	**4.2±11.5***	**.022**
	Cont.	-1.3±5.1		-0.4±5.4		2.9±7.3		-1.4±12.7	
Moderate muscle activity time (pp)	Int.	**1.4±3***	.57	0.9±2.0	.42	0.8±5.5	.08	**4.1±6.5*****	.08
	Cont.	0.7±3.3		0.1±2.7		**1.8±10.8***		2.1±6.1	
Vigorous muscle activity time (pp)	Int.	0.2±2.2	.84	-0.1±0.9	.38	0.7±3.8	.29	1.0±5.0	.74
	Cont.	-0.1±2.3		0.0±0.6		**-0.1±4.4***		0.0±5.5	
EMG amplitude (%EMG_{MVC})	Int.	0.6±2.2	.19	**0.3±0.6***	**.045**	0.5±2.3	.60	**1.6±5.5***	.07
	Cont.	-0.1±1.6		0.0±0.5		0.1±2.3		0.0±3.9	
No of bursts per minute	Int.	2.3±7.5	**.027**	**1.8±7.6***	.09	3.9±16.6	.36	3.6±13.8	.10
	Cont.	-1.7±7.6		1.1±6.9		-3.2±19.6		-3.6±12.1	

Footnote: pp=percentage point

* denotes to significance at p<.05, ** to p<.01 and *** to p<.001 * for within group changes. For group*time interactions P-values are presented.



SUPPLEMENT FIGURES 1A and B. EMG channel averaging and baseline correction. A) The channels from quadriceps and hamstring muscles were averaged in order to determine complete inactivity periods. B) Baseline fluctuation was corrected for by subtracting the minimum value of the 5 minute window from a preceding data point.

Supplementary digital content 1: Additional details of EMG analysis procedures

Muscle inactivity and activity patterns after sedentary-time targeted RCT

This supplement provides additional results and describes further details of EMG analysis procedures.

SUPPLEMENTARY TABLE 1. Group, gender and domain specific EMG inactivity and activity values at baseline.

	Intervention			Control			All
	All (n=24)	Female (n=15)	Male (n=9)	All (n=24)	Female (n=13)	Male (n=11)	n=48
Recording time							
Total	11.7±1.2	11.3±1.1	12.4±1.0	11.9±1.1	12.2±1.1*	11.6±1.0	11.8±1.1
Work	5.8±1.3	5.5±1.4	6.2±0.9	6.1±1.2	6.0±1.2	6.2±1.3	5.9±1.2
Commute	0.9±0.4	1.0±0.5	0.9±0.3	0.9±0.5	1.0±0.6	0.9±0.3	0.9±0.4
Leisure	5.1±1.2	5.0±1.1	5.3±1.5	4.9±1.3	5.1±1.2	4.6±1.5	5.0±1.3
EMG inactivity							
Muscle inactivity time (%)							
Total	69.1±8.5	67.2±8.8	72.3±7.3	69.2±13.4	67.5±13.4	71.2±13.7	69.1±11.1
Work	79.7±8.9	78.4±9.4	81.8±8.1	77.6±12.6	77.9±11.4	77.2±14.4	78.6±10.8
Commute	48.0±21.1	43.3±20.5	56.0±20.7	40.5±22.0	40.0±20.8	41.2±24.4	44.3±21.6
Leisure	59.1±11.9	58.0±11.6	61.0±12.8	64.1±18.6	61.9±19.6	66.6±17.9	61.6±15.6
Sum of the 5 longest muscle inactivity periods (min)							
Total	35.6±14.8	32.9±11.6	40.0±18.8	37.9±17.4	40.5±21.7	34.8±10.4	36.7±16.0
Work	29.7±13.1	27.8±10.7	32.9±16.6	33.6±18.5	37.9±22.6	28.6±11.1	31.7±16.0
Commute	8.5±6.5	8.0±7.2	9.3±5.5	7.2±7.1	7.2±6.7	7.1±7.9	7.8±6.8
Leisure	26.4±13.9	23.4±11.5	31.5±16.6	24.7±9.9	22.9±9.0	26.7±11.0	25.6±12.0
EMG activity							
Light muscle activity time (%)							
Total	22.2±7.9	23.2±7.9	20.4±8.1	21.7±11.9	24.4±12.7	18.5±10.4	21.9±10
Work	15.6±7.7	16.4±8	14.2±7.6	16.8±10.7	17.7±10.6	15.8±11.2	16.2±9.3
Commute	35.5±15.8	37.3±13.4	32.6±19.8	30.0±11.6	32.0±13.3	27.5±9.2	32.8±14
Leisure	29.1±11.6	29.7±11.3	28.1±12.6	25.8±15.4	29.6±17.7	21.4±11.4	27.5±13.6

Moderate muscle activity time (%)							
Total	7.1±3.2	7.7±2.4	6.3±4.2	7.6±3.3	7.5±3.5	7.9±3.3	7.4±3.2
Work	4.0±2.1	4.3±2.1	3.4±1.9	5.0±3.2	4.1±1.6	6.0±4.3	4.5±2.7
Commute	14.1±8.4	16.5±9.2	10.1±5.2	24.1±14.5*	24.6±16	23.5±13.4*	19.1±12.8
Leisure	9.4±4.7	9.7±3.4	8.9±6.6	8.1±4.3	7.9±4.7	8.2±4.1	8.7±4.5
Vigorous muscle activity time (%)							
Total	1.6±2.2	1.9±2.7	1.1±1.0	1.5±2.9	0.7±1	2.4±4.1	1.5±2.6
Work	0.8±1.2	0.9±1.4	0.6±0.6	0.6±0.8	0.3±0.3	1.0±1.0	0.7±1.0
Commute	2.3±3.3	2.9±4.1	1.3±1.0	5.4±6.6	3.4±4.7	7.8±7.8	3.9±5.4
Leisure	2.4±3.5	2.7±4.1	1.9±2.3	2.0±6.4	0.5±0.4	3.8±9.4	2.2±5.1
EMG amplitude (% EMG_{MVC})							
Total	2.5±1.3	3.0±1.4	1.7±0.9	2.2±1.8	2.0±1.1*	2.4±2.4	2.4±1.6
Work	1.6±0.9	1.8±1.0	1.1±0.6	1.4±0.6	1.3±0.6	1.4±0.6	1.5±0.8
Commute	4.2±2.6	5.2±2.8	2.6±1.3	5.2±3.2	5.4±3.7	5.0±2.6*	4.7±2.9
Leisure	3.3±1.9	3.8±2.0	2.5±1.3	2.7±4.0	2.0±1.1**	3.6±5.9**	3.0±3.1
No of bursts per minute							
Total	22.5±14.9	24±16.2	19.9±13.0	24.3±15.2	28.8±18.1	19±8.9	23.4±14.9
Work	19±14.5	18.8±13.1	19.5±17.5	19.8±14.5	22.7±17.7	16.5±9.1	19.4±14.3
Commute	26.2±16.9	29.0±20.0	21.6±8.8	36.3±30.9	43.8±39.5	27.4±12.6	31.3±25.1
Leisure	27±18.9	30.1±22.2	21.8±11	27.5±16.8	33.2±19.2	20.9±10.9	27.2±17.7

* denotes to p<.05 and ** to p<.01 within genders between groups or between group means.

Signal pre-processing. 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 of 50 Hz – 200 Hz (-3dB). The raw EMG signal was first rectified and then averaged over 100 ms non-overlapping 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).

Artefact removal. The rectified EMG signal was visually evaluated for occasional artefacts (e.g. toilet visits when electrodes were displaced, short-term movement artefacts), which were manually removed in MegaWin software (Mega Electronics Ltd., Kuopio, Finland). These occasional artefacts usually appeared simultaneously in all channels, and the corresponding data period was deleted from every channel. In case the artefact was longer than 30 min, the particular channel was removed from the analysis. These cases were probably caused by improper function of the measurement device or impedance problems between skin and electrodes due to lose contact of the particular electrodes. The effect of artifact on other channels was carefully evaluated, and only channels that contained physiological data were included in the analysis.

All channels were included in the analysis from 20 subjects (intervention n=9, control n=11). In 12 subjects analysis included three channels (intervention n=6, control n=6), in 10 subjects two channels (intervention n=5, control n=5), and in 9 subjects only one channel was included (intervention n=4, control n=5). From all channels removed, 29.5% were clean and were excluded to be able to compare the same muscle groups between the days. The effect of channel removal on EMG variables was carefully evaluated. Although omitting channels affected outcome measures, it should be noted that for both measurement days, the same channels were included in the analysis (e.g. if first day had only 1 hamstring and 1 quadriceps channel, those channels were used for analysis also on the second day).

Effect of channel removal. To take into account the possibility that results may vary depending on the number of muscle groups removed due to artefact, we investigated the differences between the averaged EMG containing all four channels, and the averaged EMG from which either one or more channels were removed. This was done with data including all four channels from 13 subjects (Supplementary table 2). The results seemed to be most sensitive on removal of hamstring muscles, but for example lack of both quadriceps muscle groups did not change inactivity time significantly if both hamstring muscle groups were included. To make the comparison between the two measurement days possible, only comparable channels from each day were included in the analysis.

SUPPLEMENTARY TABLE 2. Percent difference in variables of averaged EMG from different constitution of channels compared to average EMG from all channels. N=13.

No of quadriceps channels	No of hamstring channels	Total no of channels	Inactivity (%)	Average EMG (uV)	Aver of 5 longest inact. periods (min)	Number of bursts	Aver duration of bursts (s)
2	2	4	Ref.	Ref.	Ref.	Ref.	Ref.
1	2	3	-0,1±4,0	12,6±7,4***	-2,2±6,0	4,1±5,9	0,3±12,8***
2	1	3	5,6±4,8**	-6,4±7,6**	6,4±9,8*	13,0±10,2***	-16,8±9,0***
1	1	2	5,9±5,5**	5,2±6,7***	9,0±10,3**	22,8±16,1***	-24,6±11,3
0	2	2	0,8±8,9	33,6±12,8***	-4,8±11,0	9,5±10,6	-6,3±18,7***
2	0	2	20,3±13,1***	-23,9±13,1***	22,3±18,7***	10,0±24,2	-40,8±12,1***
1	0	1	24,5±14,6***	-20,1±13,3**	36,3±22,0***	18,8±34,0	-53,8±10,0***
0	1	1	8,0±10,3*	38,4±12,2***	9,1±19,8	28,7±25,1**	-32,6±16,7***

Ref=reference data, * denotes to p<.05, ** to p<.01 and *** to p<.001.

Channel averaging. In order to determine the complete inactivity and activity periods from quadriceps and hamstring muscles, the channels from four muscle groups were averaged after normalizing the data (Supplementary digital content 2: Supplementary figure 1A).

Matlab analysis. After artefact removal and channel averaging the data was ran through a custom made Matlab algorithm (MATLAB, MathWorks, Massachusetts), from which the final results were obtained. The signal baseline sometimes drifted and the drift was corrected for by using a 5 minute moving window throughout the entire recording time (see next paragraph). After the baseline correction the algorithm calculated the final results.

The minimum filter window length. After channel averaging any fluctuations in signal baseline were corrected by searching a minimum value from a 5 minute window and by subtracting this value from a preceding data point. This was repeated systematically throughout the recording period (Supplementary digital content 2: Supplementary figure 1B). The length of the filter window was selected according to pilot analysis in laboratory conditions and comparison of daily data analysed by alternative filter lengths. The laboratory tests included a variety of controlled activities from low to high intensities that lasted up to 1 minute, and uncontrolled periods of standing and ambulatory activities that lasted several minutes. According to pilot analysis in 5 subjects, the longest continuous burst duration was on average 88±16s. For example, during a task which included a short period of sitting and 3 minutes of standing and ambulating while talking to phone, the longest continuous burst duration was 17±9 seconds, although burst time was 71±17% of the measurement time. This can be taken as illustration of the intermittent nature of EMG even while maintaining a posture. The choice of 5 minute window may of course affect real physiological data in long-term static muscle activations, but these were assumed to be rare during normal daily life.

We also tested the effect of different minimum filter window lengths on daily data. The most sensitive variable on minimum filter was the longest continuous burst duration, but other variables seemed not to be affected considerably when changing the minimum filter window length (Supplementary table 3). The 5 minute window was considered not to shorten physiological muscle activity periods, but to effectively correct for possibly fluctuating baseline.

Repeatability. Paired t-tests were used to assess for systematic differences in laboratory tests between the days. Day-to-day reliability in laboratory tests was evaluated with intra-class correlation coefficients (ICC), coefficient of variation (CoV) and limits of agreement (LoA).

In the laboratory measurements, the maximal voluntary contraction increased significantly in post measurement (P<.001), but EMG/force -relationship assessed during maximal voluntary contraction remained the same. The intra-class correlation coefficient revealed high to moderate repeatability of the measured variables (Supplementary table 4). The poorer repeatability of submaximal laboratory tests could be explained by the fact that some subjects reported being unfamiliar with testing conditions, e.g. walking and running on treadmill during the first measurements. Therefore, the results from the second laboratory tests were used to categorize the data of both measurement days.

SUPPLEMENTARY TABLE 3. Results from pilot analysis including 42 days from 21 subjects analyzed by different minimum filter window lengths.

Filter window	Inactivity(%)	Average EMG (μV)	Bursts/min	Longest burst (min)	Longest inact. period (min)
No filter	15,1±23,4	12,1±6,7	14,9±26,0	404,3±330,8	2,3±3,7
60min	63,0±10,7	7,5±5,9	22,8±17,1	7,7±10,1	9,9±5,6
30min	64,0±10,6	7,3±5,8	22,8±16,5	6,3±8,2	10,2±5,7
10min	65,1±10,3	7,1±5,5	22,8±15,5	4,0±3,1	10,4±5,8
5min	65,7±10,1	6,9±5,3	22,9±15,2	3,1±1,9	10,4±5,8
3min	66,1±10,0	6,8±5,2	23,0±15,0	2,3±1,1	10,5±5,8
1min	67,3±9,6	6,5±4,8	23,9±15,1	1,2±0,4	10,5±5,8

SUPPLEMENTARY TABLE 4. Repeatability of maximal voluntary contraction, EMG/force - relationship (MVC), walking at 5 km/h and running at 10 km/h between pre and post measurements. N=43.

	Pre	Post	%Diff	ICC (95% CI)	Mean CoV (%)	LoA
MVC						
MVC Extension (kg)	78.2±23.2	82.7±23.4	6.6±11.2***	0.95 (0.91-0.97)	10.6	2.08-6.51
MVC flexion (kg)	46.6±18.0	48.4±17.0	6.8±13.2***	0.96 (0.93-0.98)	12.1	0.81-3.70
EMG/force quadriceps (MVC)	3.9±1.5	3.8±1.5	-1.2±17.1	0.87 (0.76-0.93)	19.5	-0.37-0.18
EMG/force hamstrings (MVC)	6.9±3.1	7.1±3.5	4.5±28.2	0.85 (0.74-0.91)	30.3	-0.43-0.68
Submaximal						
90% of Standing (%EMG_{MVC})	1.6±0.9	1.5±0.9	-4.5±44.4	0.70 (0.51-0.82)	62.0	-0.38-0.05
Walking 5 km/h (%EMG_{MVC})	8.1±3.3	7.3±3.3	-7.5±23.1**	0.79 (0.64-0.88)	27.8	-1.45--0.08
Running 10 km/h (%EMG_{MVC})	24.1±9.5	22.4±9.3	-5.2±20.3*	0.81 (0.67-0.89)	24.4	-3.53-0.08

* denotes to p<.05, ** to p<.01 and *** to p<.001.