EFFECT OF FLOORING ON LOWER EXTREMITY DISCOMFORT AND FATIGUE DURING LONG-TERM STANDING/WALKING: EVALUATION OF MUSCLE OXYGENATION AS AN OBJECTIVE MEASURE OF FATIGUE USING NEAR INFRARED SPECTROSCOPY

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Long-term standing is associated with multiple health problems affecting the lower extremity including musculoskeletal discomfort and fatigue. Unfortunately, many occupations require workers to endure prolonged periods of time spent standing. This research study investigated the effect of anti-fatigue flooring on subjective measures of discomfort and behavioral responses during long-term standing and walking. In addition to other measures of fatigue, near infrared spectroscopy was used to measure tissue oxygenation in the soleus and erector spinae muscles. Changes in muscle SO_2 can provide insight to the physiological processes that occur within muscles throughout long-term standing and walking. The goal was to determine the association between muscle SO_2 and subjective discomfort measures. Three flooring surfaces were examined in this study: a hard tile, a standard ergonomic soft mat, and a rubber tile. Subjects stood for 6 hours and walked for 2 hours on each of the 3 flooring surfaces. During this time, subjects rated levels of perceived discomfort while objective measures of fatigue were monitored. Flooring surface had a minimal impact on subjective discomfort during long-term standing. Additionally, erector spinae and soleus SO_2 were poorly related to subjective discomfort ratings. No significant changes in muscle SO_2 were found over time standing however, a positive relationship was revealed between soleus SO_2 and postural movements. Flooring effects were found after just 1 hour in subjective measures during long-term walking. Walking on the soft mat reduced overall leg tiredness, upper back discomfort, ankle discomfort, and feet discomfort compared to walking

on the hard tile. Muscle SO_2 significantly increased from resting values but similar to the standing protocol, no flooring effects were found during long-term walking. The results from this research suggest the development of subjective discomfort during long-term standing is not easily related to changes in muscle SO_2 likely due to the increase in postural movements. The effect of flooring on muscle SO_2 is inconclusive due to the similarities in subjective discomfort found across flooring conditions examined in this study.

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1.0 SPECIFIC AIMS

The primary goal of this thesis is to determine the reliability of using muscle oxygenation as an objective measure of fatigue during long-term standing. Changes in muscle oxygenation, estimated by a technique known as near infrared spectroscopy, can provide insight to the physiological processes that occur within muscles throughout long-term standing. This could have implications for reducing the risk of injury in the workplace as a result of prolonged standing. Understanding the association between perceived muscle fatigue and muscle oxygenation during long-term standing can aid in evaluating the impact of anti-fatigue flooring on muscle fatigue and discomfort.

The long-term goal of this research is to determine the impact of flooring on subjective and objective measures of muscle fatigue during long-term standing/walking. Subjective discomfort measures of interest included ratings of perceived discomfort in regions of the lower extremity and overall general fatigue. In addition to muscle oxygenation, objective fatigue measures of interest included muscle activity and distribution of body-weight during standing. This project focused on how trends in these fatigue measures varied with time standing/walking and across flooring conditions. Therefore the Specific Aims of this thesis are the following:

Specific Aim 1: To investigate the association between muscle oxygenation and fatigue during long-term standing.

H.1) Muscle oxygenation in the lower back erector spinae and soleus muscles will change throughout the duration of long-term standing as greater levels of subjective muscle fatigue and discomfort are reported.

Specific Aim 2: To examine the impact of flooring on subjective and objective measures of fatigue and discomfort during long-term standing/walking.

H.1) Implementation of anti-fatigue flooring will reduce the onset of perceived lower extremity discomfort throughout long-term standing/walking.

H.2) Lower back erector spinae and soleus muscles will undergo higher intensity muscle contractions when standing on a hard tile compared to anti-fatigue flooring.

H.3) Total number of body-weight shifts is expected to be similar during long-term standing across flooring surfaces.

H.4) Lower back erector spinae and soleus muscles will experience greater changes in muscle oxygenation during standing/walking on a hard surface when compared to standing/walking on anti-fatigue flooring.

2.0 INTRODUCTION

2.1 HEALTH RISKS ASSOCIATED TO LONG-TERM STANDING

Millions of workers in the United States endure long-term standing in the workplace [1]. Registered nurses and healthcare professionals, cashiers, janitors and cleaners, and assembly line workers are among many occupations that require employees to remain on their feet for long periods of time with limited rest breaks. Standing for long intervals throughout the day has been associated with several health problems relating to the lower extremity and lower back [2].

Nonfatal occupational injuries and illnesses which result in days away from work are common in occupations that require long-term standing in the workplace. Nursing aides, orderlies, and attendants rank among the top of this list along with registered nurses, janitors, and cleaners [3]. Musculoskeletal disorders covered 33% of injuries and illnesses that required days away from work in 2011 [3]. The back and leg regions accounted for approximately 53% and 7% of musculoskeletal disorders in registered nurses, respectively [3].

Many workers who are exposed to long-term standing in the workplace have reported lower extremity and lower back pain [4–6]. A study concerning supermarket checkout workers reported the lower back region as the most affected area [4] (Figure 1). Significant levels of discomfort and pain in the lower leg, calf, foot, and ankle regions have also been reported among Quebec workers across a variety of occupations constrained to long-term standing [7]. Fortyeight percent of a population among hospital employees in Turkey reported that they were required to stand for 5-8 hours per workday with 65% experiencing lower back pain at some point in their careers. Among all hospital employees, nurses were the most affected with 77% experiencing lower back pain [8].

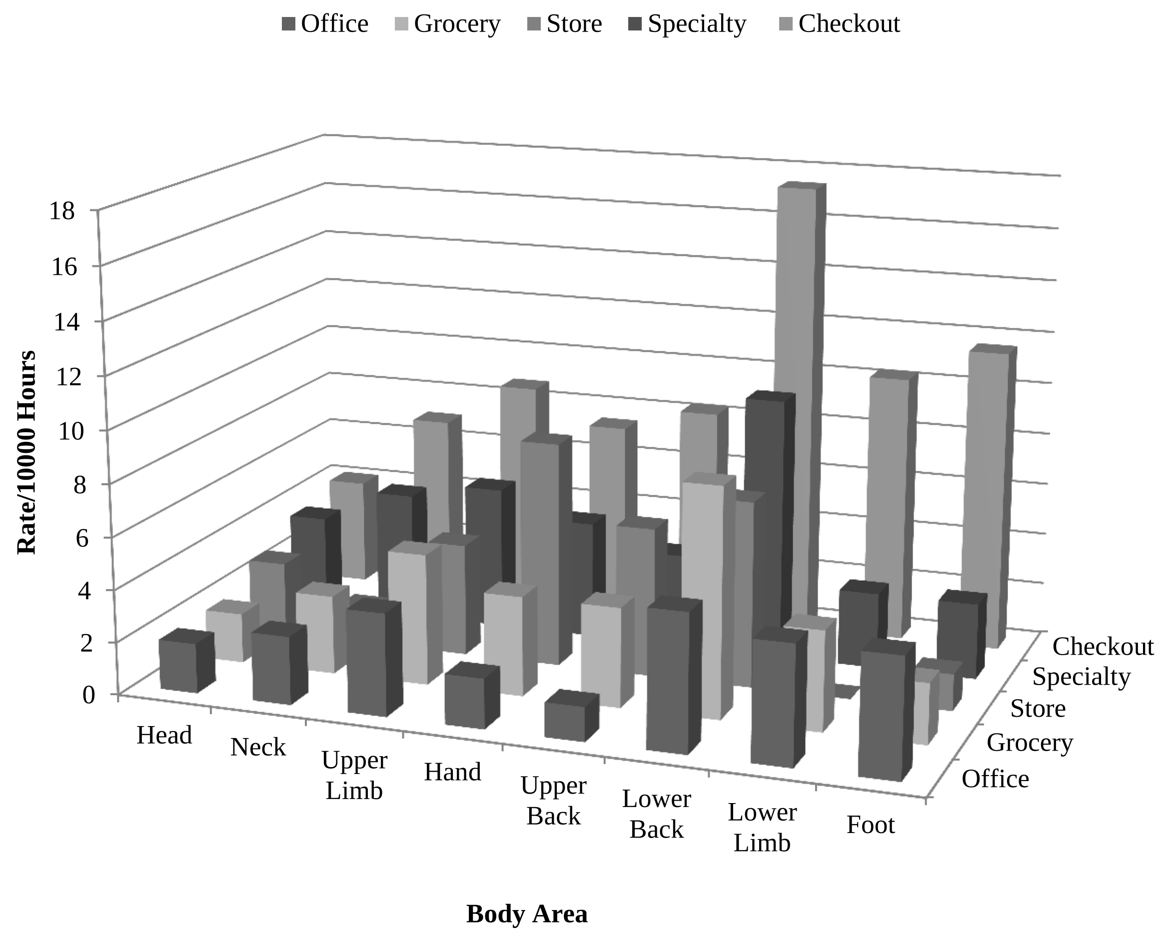


Figure 1: Prevalence of body segment discomfort experienced by supermarket employees by department. Lower back was the most affected area among checkout workers [4].

The development of chronic venous disorders has been associated to prolonged standing in the workplace [2,9], particularly among workers who stand for greater than 50% of the work day [9]. Varicose veins coincide with chronic venous insufficiency and are known to cause great discomfort to workers who are required to stand for long periods. A study of the Danish population reported a higher risk factor for the hospitalization due to varicose veins in men and women workers who are predominantly standing or walking throughout the work day [10]. Varicose veins and nocturnal leg cramps were associated to men and women in the workplace who stand for greater than 4 hours a day among the Korean population with a higher prevalence in women (21.8%) than men (9.5%) [11].

The development of osteoarthritis, which causes cartilage degeneration and chronic joint pain, is a major issue among the elderly population [12,13]. The risk of developing osteoarthritis of the knee is higher among the elderly population that has a previous work history that required standing for greater than 2 hours per day (odds ratio of 1.97) and/or walking for greater than 3 kilometers per day (odds ratio of 1.80) [14]. The most prone individuals were previous employees of the agricultural/forestry/fishery industry and factory/construction workers.

Other reported effects of long-term standing in the workplace are swelling of the lower limbs, venous blood restriction, and pregnancy complications [2]. Pregnant women who stand at work for greater than 6 hours a day have a higher risk for delivering a small-for-gestational-age infant [15]. Spontaneous abortions and preterm births are among other pregnancy complications associated to prolonged standing with pregnant women [2].

3.0 NEAR INFRARED SPECTROSCOPY

Near infrared spectroscopy (NIRS) is a valid and relatively newer technique for estimating the change in muscle oxygenation (SO_2) over a localized region [16–18]. Concentrations of oxygenated/deoxygenated hemoglobin (HbO_2/Hb) in blood are approximated by measuring the optical path length of photons of near infrared light as it illuminates biological tissue. In soft tissue, the absorption and scattering of near infrared light is only affected by the concentrations of HbO_2/Hb, myoglobin, and cytochrome c oxidase in blood [19]. The process of absorption and scattering of near infrared light is described by the linear coefficients μ_a and $\mu_{s,}$ which are defined in units of inverse centimeters and represent the inverse of the mean-free path for absorption and scattering. Estimation of the scattering coefficient will be defined as $\mu_s' = \mu_s(1-g)$, where g represents the anisotropy factor in soft tissue [20].

It is possible to estimate μ_a and μ_s' from measurements obtained using time-resolved NIRS. This can be performed in either the time or frequency domain. In the frequency domain, light that penetrates the tissue can be thought of as a photon density wave that is modulated at high frequency. Absorption and scattering of the light in the tissue attenuates the transmitted light intensity and the attenuated signal is then detected by a phase-sensitive detector. The measurement parameters from the detected signal, represented in Figure 2, involve the phase shift relative to the source (Φ), the average intensity ($U_{dc,}$ DC component), and the amplitude of the intensity ($U_{ac,}$ AC component) [20].

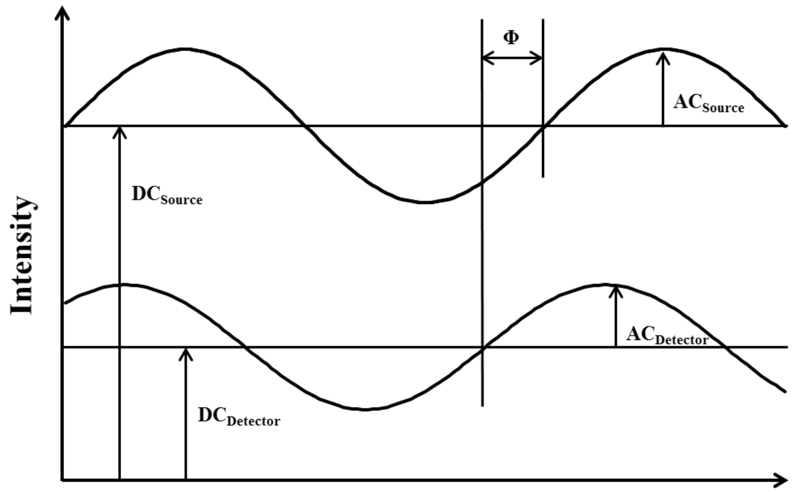


Figure 2: Representation of the change in AC, DC, and Φ components from an intensity modulated light source to the detected signal.

Measurements of Φ, U_{dc}, and U_{ac} of the detected signal, described by Fantini et al. [20] in the following equations, allow for the possibility of estimating μ_a and μ_s' of the explored medium:

$$\Phi = r\left(\frac{v^2u_a^2+\omega^2}{v^2D^2}\right)^{\frac{1}{4}}\sin\left[\frac{1}{2}\arctan\left(\frac{\omega}{v\mu_a}\right)\right], \quad 1)$$

$$\ln(rU_{dc}) = -r\sqrt{\frac{\mu_a}{D}} + \ln\left(\frac{S}{4\pi vD}\right), \quad 2)$$

$$\ln(rU_{ac}) = -r\left(\frac{v^2u_a^2+\omega^2}{v^2D^2}\right)^{\frac{1}{4}}\cos\left[\frac{1}{2}\arctan\left(\frac{\omega}{v\mu_a}\right)\right] + \ln\left(\frac{SA}{4\pi vD}\right), \quad 3)$$

where v is the speed of light in the medium, ω is 2π times the modulation frequency, D is the diffusion coefficient defined as $1/(3\mu_a+3\mu_s')$, S is the source strength, A is the modulation of the source which is the ratio of the AC to the DC component, and r is the distance between source and detector.

The Φ, $\ln(rU_{dc})$, and $\ln(rU_{ac})$ form linear relationships at multiple source-detector separation distances r [21]. Larger separation distances allow for greater depths of penetration of the light source path, represented in Figure 3.

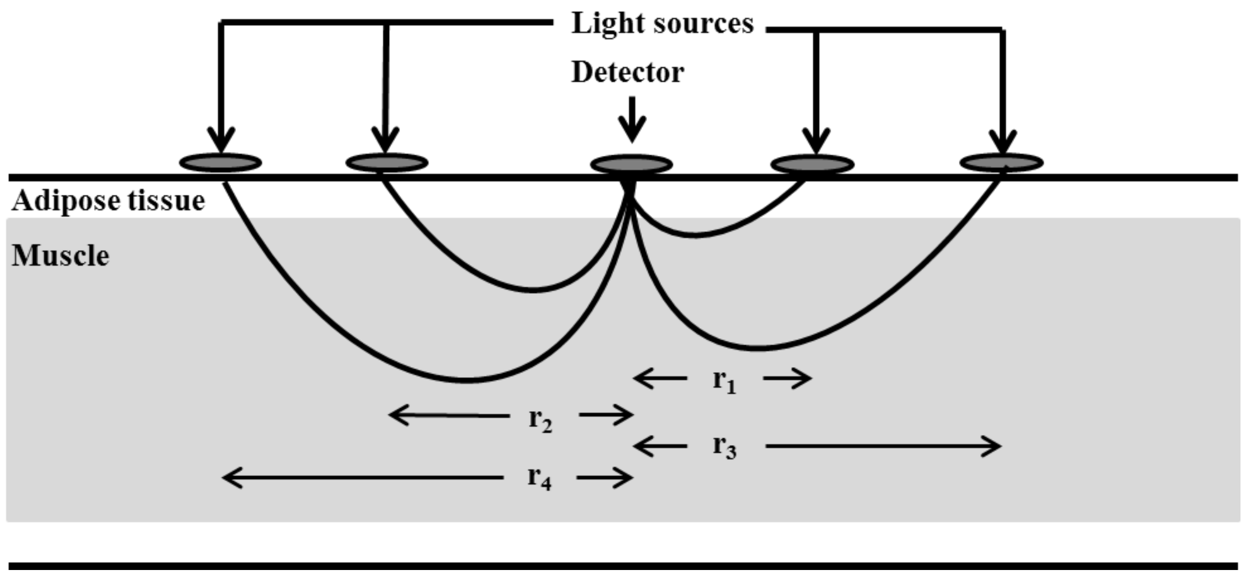


Figure 3: Schematic of multiple source-detector separation distances (r) and how they penetrate tissue

Slope variables are calculated from the linear relationships formed from the expressions in equations 1-3 as a function of source-detector separation distance r and referred to as S_Φ, S_{dc}, and S_{ac}. Estimations for μ_a and μ_s' can be computed in 3 different ways by using a combination of 2 of the 3 slope values:

1. Using U_{dc} , Φ:

$$\mu_a = -\frac{\omega}{2v}\frac{S_{dc}}{S_\Phi}\left(\frac{S_\Phi^2}{S_{dc}^2}+1\right)^{-\frac{1}{2}}, \quad 4)$$

$$\mu_s' = \frac{S_{dc}^2}{3\mu_a}, \qquad 5)$$

2. Using U_{ac}, Φ:

$$\mu_a = \frac{\omega}{2v}\left(\frac{S_\Phi}{S_{ac}} - \frac{S_{ac}}{S_\Phi}\right), \qquad 6)$$

$$\mu_s' = \frac{S_{ac}^2 - S_\Phi^2}{3\mu_a}, \qquad 7)$$

3. Using U_{dc}, U_{ac}:

$$\mu_a = \frac{\omega}{2v}\frac{S_{dc}}{S_{ac}}\left(\frac{S_{ac}^2}{S_{dc}^2} - 1\right)^{-\frac{1}{2}}, \qquad 8)$$

$$\mu_s' = \frac{S_{dc}^2}{3\mu_a}. \qquad 9)$$

The absorption coefficient, μ_a, can then be used to estimate muscle oxygenation. The Beer-Lambert law describes the relationship between μ_a and the concentrations of HbO_2 and Hb at a particular wavelength (λ):

$$\mu_a^\lambda = \varepsilon_{HbO_2}^\lambda[HbO_2] + \varepsilon_{Hb}^\lambda[Hb], \qquad 10)$$

where ε represents the extinction coefficients for [HbO_2] and [Hb] at wavelength λ. After solving for μ_a and μ_s' at two separate wavelengths, [HbO_2] and [Hb] can be estimated. The expressions for [HbO_2] and [Hb] are shown in equations 11 and 12:

$$[HbO_2] = \frac{\mu_a^{\lambda_1}\varepsilon_{Hb}^{\lambda_2} - \mu_a^{\lambda_2}\varepsilon_{Hb}^{\lambda_1}}{\varepsilon_{HbO_2}^{\lambda_1}\varepsilon_{Hb}^{\lambda_2} - \varepsilon_{HbO_2}^{\lambda_2}\varepsilon_{Hb}^{\lambda_1}} \qquad 11)$$

$$[Hb] = \frac{\mu_a^{\lambda_1}\varepsilon_{HbO_2}^{\lambda_2} - \mu_a^{\lambda_2}\varepsilon_{HbO_2}^{\lambda_1}}{\varepsilon_{HbO_2}^{\lambda_2}\varepsilon_{Hb}^{\lambda_1} - \varepsilon_{HbO_2}^{\lambda_1}\varepsilon_{Hb}^{\lambda_2}} \qquad 12)$$

The summation of [Hb] and [HbO_2] is equal to the total hemoglobin concentration (tHb), which is an approximation of the blood volume in the localized region. Finally, tissue oxygen saturation can be estimated by the proportion of oxygenated hemoglobin to total hemoglobin concentration as seen in equation 13.

$$\%SO_2 = \frac{[HbO_2]}{[HbO_2]+[Hb]} \times 100. \quad 13)$$

3.1 PREVIOUS RESEARCH

3.1.1 Static exercises

A number of researchers have tested the reliability of NIRS to estimate changes in muscle SO_2 during static fatigue tests [22–27]. McGill et al. [22] found that the level of reduction in muscle SO_2 during a sustained contraction is dependent upon the intensity of the muscle contraction. Higher intensity muscle contractions, proportional to the maximum voluntary contraction (MVC), produce greater declines in muscle SO_2. Lower back erector spinae SO_2 declined by 8.5% over a 15 second exertion interval when the intensity of the contraction was 30% MVC. Alternatively, there was a decline in SO_2 of 3.6% during 2% MVC. Quaresima et al. [25] investigated changes in SO_2 in the vastus lateralis muscle of the quadriceps using NIRS during 70% MVC and the results were similar to previous findings. Muscle SO_2 decreased to 48.8% from a resting value of 63% in a proximal region of the vastus lateralis. These researchers explained the decrease in SO_2 is likely due to the decrease in blood volume. Compression of blood vessels during a contraction causes an increase in intramuscular pressure that restricts blood flow. Muscle SO_2 will be reduced if the utilization of oxygen is greater than the quantity of oxygen that is readily available.

To summarize, the response of muscle SO_2 to muscle fatigue during a sustained isometric contraction has been well documented. Many researchers have concluded that SO_2 decreases throughout an exertion period until the time of relaxation. Additionally, it has been shown that the magnitude of the total reduction in SO_2 is dependent on the intensity of the muscle contraction.

3.1.2 Dynamic exercises

Dynamic exercises generate a physiological response to muscle fatigue that is similar to the response brought on by static contractions. The effect of walking/running speed on muscle SO_2 has been previously investigated [28–30]. Hiroyuki et al. [28] collected NIRS measures on the vastus lateralis and gastrocnemius muscles during incremental walking and running on a treadmill. Muscle SO_2 initially increased at the onset of walking while blood volume initially decreased. Blood volume decreased at the initiation of the exercise due to the compression of blood vessels at the onset of muscle contractions. However, a gradual increase in blood volume was seen throughout the exercise as a result of arterial inflow and venous return being facilitated by the repeated contractions. Consequently, vastus lateralis and gastrocnemius SO_2 increased by 8.7% and 5.5% at a walking speed of 4 km/hr. The low walking speed did not induce muscle fatigue and therefore the demand for oxygen was low. An increase in the walking/running speed generated a systemic decrease in muscle SO_2 as the muscles experienced greater fatigue and a higher demand for oxygen [28].

A few investigators have evaluated the effect of lifting frequency [31–33] on NIRS measures. Kell and Bhambhani [31] used NIRS to estimate change in lower erector spinae SO_2 and tHb during repetitive incremental lifting and lowering tasks. Erector spinae SO_2 and tHb systematically decreased as the load increased during the lifting protocol. Yang et al. [32] investigated the effect of lifting frequency on NIRS measures in the erector spinae among experienced and novice workers throughout an 8 hour workday. Erector spinae SO_2 tended to increase throughout the workday which was inconsistent to previous research. The difference in protocols and lifting tasks among researchers may explain the discrepancy in findings. Yang et al. had a less stressful protocol that persisted throughout the entire workday whereas Kell and Bhambhani's protocol was only 15 minutes of frequent lifting that isolated the erector spinae muscle in order to induce muscle fatigue. The shorter and more frequent muscle contractions increased blood flow to the erector spinae as the demand for oxygen increased.

3.1.3 Long-term standing

The effect of long-term standing on changes in muscle SO_2 has not been widely investigated. Callaghan et al. [34] measured change in oxygenation in the right erector spinae muscle group while subjects stood for 2 hours on a hard surface. While perceived lower back discomfort increased throughout standing, no significant changes in SO_2 were reported. The short duration of time spent standing and the subjective scoring method used for the ratings of perceived discomfort in the lower back could explain the contradiction in results. Perhaps the scoring method inaccurately captured subjects' true discomfort level or 2 hours of standing was not enough time to induce fatigue in the lower back [34]. However, the low intensity contractions exerted by the lower back erector spinae muscle group may not be substantial enough to induce excessive changes in muscle SO_2 during long-term standing. Other muscles that play a role in supporting the body during stance, such as the soleus muscle, may undergo greater changes in SO_2.

Previous research has indicated muscle SO_2 decreases during sustained contractions at submaximal levels. Although Callaghan et al. [34] reported erector spinae SO_2 does not change over 2 hours of standing on a hard surface, it is hypothesized that the implementation of a longer standing protocol will result in significant changes in muscle SO_2 and tHb. The effect of flooring on change in muscle SO_2 and tHb during long-term standing and walking has not been widely investigated. It is hypothesized that flooring will have an effect on muscle SO_2 during long-term standing and walking. Harder flooring surfaces will require higher intensity muscle contractions during long-term standing and walking which will induce greater changes in SO_2.

4.0 INTRODUCTION TO FLOORING

The health problems linked to prolonged standing in the workplace have opened the market for fatigue and discomfort reducing mechanisms. This has led to the commercialization of so called "anti-fatigue" surface mats/tiles that are manufactured specifically to reduce lower extremity fatigue and discomfort. There are several types of mats that are comprised of varying material properties and thicknesses. Anti-fatigue flooring surfaces are designed with the intentions of diminishing pain and discomfort brought on by long-term standing and walking.

Quantifying fatigue and discomfort is essential to understanding the reasons for their onset during prolonged standing. A number of investigators have evaluated the effectiveness of anti-fatigue flooring in reducing subjective and objective measures of fatigue during long-term standing [35–42]. Table 1 provides an updated summary from Redfern and Cham's review paper [43] of researchers who have investigated the influence of flooring on standing comfort and fatigue.

Table 1: Summary of methodologies in standing fatigue studies [43].

Researchers	**Madeleine et al., 1998** [37]	**Cham and Redfern, 2001** [39]	**King, 2002** [40]	**Orlando and King, 2004** [41]	**Wiggermann and Keyserling, 2011** [42]
Study type	lab study	lab study	field study	field study	lab study
Testing duration	2 hours	4 hours	8-hr shift/day	8-hr shift/day	4 hours
Time	1 session/day	1 session/day	5 shifts/condition	5 shifts/condition	1 session/day
Number of subjects	13	10	22	16	10
Independent variables	1 hard floor 1 soft mat	1 hard floor 6 floor mats	1 hard floor 1 floor mat 1 shoe insole	1 wood block 1 floor mat 1 shoe insole	1 hard floor 4 floor mats
Dependent variables	subjective emg (leg) COP shank circumference ankle movement skin temperature	subjective emg (leg and back) leg volume skin temperature	subjective	subjective	subjective COP

4.1 PREVIOUS RESEARCH

4.1.1 Subjective discomfort

Psychological methods involve administering questionnaires that ask subjects to rate levels of perceived discomfort in regions including the upper and lower back, hips, upper and lower legs, knees, feet, and ankles. Some questionnaires include the perception of overall tiredness and the change in floor surface hardness.

Nearly all investigators who have evaluated the effect of flooring on lower extremity discomfort and fatigue have used discomfort questionnaires to obtain ratings of perceived discomfort (RPD). A variety of scaling methods have been applied in long-term standing experiments to measure RPDs including the CR10-Borg scale [39], 5- [40,41], 7- [44], and 10-

[37] point Likert scales, and visual analog scales. Subjects would answer questionnaires which asked them to rate levels of discomfort throughout long-term standing. The rate at which the questionnaires were administered varied from every 15 minutes of standing [37] to the end of each hour [39,44]. Studies that were completed in a factory setting only asked subjects to give RPDs once at the end of the work day [40,41]. Some investigators only collected RPD for general fatigue in a few selected regions [37,38]. Others collected RPD data from the upper and lower back and from multiple regions of the lower extremity including the hips, upper legs, knees, lower legs, ankles, and feet [39–41]. Perception of overall general fatigue, overall leg tiredness, and firmness of floor surface has also been quantified in addition to lower extremity RPD [39–41].

The findings of the effect of flooring on RPDs have been mostly consistent with many investigators concluding that anti-fatigue and soft mats reduce the psychological perception of fatigue and discomfort during long-term standing [37,39,40,42,45]. A summary of the most recent findings are provided in Table 2, a continuation from a table in Redfern and Cham's review paper [43].

Table 2: Statistically significant effect ($p < .05$) of floor and/or shoes on subjective measures of fatigue [43].

	Madeleine et al., 1998 [37]	**Cham and Redfern, 2001** [39]	**King, 2002** [40]	**Orlando and King, 2004** [41]	**Wiggermann and Keyserling, 2011** [42]
overall fatigue	yes-floor	no-floor	yes-floor/insert	no	no
overall leg fatigue	N/A	yes-floor	yes-floor/insert	no	yes-floor
upper back	N/A	no-floor	yes-insert	no	N/A
lower back	N/A	yes-floor	yes-insert	no	yes-floor
hips	N/A	yes-floor	yes-insert	no	N/A
upper legs	N/A	yes-floor	no	no	no
knees	N/A	yes-floor	yes-insert	no	yes-floor
lower legs	N/A	yes-floor	no	no	yes-floor
ankles	N/A	yes-floor	no	no	N/A
feet	N/A	yes-floor	yes-floor/insert	no	yes-floor

Cham and Redfern [39] found significant decreases in subjective discomfort when standing on soft flooring mats compared to a hard reference tile. It was concluded that flooring surface had no impact on subjective discomfort measures until the 3rd and 4th hours of standing. Interestingly, it was observed that reductions in subjective discomfort were not necessarily positively related with stiffness of flooring surface. In other words, anti-fatigue mats that are extremely soft may actually increase subjective discomfort compared to a harder surface. Wiggermann and Keyserling [42] investigated the impact of 4 flooring mats on reducing discomfort during long-term standing. They also found significant decreases in subjective discomfort when standing on soft flooring mats compared to a hard reference tile but no differences between mats were reported. However, the findings are not consistent. Orlando and King [41] found no changes in lower extremity fatigue across flooring and shoe conditions in a field study among factory workers. Discrepancy among investigators may result from differences in protocols such as: duration of standing, type of scaling method, or analysis procedure.

Additionally, the variations in the material properties of the flooring surfaces investigated between studies may have a big impact on the differing results.

Based on previous research findings, it is hypothesized that the implementation of anti-fatigue flooring will reduce the onset of perceived discomfort throughout long-term standing [43]. Additionally, anti-fatigue flooring is expected to reduce perceived discomfort during long-term walking.

4.1.2 Objective measures of fatigue

Subjective measures have difficulty distinguishing between subtle differences among flooring surfaces. It is necessary to measure behavioral responses to muscle fatigue to properly evaluate the effect of fatigue reducing flooring surfaces. There are a number of objective measures that investigators have used to quantify fatigue and discomfort during long-term standing studies. A limited number of researchers have evaluated the flooring effects of long-term standing on objective measures of fatigue over the past decade, as seen in Table 3, a continuation from a table in Redfern and Cham's review paper [43].

Table 3: Statistically significant effect ($p < .05$) of floor/shoes on objective measures of fatigue [43].

Objective Measure	**Madeleine et al., 1998** [37]	**Cham and Redfern, 2001** [39]	**Wiggermann and Keyserling, 2011** [42]
COP	yes-floor	yes-floor	yes-floor
EMG: legs RMS MPF	yes-floor yes-floor	 no	N/A
EMG: back RMS MPF	N/A	 no	N/A
leg volume	N/A	no	N/A
leg and/or foot dimensions	yes-floor	N/A	N/A
skin temperature	no	yes-floor	N/A
ankle movement	yes-floor	N/A	N/A
Performance	N/A	yes-floor	N/A

4.1.2.1 EMG fatigue measures

Surface electrodes can be utilized to monitor muscle activity throughout the duration of a sustained contraction. Electromyography has allowed investigators to track changes in electrical activity throughout the duration of a muscle contraction. The EMG signal can be analyzed in either the time or frequency domain in order to evaluate fatigue. In the time domain, the intensity of the muscle contraction can be measured by tracking the changes in the EMG signal amplitude over time. An indicator of muscle fatigue is an increase in EMG amplitude over a contraction interval. A standard parameter derived from the amplitude is the root mean-square (RMS) which gives a good representation of the total power in the signal. Spectral analysis in the frequency domain of EMG signals is more frequently used to evaluate muscle fatigue. Median power frequency (MPF), estimated from the signal's power spectrum, gives insight to muscle fatigue [46]. Median power frequency is the frequency that splits the power spectrum in half. Fifty percent of the signal's power is contained at lower frequency values. Shifts to lower levels of MPF indicate slower firing rates of muscle fibers which is a result of the recruitment of slow twitch muscle fibers. Therefore, a larger shift to the left of the power spectrum implies greater fatigue [46].

Many researchers have studied changes in muscle activity during long-term standing using surface electromyography (EMG) [35,37–39,47,48]. A few have investigated the effect of flooring on lower extremity muscle fatigue using EMGs. Madeleine et al. [37] measured muscle activity in the tibialis anterior and soleus muscles. Root mean-square amplitude significantly increased in the tibialis anterior and significantly decreased in the soleus when standing on the soft surface compared to a hard surface, while mean power frequency was significantly higher in both muscles when standing on the hard surface compared to the soft surface [37]. Contrarily, Cham and Redfern [39] found no changes in MPF across time and 7 different flooring conditions. Cook et al. [35] compared the amplitude of EMG recordings on the paraspinal and tibialis anterior muscles and found no significant changes among a linoleum tile and soft mat.

The discrepancy across researchers has led to broad conclusions on the effect of flooring on muscle fatigue defined by EMG analysis. A vast difference in the methodology and analysis procedures for collecting and monitoring muscle activity using EMGs have attributed to contradictory findings among investigators. Based on previous research, it is hypothesized that the low intensity contractions experienced during long-term standing are not of the magnitude to induce muscle fatigue over time, as described by EMG parameters [49]. Root mean-square and MPF will not change over time, however it is hypothesized there will be a difference across flooring conditions. The implementation of anti-fatigue flooring will decrease the intensity of muscle contractions and consequently decrease MPF [37].

4.1.2.2 Postural measures

The effect of flooring on postural measures has been monitored during long-term standing studies [37–39,50]. It has been suggested that subjects will be more inclined to shift their body-weight as they experience discomfort brought on by long-term standing [39]. Cham and Redfern [39] tracked subject center of pressure (COP) to analyze the number of lateral weight shifts. They defined a weight shift as a change in the lateral COP beyond 10% of the total distance range seen in the trial. No significant differences ($p < .05$) among 7 flooring surfaces were found during the first 3 hours of standing. However, the hard floor produced a significantly higher number of weight shifts when compared to one of the soft mats during the 4^{th} hour of standing. All other soft mats produced a similar number of weight shifts compared to the hard tile.

Additionally, body-weight distribution between the feet has been used to investigate the effect of flooring on postural movements. Wiggermann [50] defined a body-weight shift as a transition between the following conditions: (1) At least 20% of total body-weight being supported by both the left and right foot, (2) >80% total body-weight being supported by the left foot, (3) >80% total body-weight being supported by the right foot. The number of body-weight shifts significantly increased over time ($p = 0.01$) and a hard surface mat produced a greater number of shifts compared to softer mats and a hard control. No significant differences in body-weight shifts were found between standing on the 3 softest mats investigated and the hard tile. Additionally, foot discomfort, lower back discomfort, and overall leg discomfort was positively correlated to body-weight shifts during standing [50].

Previous research supports that postural movements experienced during long-term standing are positively related to subjective discomfort measures [37,39,50]. Therefore, it is hypothesized that body-weight shifts will increase as subjective discomfort measures increase. Additionally, standing on anti-fatigue flooring has been shown to generate both a similar and different number of body-weight shifts compared to standing on a hard surface depending on the material properties of the floor. The degree of "softness" of the flooring mat selected for this study is average compared to other flooring mats available. These flooring mats have been shown to generate a similar number of body-weight shifts compared to a hard surface tile [39]. It is hypothesized that the number of body-weight shifts generated during long-term standing will be similar across flooring surfaces due to the characteristics of the anti-fatigue flooring used in this study.

5.0 METHODS

5.1 SUBJECT POPULATION

A total of 9 healthy young adults, 5 male and 4 female, completed the testing protocol for standing on a hard tile and 5 of the participants completed 3 testing sessions for each of the 3 flooring conditions. A total of 9 healthy young adults, 5 male and 4 female, completed 3 testing sessions for the walking protocol. Subject information is provided in Table 4.

Inclusion criteria for study participants encompassed being free of the following: balance or dizziness problems, osteoporosis, history of orthopedic problems such as fractured limbs or torn ligaments within the last 3 years, and any neurological, pulmonary, or cardiovascular health problems. All participants had self-verified their ability to walk normally at a self-selected speed without pain and their ability to stand/walk for 2-6 hours. The same brand of shoes and socks were provided to all subjects to wear during the testing duration.

Table 4: Subject information

Mean (SD)	**Standing Protocol**		**Walking Protocol**
	Hard Tile	All Floors	All Floors
Age (y)	23.3 (2.9)	23.0 (3.0)	22.4 (2.3)
Height (m)	1.8 (0.1)	1.8 (0.1)	1.8 (0.1)
Mass (kg)	76.9 (14.3)	81.1 (17.1)	76.7 (15.1)

5.2 EXPERIMENTAL ENVIRONMENT

Standing sessions were completed at the Medical Virtual Reality Center located at the University of Pittsburgh Medical Center - Eye & Ear Institute. Walking sessions were completed at the Human Movement and Balance Laboratory at the University of Pittsburgh.

5.3 EXPERIMENTAL SETUP AND EQUIPMENT

5.3.1 Flooring surfaces

(1) Hard Tile: The hard surface served as the control for the study. The hard flooring condition was considered to be the aluminum surface of the balance plates for the standing protocol, whereas the hard flooring condition for the walking protocol was the vinyl tile embedded in the gait laboratory that had a thickness of 3 millimeters.

Figure 4: Hard flooring surface. (Left) Aluminum balance plate tile served as the hard flooring surface during standing sessions. (Right) Vinyl tile served as the hard flooring surface during walking sessions.

(2) Soft Mat: A standard diamond plated polyvinyl foam mat was defined as the soft flooring condition for both the standing and walking portions of the study. The soft mat had a material thickness of 10 millimeters. Square sections of the mat **(**20 in. x 20 in.) were placed over the balance plate tiles during standing sessions. The soft mat was rolled out on top of the vinyl flooring in the gait laboratory for walking sessions. The pathway had a length of 24 feet and a width of 3 feet.

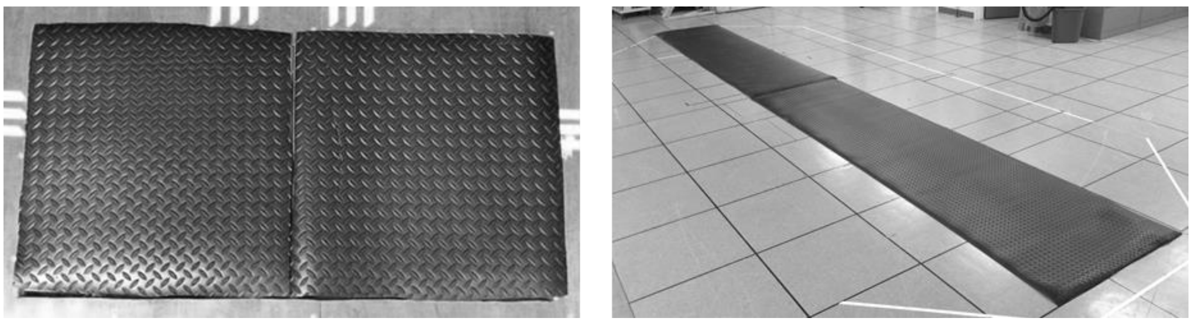


Figure 5: Standard ergonomical soft mat. (Left) Square sections (20 in. x 20 in.) were placed over balance plate tiles during standing sessions. (Right) The soft mat was rolled out on top of the vinyl flooring in the gait laboratory for walking sessions (length 24 ft.; width 3 ft.).

(3) Rubber Tile: A rubber tile was used as the 3rd flooring condition for both the standing and walking portions of the study. The tile had a material thickness of 3 millimeters. Square sections of the rubber tile **(**20 in. x 20 in.) were placed over the balance plate tiles during standing sessions. Rubber tiles were installed in the gait laboratory for walking sessions. The pathway had a length of 24 feet and a width of 4 feet.

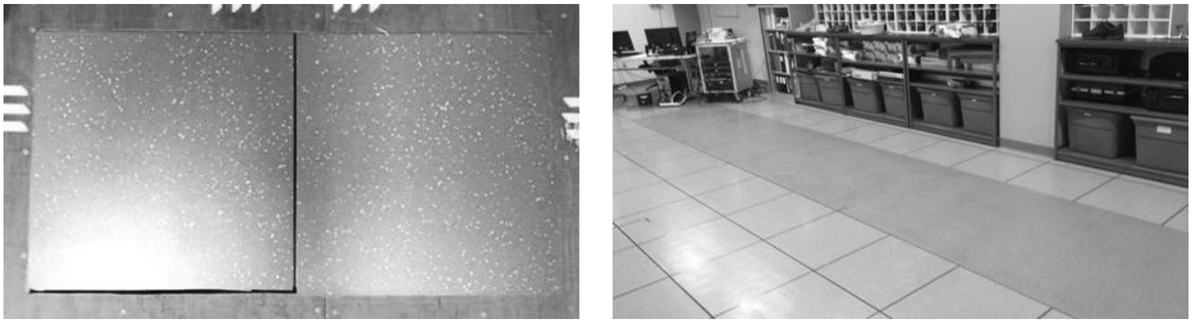
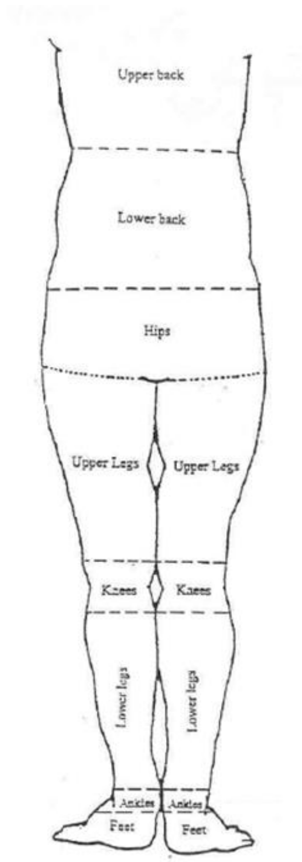


Figure 6: Rubber tile flooring surface. (Left) Square sections (20 in. x 20 in.) were placed over balance plate tiles during standing sessions. (Right) Rubber tiles were installed in the gait laboratory for walking sessions (length 24 ft.; width 4 ft.).

5.3.2 Discomfort questionnaire

Surveys were administered to subjects throughout testing sessions to monitor ratings of perceived discomfort (RPDs). The survey asked subjects to rate floor surface softness, overall tiredness, overall leg tiredness, and perceived discomfort in the following body segments: upper and lower back, hips, upper legs, knees, lower legs, ankles, and feet. Ratings of perceived discomfort were based on the nonlinear CR10-Borg scale which ranged from 0 (No discomfort at all) – 10 (Extremely stressful) [51]. Values of 11, "~" and "▪" were also a scaling option that represented maximum stress levels.



RPD	Description
0	No discomfort at all
0.3	
0.5	Extremely comfortable
1	Very comfortable
1.5	
2	Fairly comfortable
2.5	
3	Somewhat stressful
4	
5	Stressful
6	
7	Very stressful
8	
9	
10	Extremely stressful
11	
~	
▪	Maximally stressful

Figure 7: Discomfort survey administered to subjects throughout long-term standing and walking. Ratings of perceived discomfort were based on the CR10-Borg scale [51].

A baseline questionnaire was administered during the first 5 minutes of standing in the overall session. Subsequent questionnaires were administered halfway through and at the end of each hour of standing to accumulate to a total of 13 ratings. Questionnaires were administered during the 5 minute standing baseline and the following 5 minute standing rest breaks for a total of 5 ratings during walking sessions.

5.3.3 NIRS

Muscle SO_2 was measured using a frequency domain multi-distance NIRS system (Imagent, ISS, Champaign, IL). NIRS probes were placed on the dominant side of the lower back erector spinae muscle group at the L3 vertebrae level approximately 2 cm away from the spinal column and the lateral soleus muscle.

Figure 8: Erector spinae (left) and soleus (right) muscle NIRS probes placement.

Before each testing session, the probes were calibrated to a phantom with a known absorption coefficient. The probes consisted of 4 light-emitting diodes that operated at 2 wavelengths (690 and 830 nm) and 2 phase-sensitive detectors, as seen in Figure 9. The near infrared light was modulated at a frequency of 110 MHz and collected at a sampling rate of 1.2 Hz.

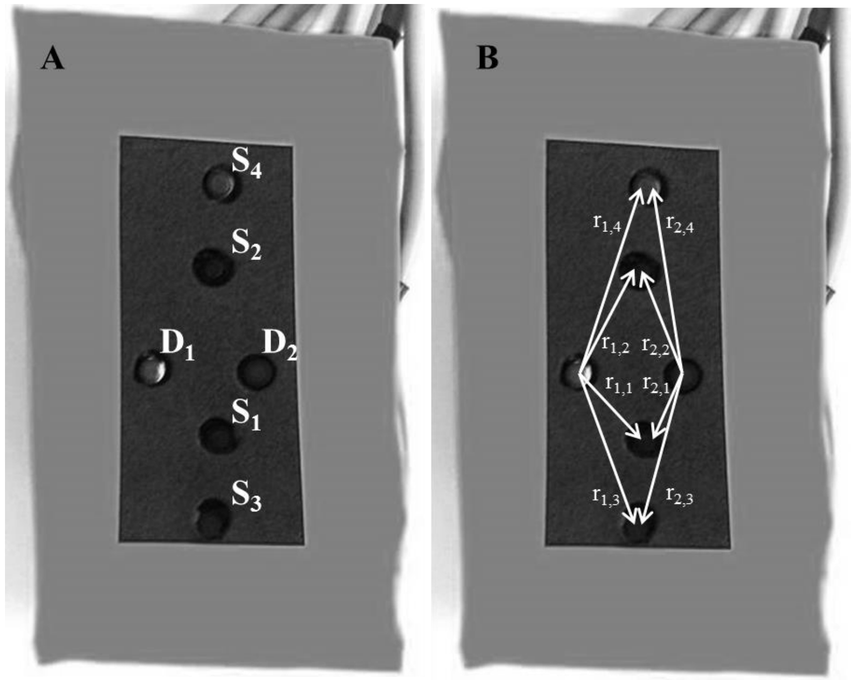


Figure 9: (A) Line orientation probe design with 4 light emitting diodes ($S_{1\text{-}4}$) and 2 phase sensitive detectors (D_1 and D_2). (B) Source-detector separation distance diagram for each detector.

The line orientation design was chosen for both the erector spinae and soleus probes. The source-detector (S-D) separation distances are shown in Table 5.

Table 5: Separation distances between source and detector for NIRS probes used in this study

	Erector Spinae Probe		**Soleus Probe**	
S-D separation	Detector 1	Detector 2	Detector 1	Detector 2
r_1 (cm)	1.3	1.5	1.3	1.5
r_2 (cm)	1.7	1.9	1.6	1.7
r_3 (cm)	2.7	2.8	2.5	2.9
r_4 (cm)	3.1	3.2	3.0	3.2

Equations 6 and 7 involving frequency domain parameters U_{ac} and Φ were chosen to estimate μ_a and μ_s'. Four S-D separation distances were used to estimate the slopes of the linear relationships of the frequency domain parameters as a function of r. In some circumstances, the 4^{th} distance was removed from the analysis if the fitted line had a poor coefficient of determination (R^2) value. Concentrations of HbO_2 and Hb were estimated using equations 11 and 12 and the percent muscle SO_2 was estimated by equation 13

5.3.4 Electromyography

Muscle activity was monitored for both standing and walking protocols on the subject's dominant side. The muscles monitored and the placements of the surface electrodes are shown in Table 6 and Figure 10.

Table 6: Surface EMG placement

Muscle	EMG Placement
1. Rectus femoris:	50% of the distance from the ASIS to the superior patella
2. Tibialis anterior:	15% of distance from the tuberosity of tibia to the inter-malleoli line
3. Soleus:	76% of the distance from the tibial tuberosity to the medial achilles tendon insertion
4. Medial hamstrings:	36% of the distance from the ischial tuberosity to the to the medial popliteus cavity
5. Erector spinae:	L3 vertebrae level approximately 2 cm away from the spinal column

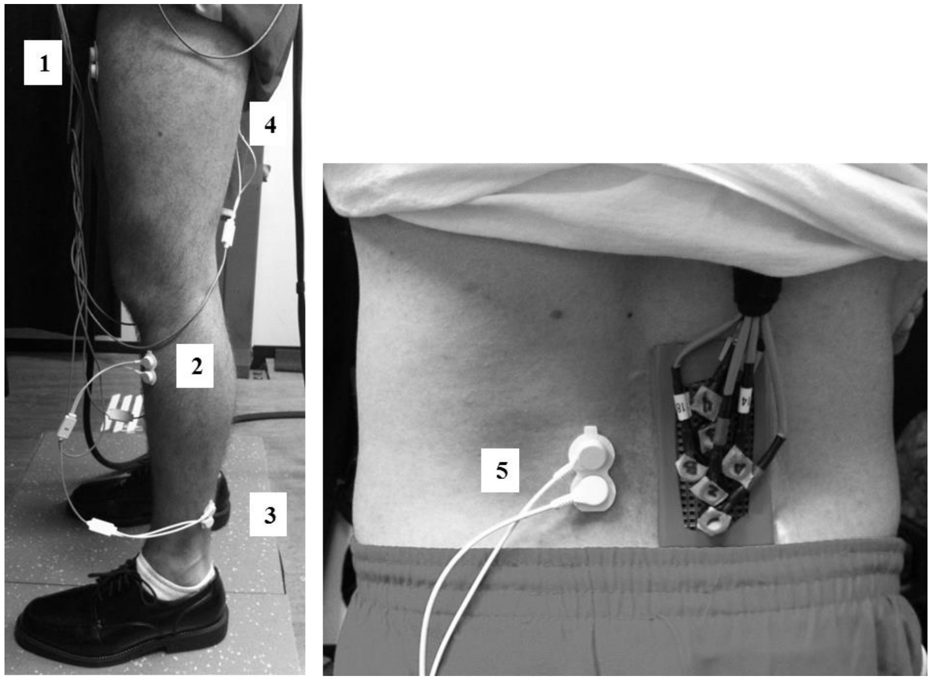


Figure 10: Surface electrode muscle placement. (1) rectus femoris, (2) tibialis anterior, (3) soleus, (4) medial hamstrings, (5) erector spinae

Electromyography data was collected using bipolar surface EMG electrodes and a Noraxon Telemyo 8-channel electromyography system (900, Noraxon, Scottsdale, Arizona) with an internal cutoff of 10-500 Hz. Before positioning the electrodes, the subject's skin was shaved and rubbed with an alcohol swab. The EMGs recorded muscle activity at a sampling rate of 1000 Hz.

5.3.5 Balance Plates

Two balance plates (BP5050, Bertec Corporation, Columbus, OH) were used to track postural movements during standing at a sampling rate of 1000 Hz.

5.4 EXPERIMENTAL DESIGN AND PROCEDURE

Each participant completed 3 testing sessions for both the standing and walking portions of the study. Subjects stood/walked on each of the 3 different flooring conditions. The order of the flooring conditions for the standing/walking sessions was randomized. A minimum time of 96 hours (4 days) between testing sessions was used to allow ample time for recuperation between sessions.

Standing: The standing sessions began with a 2 minute seated baseline followed by 6 consecutive hours of standing. Subjects were instructed to maintain ground contact with both feet the entire time but no other instructions were provided. Two minute seated breaks were given after each hour of standing and an additional 2 minute rest break per hour was permitted upon request. Any break longer than 4 minutes per hour disqualified the subject from the study. A cart was placed directly in front of study participants to provide room for task materials but they were instructed not to rest their weight or lean on the cart. Subjects were permitted to do work on a laptop computer, watch movies, or read while standing.

Walking: The walking sessions began with a 2 minute seated baseline followed by a 5 minute standing baseline. The walking protocol consisted of four 30 minute periods of walking to accumulate to a total of 2 hours. Subjects walked around in a gait lab in a figure eight pattern at a self-selected speed. At the end of each 30 minute walking period, subjects were instructed to stop walking and remain standing for 5 minutes while maintaining ground contact with both feet.

5.5 VARIABLES OF INTEREST

5.5.1 Subjective discomfort

Subjective discomfort measures were obtained for overall tiredness, overall leg tiredness, upper and lower back discomfort, hip discomfort, upper leg discomfort, knee discomfort, lower leg discomfort, ankle discomfort, and feet discomfort throughout standing and walking. The RPDs were transformed to a linear scale that ranged from 6-23, where a rating of 6 represented no discomfort at all [51]. The responses were normalized to the first survey response that was given during the initiation of the standing and walking protocols.

5.5.2 NIRS measures

Standing: Muscle SO_2 and tHb were calculated using computer software (Matlab R2012a) for both detectors on each of the two probes. A 4^{th} order low-pass filter with a cutoff frequency of 0.15 Hz was applied to the signal before analysis. The output from one detector from each probe was chosen after visual comparison. Muscle SO_2 and tHb were normalized to the average SO_2 and tHb during the 2 minute seated baseline. The mean muscle SO_2 and tHb were analyzed in 1 minute periods around the time each survey was administered at the beginning of the first hour, and the middle and end of each subsequent hour of standing.

Walking: Muscle SO_2 and tHb were calculated using computer software (Matlab R2012a) for both detectors on each of the two probes. The data was filtered at 0.15 Hz before analysis and the output from one detector from each probe was chosen after visual comparison. Muscle SO_2 and tHb were normalized to the average SO_2 and tHb during the 2 minute seated baseline. The mean muscle SO_2 and tHb were analyzed during the final 1 minute of the standing baseline and the final 1 minute period of each half hour of walking.

5.5.3 EMG fatigue measures

MPF: The raw EMG signals were downsampled to 840 Hz. A notch filter was applied at 60 Hz and its harmonics in order to remove power line noise from data collection. The soleus EMG signal was high-pass filtered at 20 Hz while the erector spinae EMG signal was high-pass filtered at 30 Hz in order to eliminate ECG noise [52]. The MPF was then estimated between 0-275 Hz in 1 minute periods for each hour of standing.

RMS: The raw EMG signals were downsampled to 840 Hz. A 4^{th} order low-pass filter was applied with a cutoff frequency at 10 Hz in order to obtain an envelope of the signal's amplitude. The RMS was then estimated in 1 minute periods for each hour of standing.

5.5.4 Postural measures

Body-weight shifts: The total force output from each balance plate was used to calculate the distribution of total body-weight on the left and right feet during standing. Three conditions describing weight distribution during standing were previously defined by Wiggermann [50]: (1) At least 20% of total body-weight being supported by both the left and right foot, (2) >80% total body-weight being supported by the left foot, (3) >80% total body-weight being supported by the right foot. A weight shift was counted when there was a change in weight distribution between any of the three conditions. Body-weight shifts that occurred less than 7.5 seconds apart were considered to be a continuation of 1 shift. The total number of shifts was estimated in 30 minute intervals throughout standing.

COP path length: COP path length was used to investigate the relationship between muscle SO_2 and postural measures. The net COP was estimated throughout the duration of the standing protocol. The raw balance plate signals were downsampled to 20 Hz. A 4^{th} order low-pass filter was applied with a cutoff frequency of 5 Hz. Within each hour of standing, the COP path length was estimated in 5 minute intervals:

$$\text{COP pathlength} = \sum_{i=2}^{N} \sqrt{(\text{COPx}_i - \text{COPx}_{i-1})^2 + (\text{COPy}_i - \text{COPy}_{i-1})^2} \qquad 14)$$

where COPx and COPy represent the net COP in the medial/lateral and anterior/posterior directions. For the correlation analysis between postural measures and muscle SO_2, the mean SO_2 was estimated during the final 60 seconds of each 5 minute interval (i.e. the mean muscle SO_2 from minute 4 to minute 5 corresponded to the total COP path length from time 0 to minute 5). The change in these parameters from the previous 5 minute interval was estimated within each hour of standing (ΔPL and ΔSO_2).

$$\Delta \text{PL}_i = \text{mean}(\text{COP path length})_i - \text{mean}(\text{COP path length})_{i-1}, \quad \text{for i} = 2, 3,4 \ldots 12 \qquad 15)$$

$$\Delta SO_{2_i} = \text{mean}(\text{SO}_2)_i - \text{mean}(\text{SO}_2)_{i-1}, \quad \text{for i} = 2, 3,4 \ldots 12 \qquad 16)$$

5.6 STATISTICAL ANALYSIS

All statistical analyses were performed using JMP version 10.0 (Cary, North Carolina).

Specific Aim 1: To investigate the association between muscle oxygenation and fatigue during long-term standing.

H.1) Muscle oxygenation in the lower back erector spinae and soleus muscles will change throughout the duration of long-term standing as greater levels of subjective muscle fatigue and discomfort are reported.

Subjective measures of discomfort (RPDs) and the behavioral responses (muscle SO_2/tHb and postural measures) collected during long-term standing on a hard tile were statistically compared to determine if the variables of interest changed over time at the periods analyzed. Analysis of variance (ANOVA) models were fit with RPDs, muscle SO_2/tHb, and postural measures as response outcomes. The effect of subject and time standing (at the periods analyzed) were included in the models. Additionally, Tukey comparison tests were performed when duration of standing was significant. Finally, a correlation analysis was performed using pairwise comparisons to determine the relationship between the subjective measures and behavioral responses. Statistical significance was determined at $p \leq 0.05$.

Specific Aim 2: To examine the impact of flooring on subjective and objective measures of fatigue and discomfort during long-term standing/walking.

H.1) Implementation of anti-fatigue flooring will reduce the onset of perceived lower extremity discomfort throughout long-term standing/walking.

H.3) Total number of body-weight shifts is expected to be similar during long-term standing across flooring surfaces.

H.4) Lower back erector spinae and soleus muscles will experience greater changes in muscle oxygenation during standing/walking on a hard surface when compared to standing/walking on anti-fatigue flooring.

Subjective measures of discomfort (RPDs) and the behavioral responses (muscle SO_2/tHb and postural sway measures) collected during long-term standing and walking were statistically compared to determine if type of flooring surface impacted the variables of interest. Analysis of variance models were fit with RPDs, muscle SO_2/tHb, and postural sway measures (standing sessions) as response outcomes. The effect of subject, flooring surface, time standing/walking (at the periods analyzed), and the interaction of flooring surface with time standing/walking were included in the models. Separate ANOVA models were fit to determine the effect of time standing/walking on the response outcomes by flooring surface. Additionally, the effect of flooring condition on the response outcomes was tested at each analysis period of time standing/walking. Tukey comparison tests were performed when the outcome of the ANOVA tests were significant. Finally, a correlation analysis was performed using pairwise comparisons to determine the relationship between the subjective discomfort measures and behavioral responses. Statistical significance was determined at $p \leq 0.05$.

H.2) Lower back erector spinae and soleus muscles will undergo higher intensity muscle contractions when standing on a hard tile compared to anti-fatigue flooring.

A qualitative data analysis was performed to search for trends in erector spinae and soleus EMG fatigue measures (MPF and RMS). Median power frequency and RMS were plotted against time standing. The figures were visually examined to investigate the effect of time and flooring surface on MPF and RMS.

6.0 RESULTS

6.1 LONG-TERM STANDING ON A HARD SURFACE

6.1.1 Subjective discomfort

The subjective ratings of perceived discomfort were transformed to a linear scale ranging from 6 to 23 [51] and normalized to the first discomfort survey response for each segment. The mean RPDs is plotted at each period the discomfort survey was administered during standing (Figure 11).

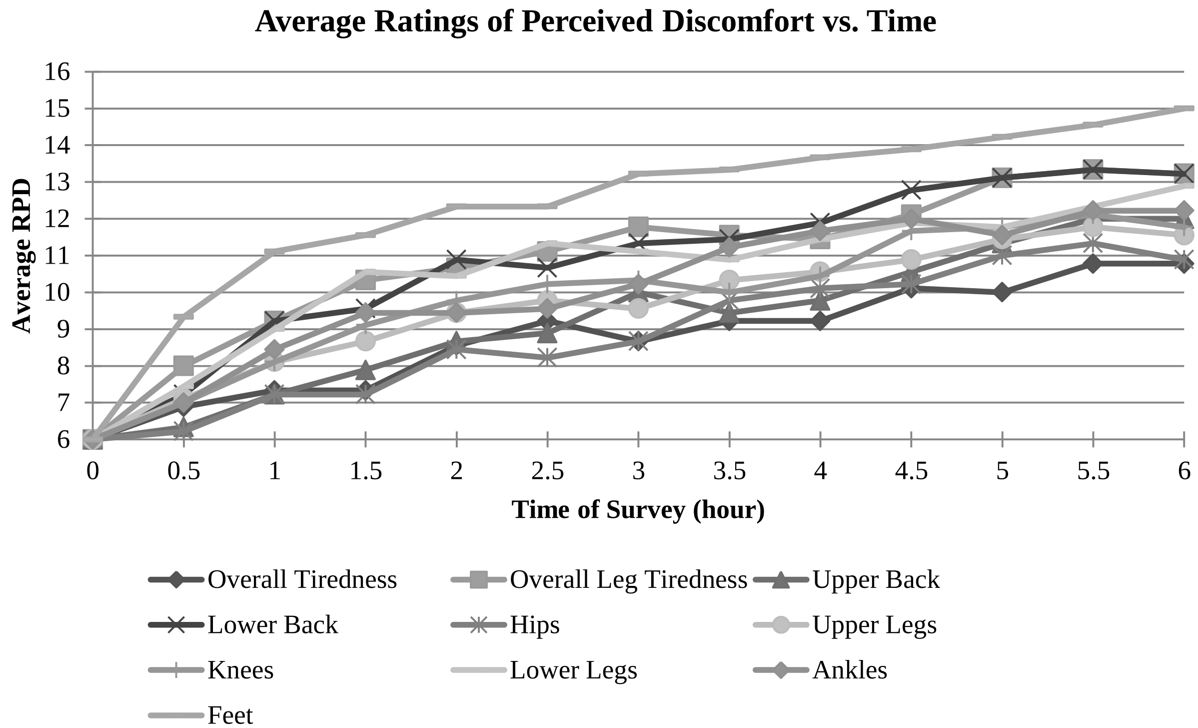


Figure 11: Average subjective discomfort ratings (RPD) versus time during long-term standing on a hard tile. Average discomfort ratings increased over time for each body region and general tiredness.

The effect of time standing was significant ($p < .0001$) for all subjective measures of discomfort. Overall leg tiredness and feet discomfort significantly increased from the start of the standing session to just after 30 minutes of standing. Additionally, 2 hours of standing yielded significant increases in discomfort ratings for general tiredness and all body regions excluding the hips. In general, feet discomfort was the most affected body region and had more cumulative discomfort than any other region (mean RPD = 12.3, $p < .0001$) followed by overall leg tiredness (mean RPD = 10.9), lower back (mean RPD = 10.8), and lower leg (mean RPD = 10.5) discomfort (Figure 12).

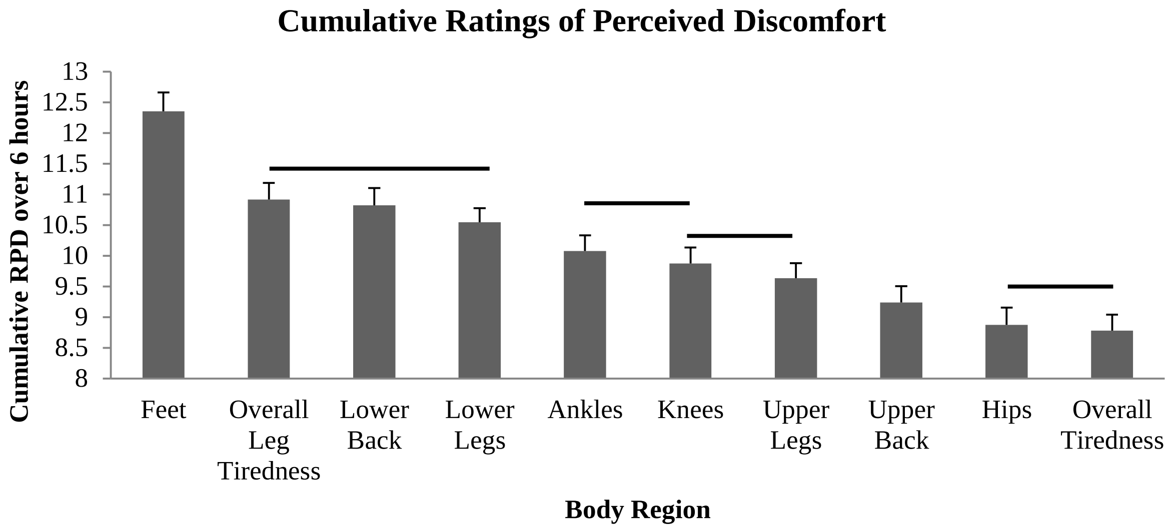


Figure 12: Cumulative subjective discomfort ratings averaged across subjects during 6 hours of standing on a hard tile. Feet discomfort was the most affected body region. Horizontal bars indicate no significant difference in discomfort between regions. (Standard error bars)

6.1.2 NIRS measures

Muscle SO_2 and tHb were normalized to the average muscle SO_2 and tHb during the resting baseline before the standing protocol. The average erector spinae (Figure 13) and soleus (Figure 14) SO_2 and tHb are plotted for each time point during standing.

In general, the erector spinae experienced large variations in SO_2 within each hour and across the entire duration of standing. The effect of time standing was significant for erector spinae SO_2 for the periods analyzed. Average erector spinae SO_2 at the end of the 3rd hour and the end of the 6th hour were significantly higher than the average erector spinae SO_2 measured at the middle of the 1st hour of standing ($p = .0188$ and $p = .0356$, respectively). Erector spinae tHb at the periods analyzed was not affected by duration of standing.

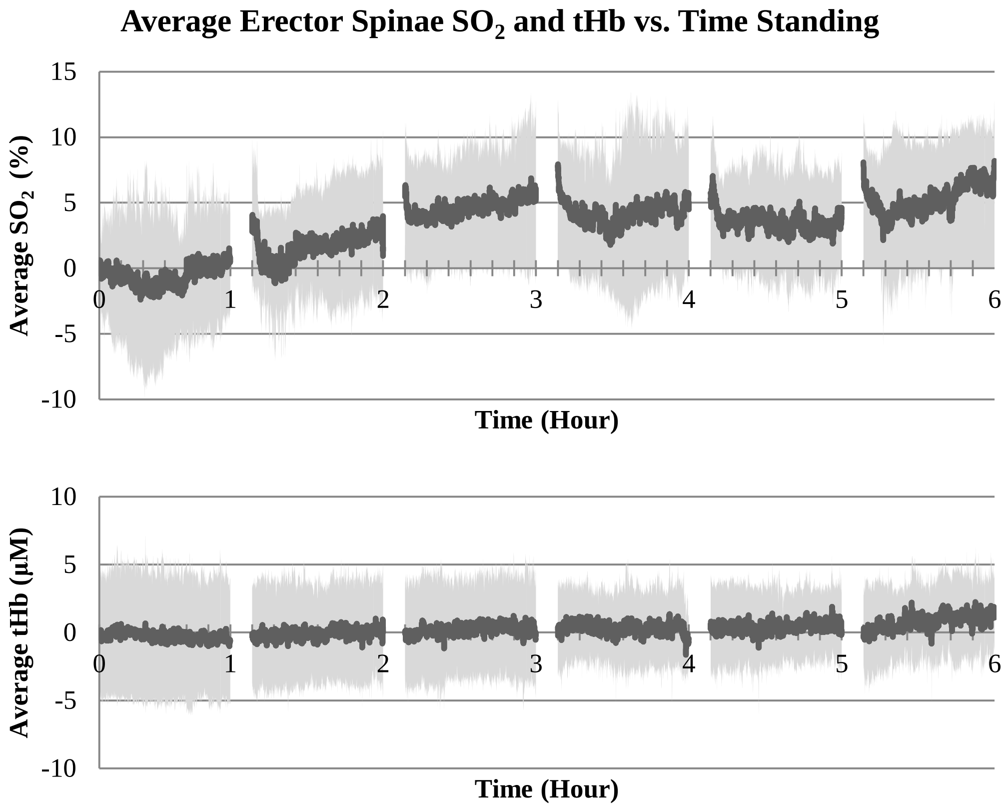


Figure 13: Average erector spinae muscle SO_2 (top) and tHb (bottom) versus time standing on a hard tile. The breaks in the data represent the 2 minute seated rest breaks. Erector spinae SO_2 gradually increased over time while tHb generally remained similar to resting values. Shaded areas represent ± 1 standard deviation.

The average soleus SO_2 and tHb at the periods analyzed were not affected by time standing. However, trends in soleus SO_2 were observed. Soleus SO_2 tended to decrease during the beginning of each hour of standing. This initial decline in oxygenation would eventually plateau or begin to recover back to resting values. Soleus tHb tended to increase compared to resting values during the seated baseline and experienced little change within each hour of standing.

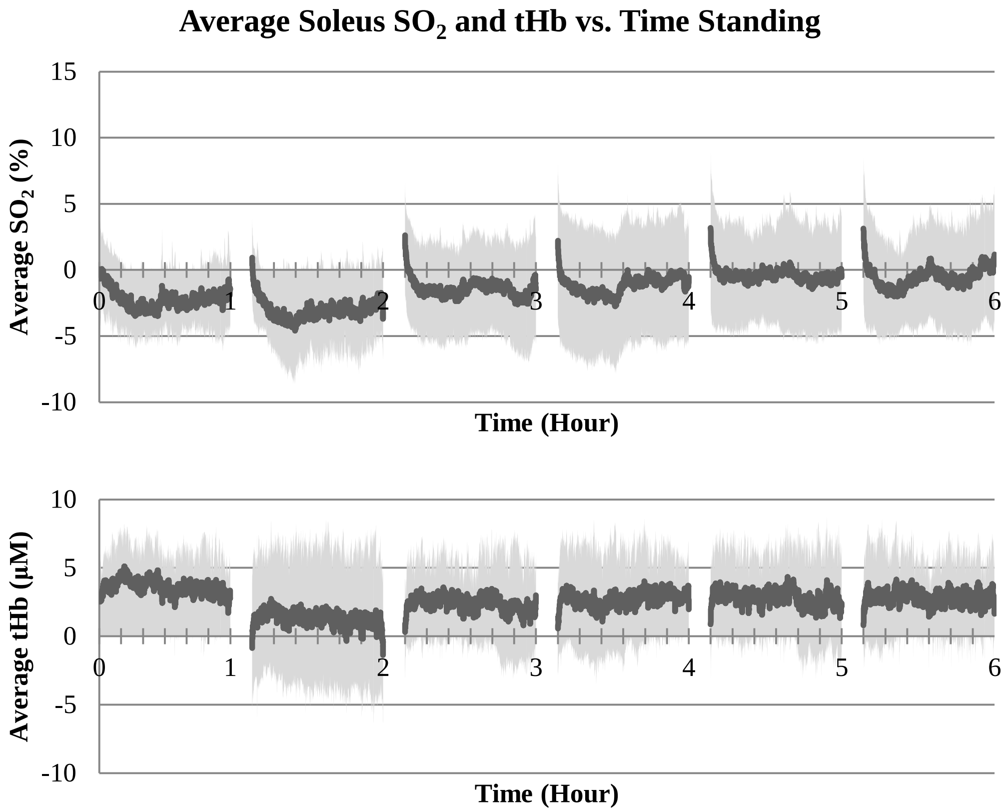


Figure 14: Average soleus SO_2 (top) and tHb (bottom) versus time standing on a hard tile. The breaks in the data represent the 2 minute seated rest breaks. No significant differences in soleus SO_2 and tHb were found over time. Soleus SO_2 tended to gradually decrease at the beginning of each hour and then eventually level off while tHb tended to initially increase. Shaded areas represent ± 1 standard deviation.

6.1.3 Postural measures

Postural movements were quantified by the total number of body-weight shifts in 30 minute intervals throughout standing. The conditions for a shift in body-weight were previously defined in section 3.5.4. The total number of shifts during each period of standing is shown in Figure 15.

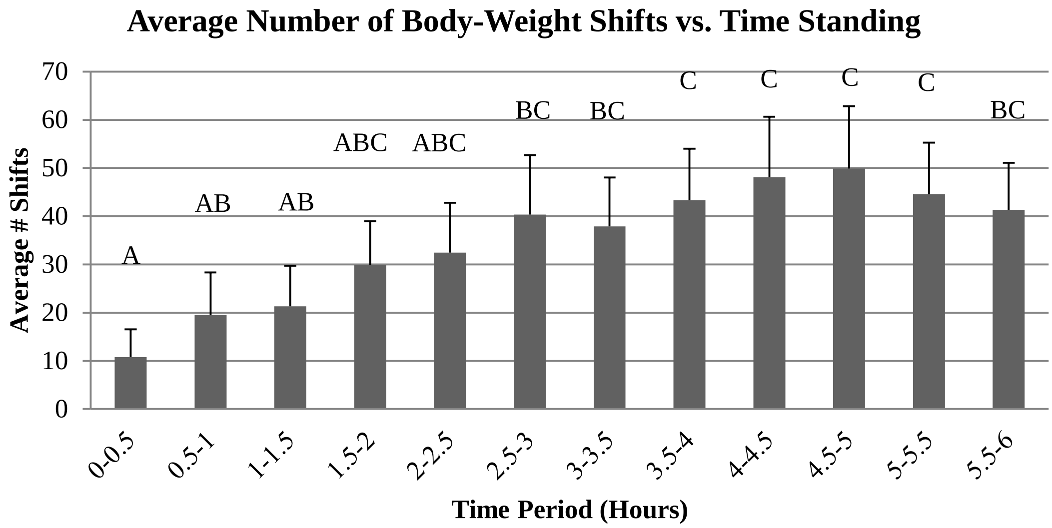


Figure 15: Average number of body-weight shifts in 30 minute intervals during 6 hours of long-term standing on a hard tile. The effect of time standing was significant. Statistically similar number of shifts between time period intervals is noted by similar letters (A, B, and C). (Standard error bars)

The effect of time standing was significant for the number of body-weight shifts ($p < .0001$). The lowest number of body-weight shifts on average across the subjects was during the first 30 minutes (10.8) of standing. The outcomes of the Tukey comparison tests revealed that the number of body-weight shifts within each 30 minute interval did not significantly increase until the interval from 2.5 to 3 hours (37.9) of standing ($p = .0011$). The most number of shifts on average across subjects occurred during the interval from 4.5 to 5 hours (49.9).

6.1.4 Correlation analysis

Pairwise correlations were performed to examine relationships between the subjective discomfort ratings and the behavioral responses (muscle SO_2 and number of body-weight shifts). The subjective discomfort ratings were considered to be the independent variables and the behavioral responses were the dependent variable. Erector Spinae SO_2 was compared to subjective discomfort ratings for the lower back region and soleus SO_2 was compared to subjective discomfort ratings for the lower leg region. A significant relationship was found between lower back discomfort and erector spinae SO_2 ($r = 0.33$, $p = .0007$). An increase in lower back discomfort was associated to an increase in erector spinae SO_2 during standing. No relationship was found between lower leg discomfort and soleus SO_2 ($r = -.05$).

Pairwise correlations were performed to compare subjective discomfort ratings for lower extremity discomfort and number of body-weight shifts (Table 7). The correlation analysis revealed a significant relationship between the number of body-weight shifts and overall leg tiredness ($r = .25$, $p = .0079$), hip discomfort ($r = .32$, $p < .0007$), upper leg discomfort ($r = .25$, $p = .0081$), lower leg discomfort ($r = .53$, $p < .0001$), ankle discomfort ($r = .36$, $p = .0001$), and feet discomfort ($r = .56$, $p < .0001$). No relationship was found between knee discomfort and body-weight shifts ($r = .10$).

Table 7: Relationship between lower extremity subjective discomfort ratings and number of body-weight shifts during 6 hours of long-term standing on a hard tile. (* indicates significant relationship)

Pearson coefficient (r)		**Number of Body-Weight Shifts**
		Hard Tile
Body Region	**Overall Leg Tiredness**	r = .25*
	Hip Discomfort	r = .32*
	Upper Leg Discomfort	r = .25*
	Knee Discomfort	r = .10
	Lower Leg Discomfort	r = .53*
	Ankle Discomfort	r = .36*
	Feet Discomfort	r = .56*

For each case, increases in subjective discomfort ratings were associated to increases in body-weight shifts over 6 hours of standing. The body regions with the strongest agreement with number of body-weight shifts were lower leg discomfort and feet discomfort.

Finally, a correlation analysis was performed to investigate the relationship between behavioral responses (muscle SO_2 and postural sway measures). Center of pressure path length was used to describe postural sway. Pairwise correlations were performed on the change in COP path length (ΔPL) and muscle SO_2 (ΔSO_2) at the beginning, middle and end of each hour (Figure 16).

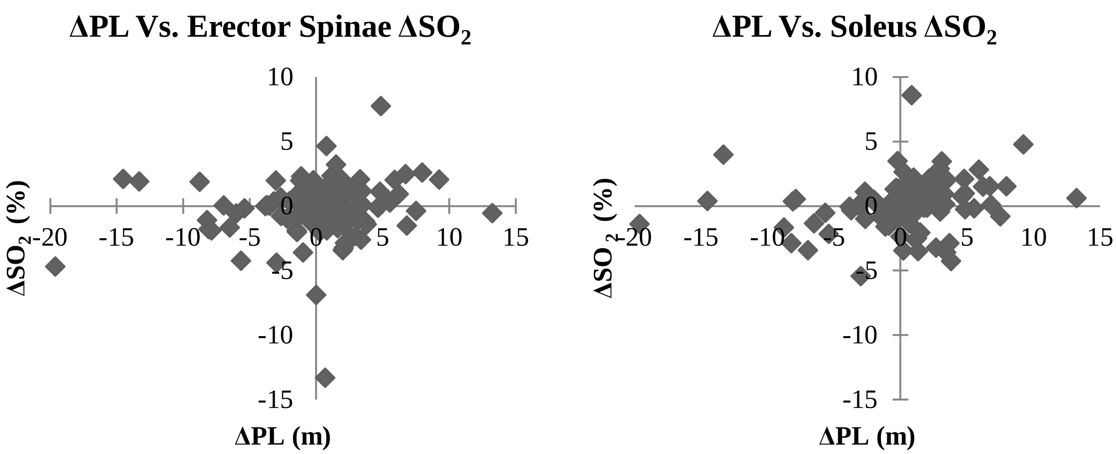


Figure 16: Relationship between ΔPL and ΔSO_2 during 6 hours of long-term standing on a hard tile. A significant relationship was found between soleus SO_2 and COP path length ($r = .20$, $p = .0223$) and a trend was found between erector spinae SO_2 and COP path length ($r = .16$, $p = .0564$). Increases in muscle SO_2 corresponded to an increase in COP path length.

The correlation analysis revealed a significant relationship between ΔPL and ΔSO_2 in the soleus ($r = .20$, $p = .0223$). An increase in ΔPL was associated with an increase in soleus ΔSO_2. The correlation analysis did not reveal a significant relationship between ΔPL and ΔSO_2 in the erector spinae but a trend was observed ($r = .16$, $p = .0564$). An increase in ΔPL tended to correspond with an increase in erector spinae ΔSO_2.

6.2 FLOORING EFFECT ON LONG-TERM STANDING

6.2.1 Subjective discomfort

No interaction effect was found between flooring surface and time standing for the subjective discomfort ratings. The ANOVA revealed time standing as a significant effect for all flooring surfaces ($p < .0001$) (Figure 17). Separate ANOVA was performed to test the impact of flooring surface on subjective discomfort ratings by time standing. Tukey comparison tests revealed that flooring surface had no significant impact on subjective discomfort ratings at the standing periods analyzed except for upper back discomfort in the middle of the third hour where the soft mat reduced discomfort compared to the hard tile ($p = .0187$).

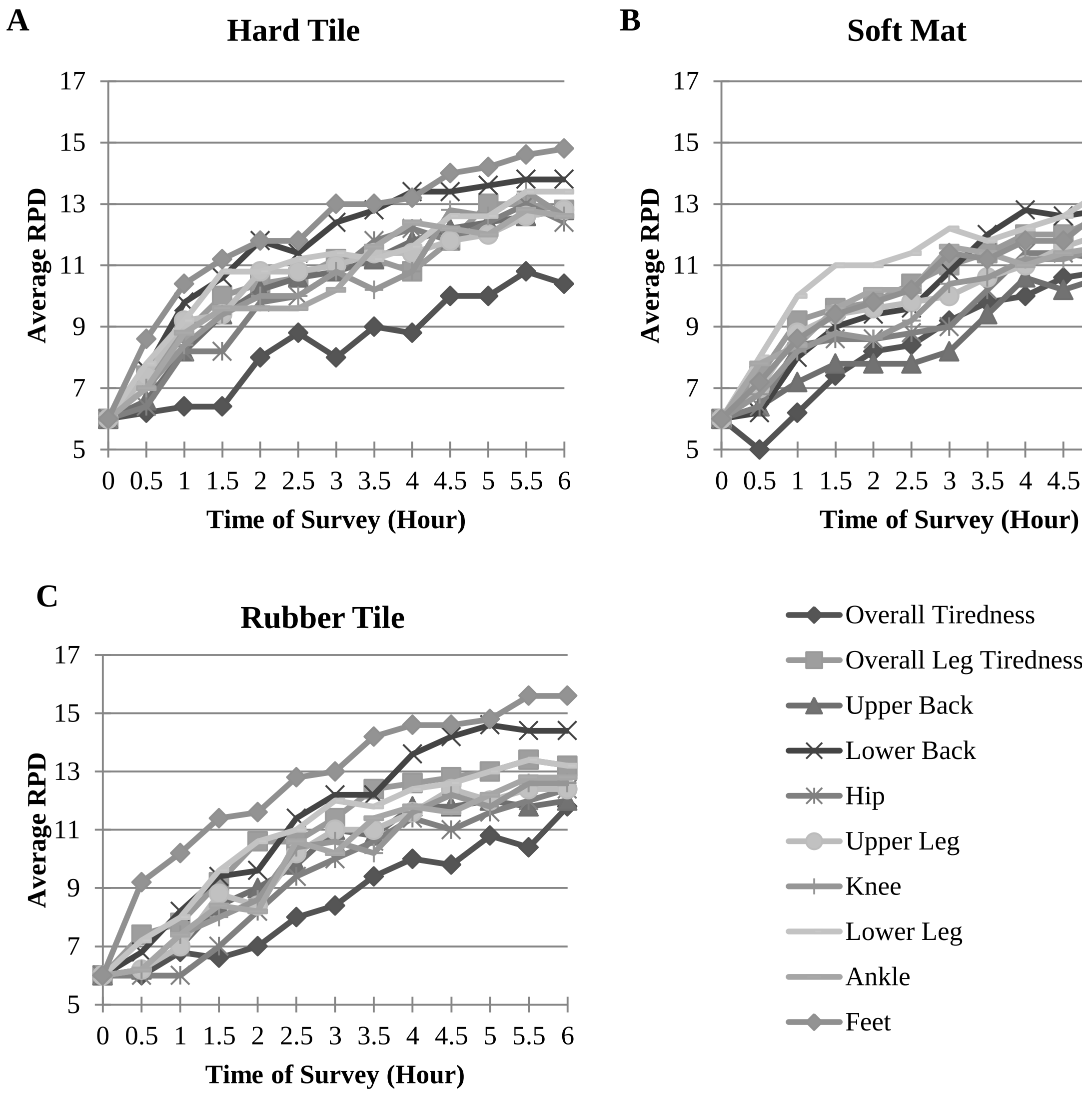


Figure 17: Average subjective discomfort ratings (RPD) versus time standing on a hard tile (A), soft mat (B), and rubber tile (C). The effect of time standing was significant for each subjective discomfort rating across all flooring surfaces.

Finally, the impact of flooring surface on cumulative subjective discomfort ratings over 6 hours was tested. An ANOVA model was fit that contained subjective discomfort ratings as the response and included the effects of subject and flooring surface. The effect of flooring surface was significant for the upper back ($p = .0021$) and the feet ($p = .0004$). Standing on the soft mat significantly decreased cumulative upper back discomfort compared to standing on the hard tile ($p = .0015$). Similarly, standing on the soft mat decreased cumulative feet discomfort compared to standing on the hard tile ($p = .0004$) and the rubber tile ($p = .0117$). Flooring surface did not affect subjective discomfort ratings for general tiredness or any other body region (Figure 18).

General trends in cumulative subjective discomfort ratings by a function of flooring surface were noticed (Figure 18). Standing on the hard tile created the greatest cumulative discomfort for most of the body regions (upper back, lower, back, hip, upper leg, knees, and ankles). The soft mat generated the least cumulative discomfort in the upper back, lower back, knee, and feet regions. The rubber tile generated the least cumulative discomfort in the hip, upper leg, lower leg, and ankle regions.

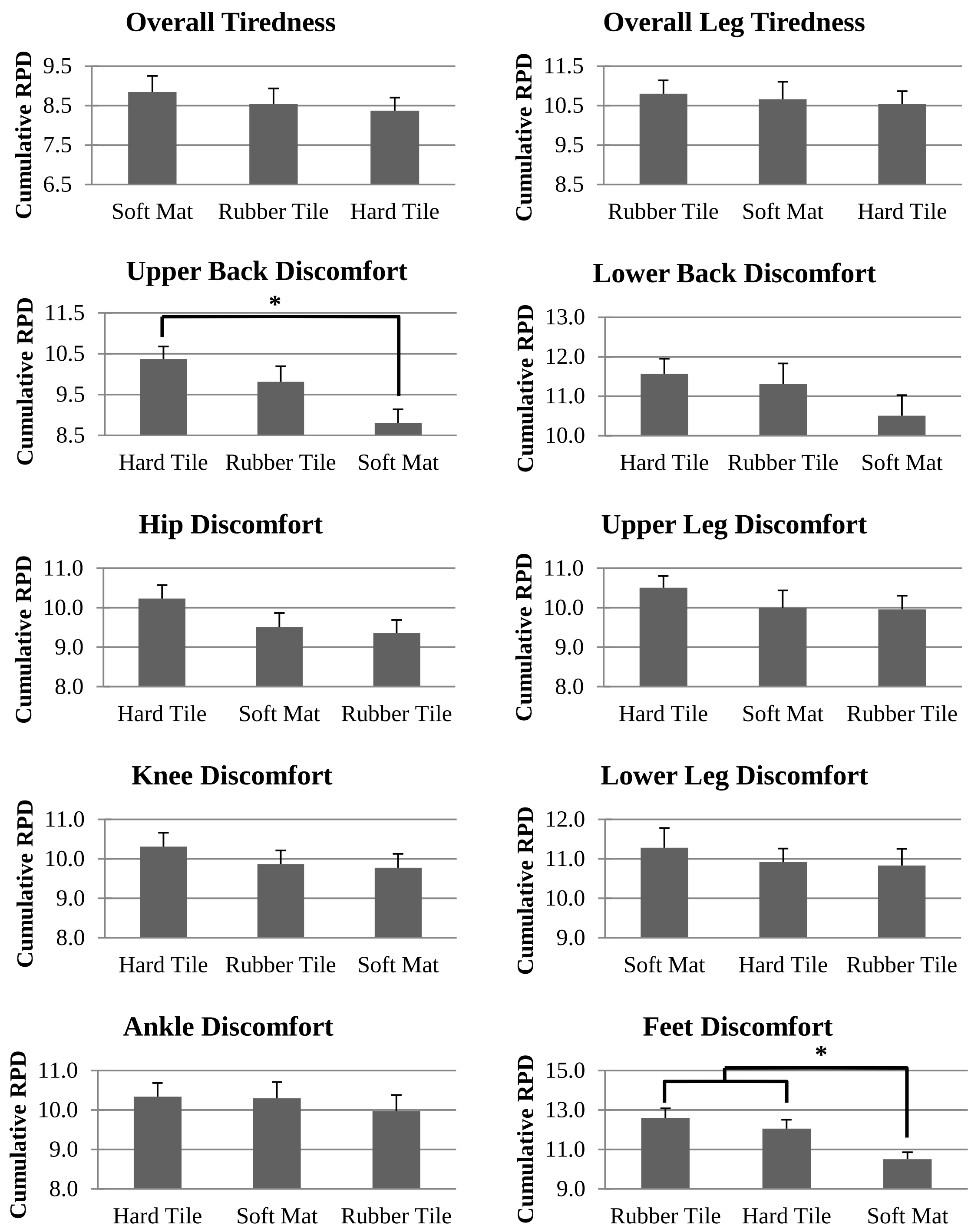


Figure 18: Cumulative subjective discomfort ratings over 6 hours of standing averaged across subjects as a function of flooring surface. Significant differences were found in upper back discomfort and feet discomfort across flooring surfaces. (Standard error bars)

6.2.2 EMG fatigue measures

Post processing of the EMG signals was previously described in section 3.5.3. A qualitative analysis was performed to investigate the impact of flooring surface on MPF and RMS in the soleus and erector spinae muscles during long-term standing.

Erector spinae MPF and RMS is plotted against time for an example subject (S13) (Figure 19). The gaps in the data represent the seated rest breaks given to the subjects after every hour of standing. Large changes in MPF were noticed within each hour of standing but overall no clear trend in MPF could be determined. Similarly, RMS tended to vary within each hour of standing but generally remained at a constant value over the 6 hours of standing. No clear differences across flooring surfaces were noticed.

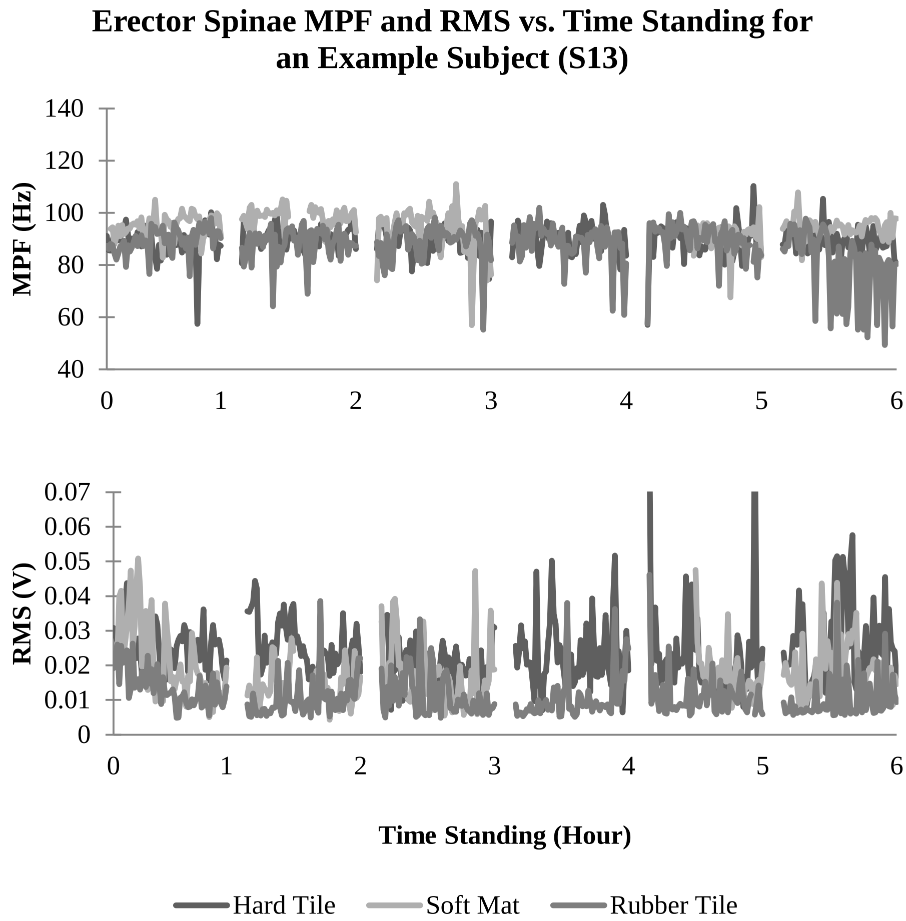


Figure 19: Erector Spinae MPF and RMS for an example subject (S13) during 6 hours of long-term standing. No trends in MPF and RMS were observed over time and across flooring surfaces.

Soleus MPF and RMS is plotted against time for an example subject (S10) (Figure 20). Small changes in MPF were noticed within each hour of standing but overall MPF appeared to be unaffected by time standing. Similarly, RMS tended to vary within each hour of but generally remained at a constant value over 6 hours of standing. For the example subject shown in Figure 20, standing on the hard tile increased MPF and RMS compared to standing on the soft mat and rubber tile.

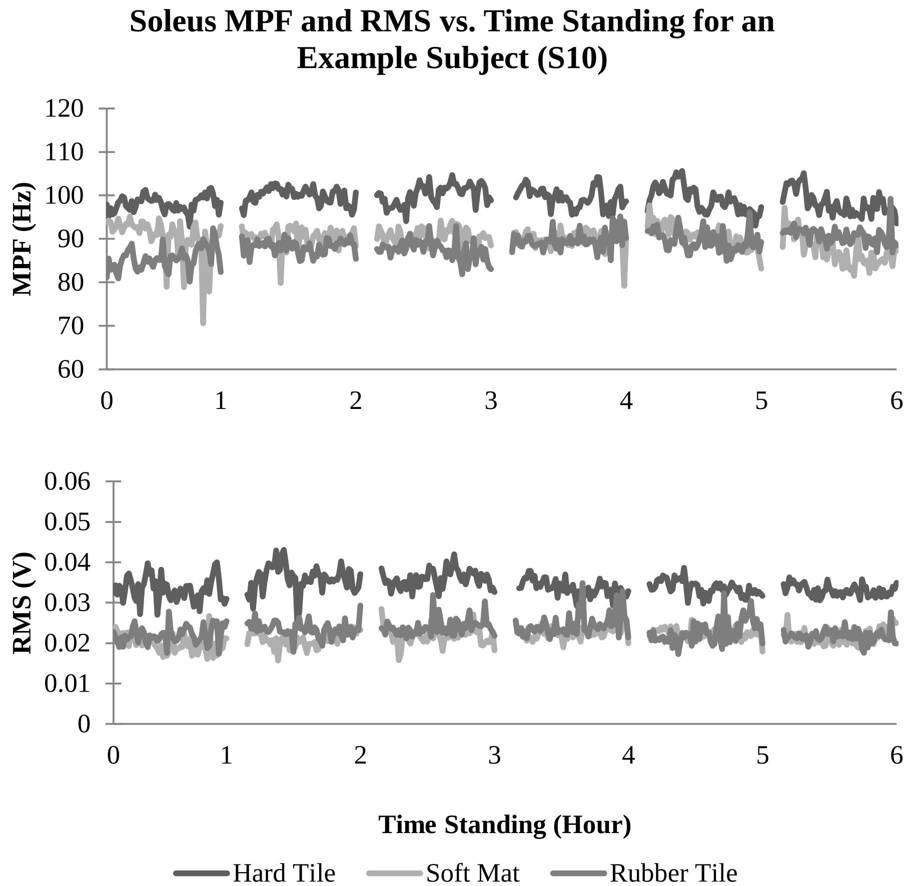


Figure 20: Soleus MPF and RMS for an example subject (S10) during 6 hours of long-term standing. The hard tile increased MPF and RMS compared to the soft mat and rubber tile. No changes were observed over time standing.

The effect of flooring on soleus MPF and RMS over time standing, as seen in S10 (Figure 20), was not consistent with other subjects examined, as seen in Figure 21. Soleus MPF and RMS is plotted against time for another example subject (S14) (Figure 21).

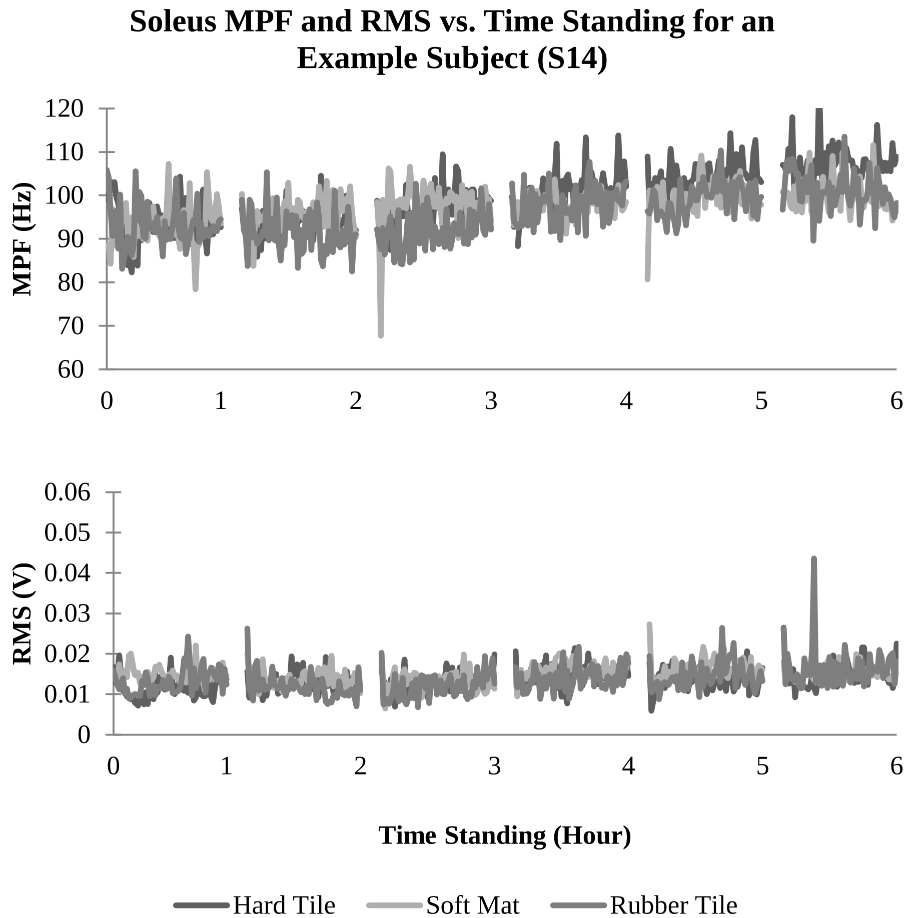


Figure 21: Soleus MPF and RMS for an example subject (S14) during 6 hours of long-term standing. No trends in MPF and RMS were observed over time and across flooring surfaces.

For this particular subject, large changes in MPF were observed within each hour but overall no clear trend in MPF could be determined. However, it was observed that soleus MPF started to increase after the third hour of standing. There was little variation in RMS within each hour and it generally remained at a constant value over the 6 hours of standing. No clear differences across flooring surfaces were noticed.

In summary, the qualitative data analysis determined flooring surface had no effect on erector spinae MPF and RMS. Flooring surface affected soleus MPF and RMS in one of the example subjects shown but overall this trend was not observed in other subjects.

6.2.3 Postural measures

There was no interaction effect between flooring surface and time standing on body-weight shifts. Separate ANOVA models were fit to investigate the impact of time standing on the number of body-weight shifts by flooring surface. Time standing significantly affected the number of body-weight shifts for the hard tile. Tukey comparison tests were performed to determine which intervals of standing were different from another (Figure 22). Body-weight shifts increased starting at the interval from 2.5 to 3 hours when compared to the first 30 minutes of standing ($p = .0130$).

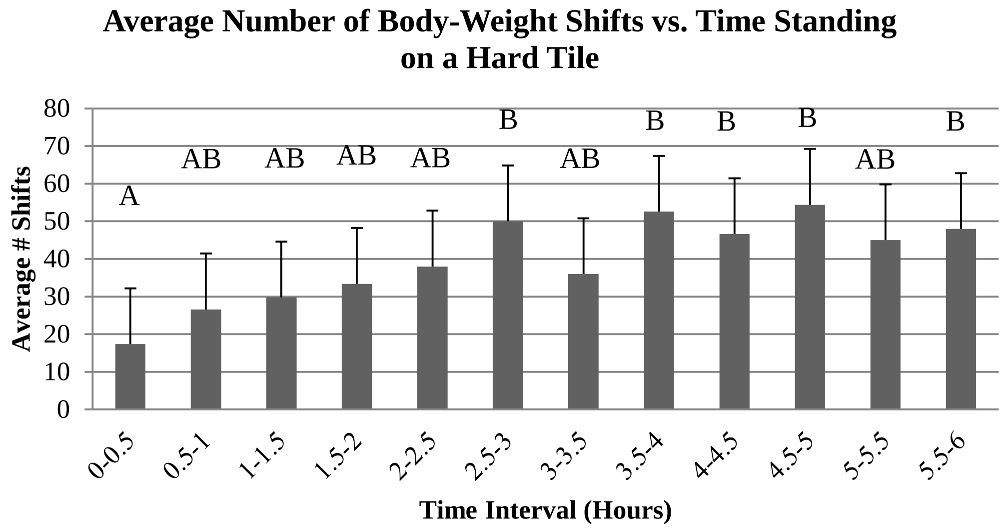


Figure 22: Average number of body-weight shifts vs. time standing on a hard tile. Intervals of time that are labeled with the same letter had the same number of body-weights shifts. (Standard error bars)

Time standing also had a significant effect on the number of body-weight shifts for the rubber tile. Body-weight shifts increased during the interval from 3.5 to 4 hours when compared to the first 30 minutes of standing on the rubber tile (p = .0130). Time standing did not affect the total number of body-weight shifts for the soft mat (Figure 23).

Average Number of Body-Weight Shifts vs. Time Standing

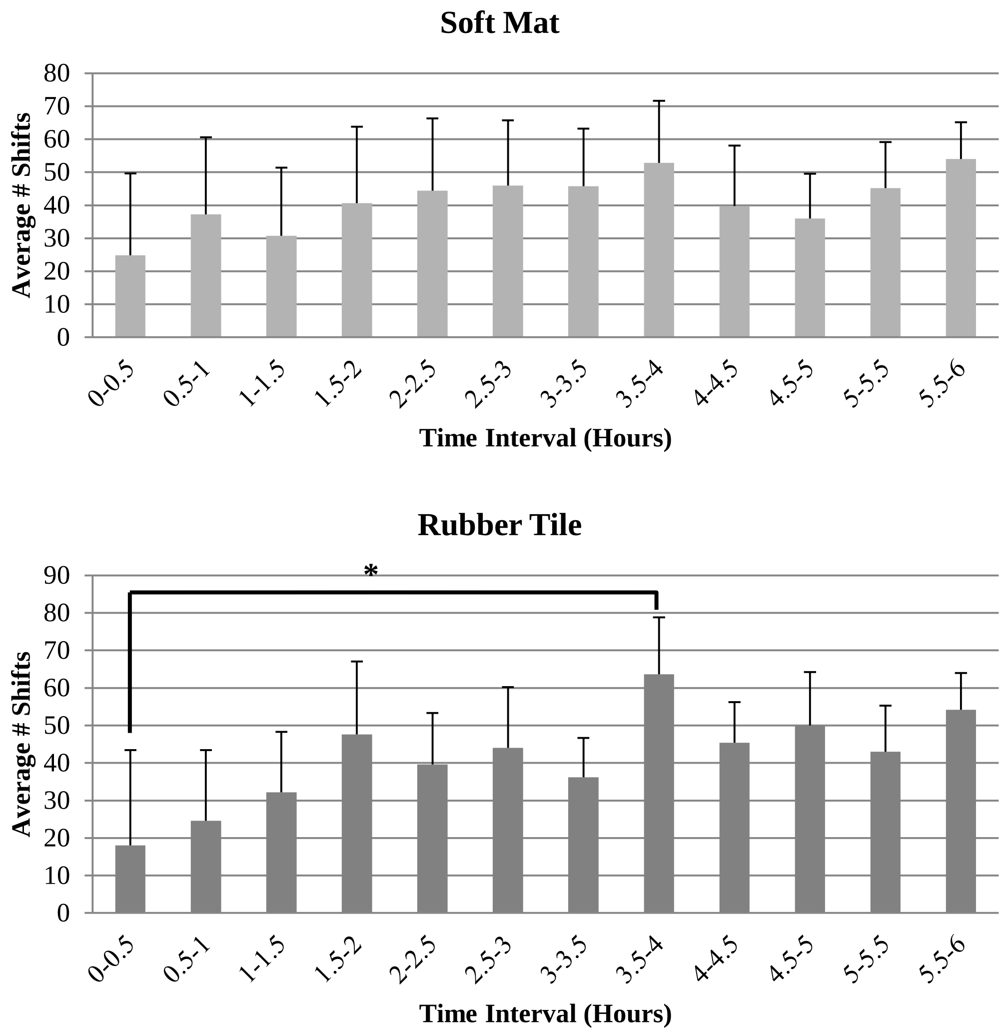


Figure 23: Average number of body-weight shifts vs. time standing on a soft mat (Top) and rubber tile (bottom). The soft mat yielded no significant differences over time standing. The interval from 3.5 to 4 hours significantly increased compared to the first 30 minutes (denoted by *) during standing on the rubber tile. (Standard error bars)

Separate ANOVA models were fit to investigate the impact of flooring surface on the number of body-weight shifts by time standing. Tukey comparison tests revealed that standing on the rubber tile increased body-weight shifts during the interval from 1.5 to 2 hours compared to standing on the hard tile (p = .0429). Flooring surface did not impact total number of body-weight shifts during any other interval of standing. The cumulative number of body-weight shifts over each interval of standing was estimated for each flooring condition (Figure 24). No differences across flooring surfaces were found.

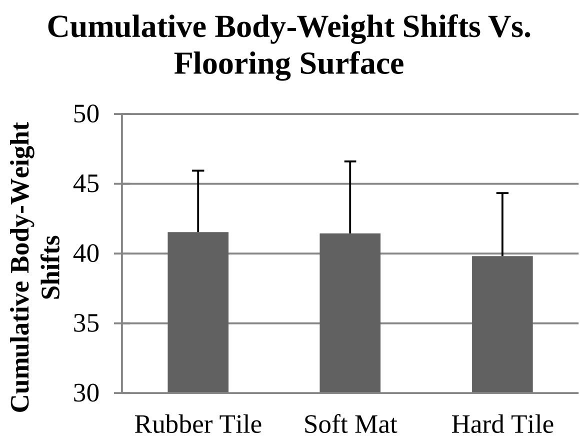


Figure 24: Cumulative number of body-weight shifts over 6 hours of standing as a function of flooring surface. No difference across flooring surfaces was found. (Standard error bars)

Finally, pairwise correlations were performed to investigate the relationship between subjective discomfort ratings for lower extremity discomfort and number of body-weight shifts across the flooring surfaces. Pearson coefficients were estimated from the correlations for each flooring surface (Table 8).

Table 8: Relationship between lower extremity subjective discomfort ratings and number of body-weight shifts during 6 hours of long-term standing. (* indicates significant relationship)

Pearson coefficient (r)		Number of Body-Weight Shifts		
		Hard Tile	Soft Mat	Rubber Tile
Body Region	**Overall Leg Tiredness**	r = .27*	r = .27*	r = .50*
	Hip Discomfort	r = .19	r = .50*	r = .26*
	Upper Leg Discomfort	r = .35*	r = .23	r = .36*
	Knee Discomfort	r = .24	r = .19	r = .33*
	Lower Leg Discomfort	r = .51*	r = .47*	r = .40*
	Ankle Discomfort	r = .16	r = .40*	r = .20
	Feet Discomfort	r = .57*	r = .10	r = .69*

Significant relationships were found between subjective discomfort ratings and number of body-weight shifts. In general, the number of shifts increased as subjective discomfort ratings increased. Body-weight shifts were associated to overall leg tiredness and lower leg discomfort for all flooring surfaces. Additionally, strong correlations were found in feet discomfort for the hard tile and rubber tile.

In summary, the flooring surfaces tested in this study had a minor effect on body-weight shifts during long-term standing. The number of shifts increased over time standing for the hard tile and rubber tile. While no significant increases over time were found for standing on the soft mat, a general trend was observed. Additionally, no changes were found in the cumulative number of body-weight shifts when compared across flooring surfaces.

6.2.4 NIRS measures

Muscle SO_2 and tHb were normalized to the average muscle SO_2 and tHb during the seated baseline. The first analysis period (time standing equal to 0 hours) is the average SO_2 and tHb during the first minute of standing.

There was no interaction effect between flooring surface and time standing on muscle SO_2 and tHb. Separate ANOVA models were fit to determine the effect of time standing on muscle SO_2 and tHb by flooring surface. The outcome of the ANOVA revealed time standing did not have a significant effect on soleus and erector spinae SO_2 and tHb for all flooring surfaces. Additionally, ANOVA was performed to test the effect of flooring surface on muscle SO_2 and tHb at each analysis period of standing and no differences in muscle SO_2 and tHb were found across flooring surfaces (Figures 25, 26).

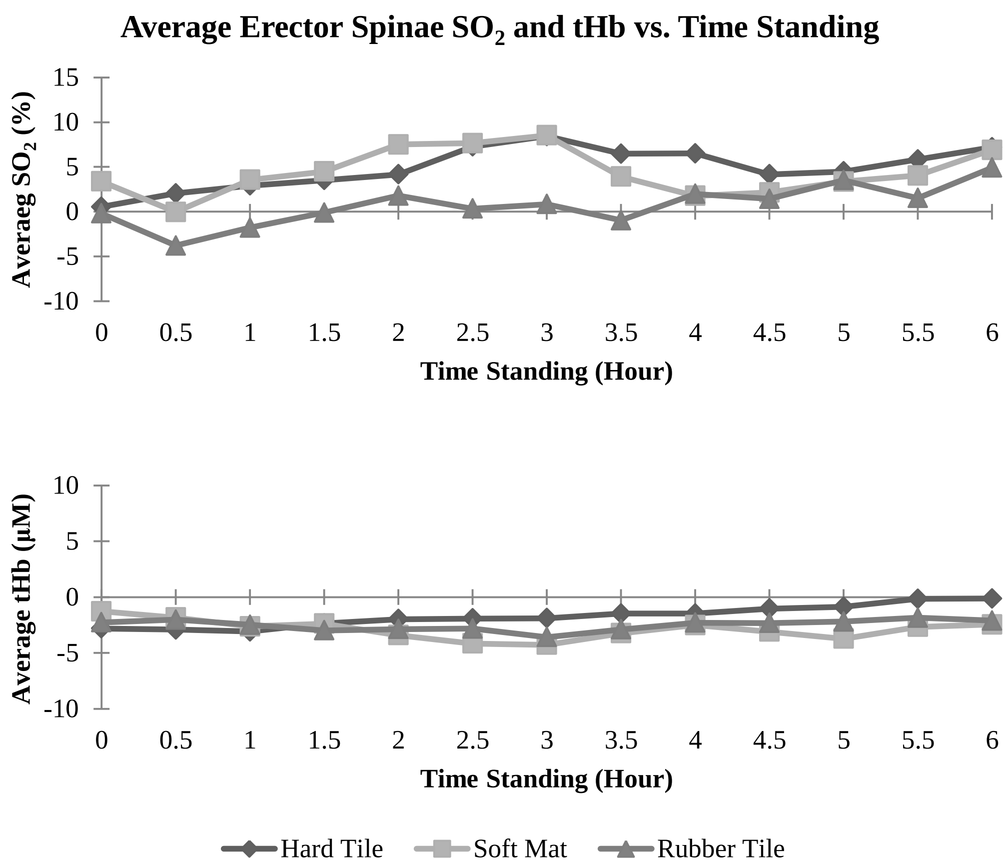


Figure 25: Average erector spinae SO_2 (top) and tHb (bottom) across time standing normalized to resting baseline values. No significant differences were found across flooring surfaces at each analysis period. Additionally, time standing did not significantly impact SO_2 and tHb for each flooring surface.

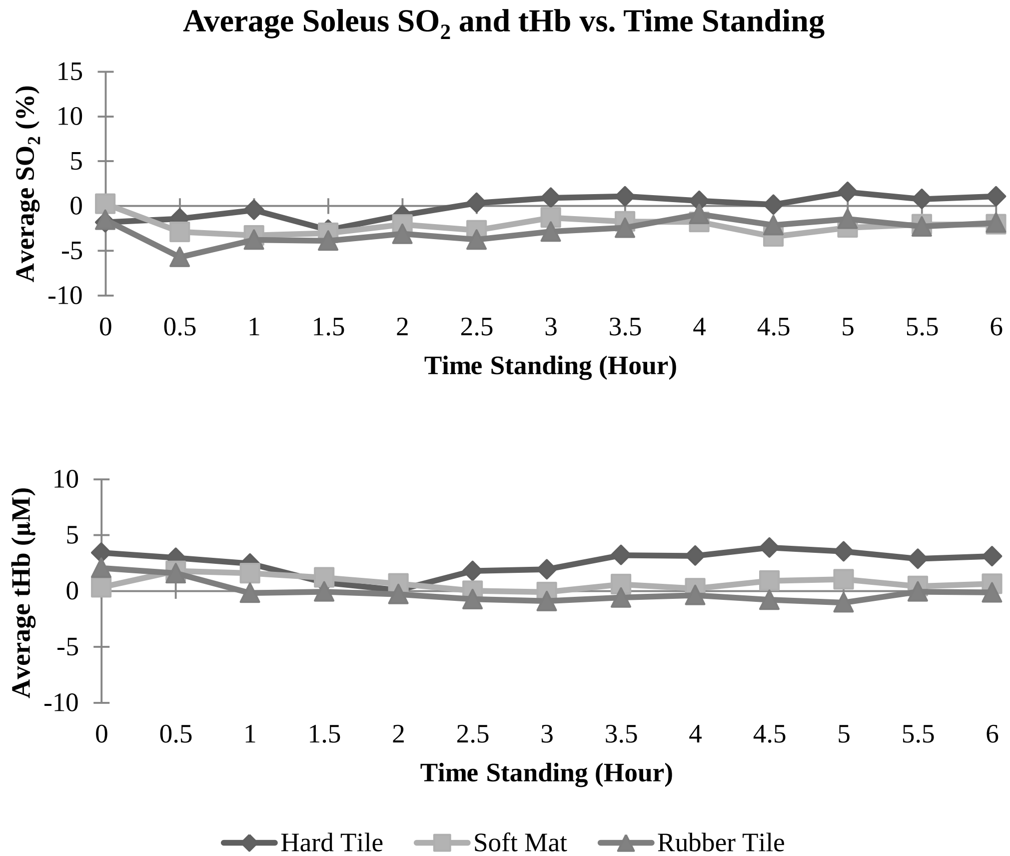


Figure 26: Average soleus SO_2 (top) and tHb (bottom) across time standing normalized to resting values. No significant differences were found across flooring surfaces at each analysis period. Additionally, time standing did not significantly impact SO_2 and tHb for each flooring surface.

A correlation analysis was performed to investigate the relationship between muscle SO_2 and subjective discomfort ratings during long-term standing. Soleus and erector spinae SO_2 were compared to subjective discomfort ratings for the lower leg and lower back regions, respectively. Pearson coefficients were estimated from the correlations for each flooring surface (Table 9).

Table 9: Relationship between muscle SO_2 and subjective discomfort ratings during long-term standing. Erector spinae SO_2 was compared to lower back discomfort and soleus SO_2 was compared to lower leg discomfort. (* indicates significant relationship)

Pearson coefficient (r)		Muscle SO_2		
		Hard Tile	**Soft Mat**	**Rubber Tile**
Body Region	**Lower Back Discomfort**	r = .27*	r = -.31*	r = -.02
	Lower Leg Discomfort	r = .0435	r = .07	r = .31*

Significant relationships were found between erector spinae SO_2 and lower back discomfort for standing on the hard tile and soft mat. Standing on the hard tile yielded a positive relationship while standing on the soft mat yielded a negative relationship. Soleus SO_2 was positively correlated to lower leg discomfort during standing on the rubber tile.

Finally, a correlation analysis was performed to investigate the relationship between postural movements (COP path length) and muscle SO_2 by flooring condition. Pairwise correlations were performed on the change in COP path length (ΔPL) and change in muscle SO_2 (ΔSO_2) for 2 consecutive intervals at the beginning, middle and end of each hour. The Pearson coefficients for each correlation are shown in Table 10.

Table 10: Relationship between ΔCOP path length and ΔSO_2 during long-term standing on a hard tile, soft mat, and rubber tile. (* indicates significant relationship)

Pearson coefficient (r)		ΔPL		
		Hard Tile	**Soft Mat**	**Rubber Tile**
ΔSO_2	**Erector Spinae**	r = .17	r = -.08	r = .33*
	Soleus	r = .44*	r = .45*	r = .35*

Erector spinae ΔSO_2 and ΔPL had a significant relationship for standing on the rubber tile. No relationship was found during standing on the hard tile or soft mat. Soleus ΔSO_2 and ΔPL had a significant relationship for all flooring surfaces. In all cases, an increase in COP path length corresponded to an increase in muscle SO_2.

In summary, flooring surface had no significant impact on muscle SO_2 and tHb throughout 6 hours of long-term standing. No changes were detected across time for each flooring surface and no changes in SO_2 and tHb were detected across flooring surfaces at each analysis period.

6.3 FLOORING EFFECT ON LONG-TERM WALKNG

6.3.1 Subjective discomfort

There was no interaction effect between flooring surface and time walking for the subjective discomfort ratings. Separate ANOVA models were fit to test the impact of flooring surface on subjective discomfort ratings. General tiredness and discomfort ratings for each body region increased with time walking for all flooring surfaces ($p < .0001$) (Figure 27). Tukey comparison tests revealed no difference in flooring surface until 1 hour of walking. Walking on the soft mat significantly decreased overall leg tiredness after 1 hour ($p = .0382$), 1.5 hours ($p = .0315$), and 2 hours ($p = .0489$) compared to walking on the hard tile. The soft mat also reduced discomfort compared to the hard tile in the upper back at 1 hour of walking ($p = .0310$) and the ankle at 1.5 and 2 hours ($p = .0213$, $p = .0289$). No differences in flooring surface were found at each survey period for overall tiredness, lower back, hip, upper leg, knee, lower leg, and feet discomfort.

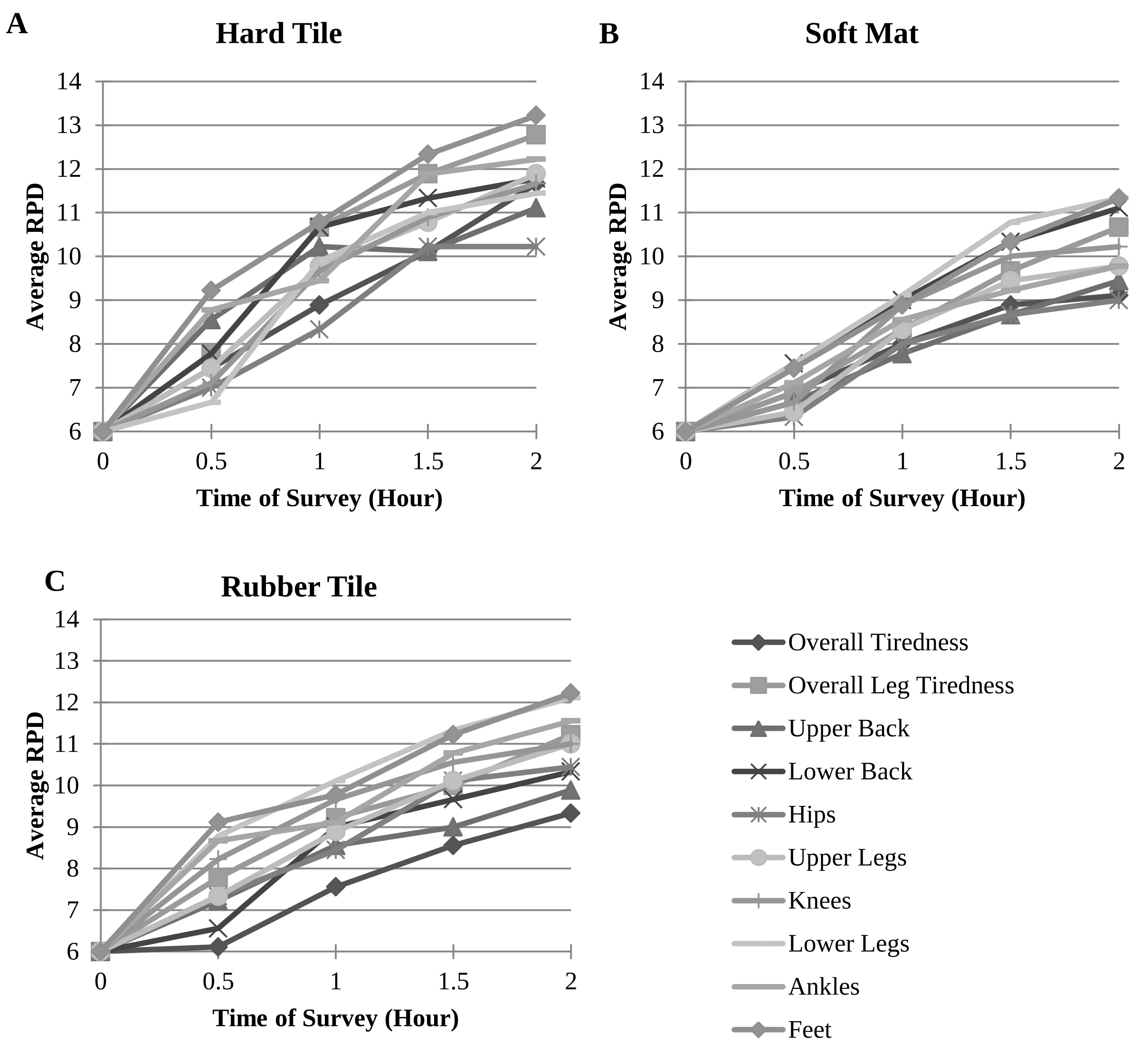


Figure 27: Average subjective discomfort ratings (RPD) versus time walking on a hard tile (A), soft mat (B), and rubber tile (C). The effect of time standing was significant for each subjective discomfort rating across all flooring surfaces.

Cumulative subjective discomfort over 2 hours of walking was impacted by flooring surface (Figure 28). Compared to walking on the hard tile, the soft mat reduced cumulative discomfort ratings for overall leg tiredness ($p = .0198$), upper back discomfort ($p = .0092$), ankle discomfort ($p = .0192$), and feet discomfort ($p = .0312$). The rubber tile reduced cumulative discomfort ratings for overall tiredness when compared to walking on the hard tile ($p = .0259$).

In summary, flooring surface had an effect on subjective measures of discomfort. In general, walking on the hard tile increased cumulative subjective discomfort compared to walking on the rubber tile and soft mat.

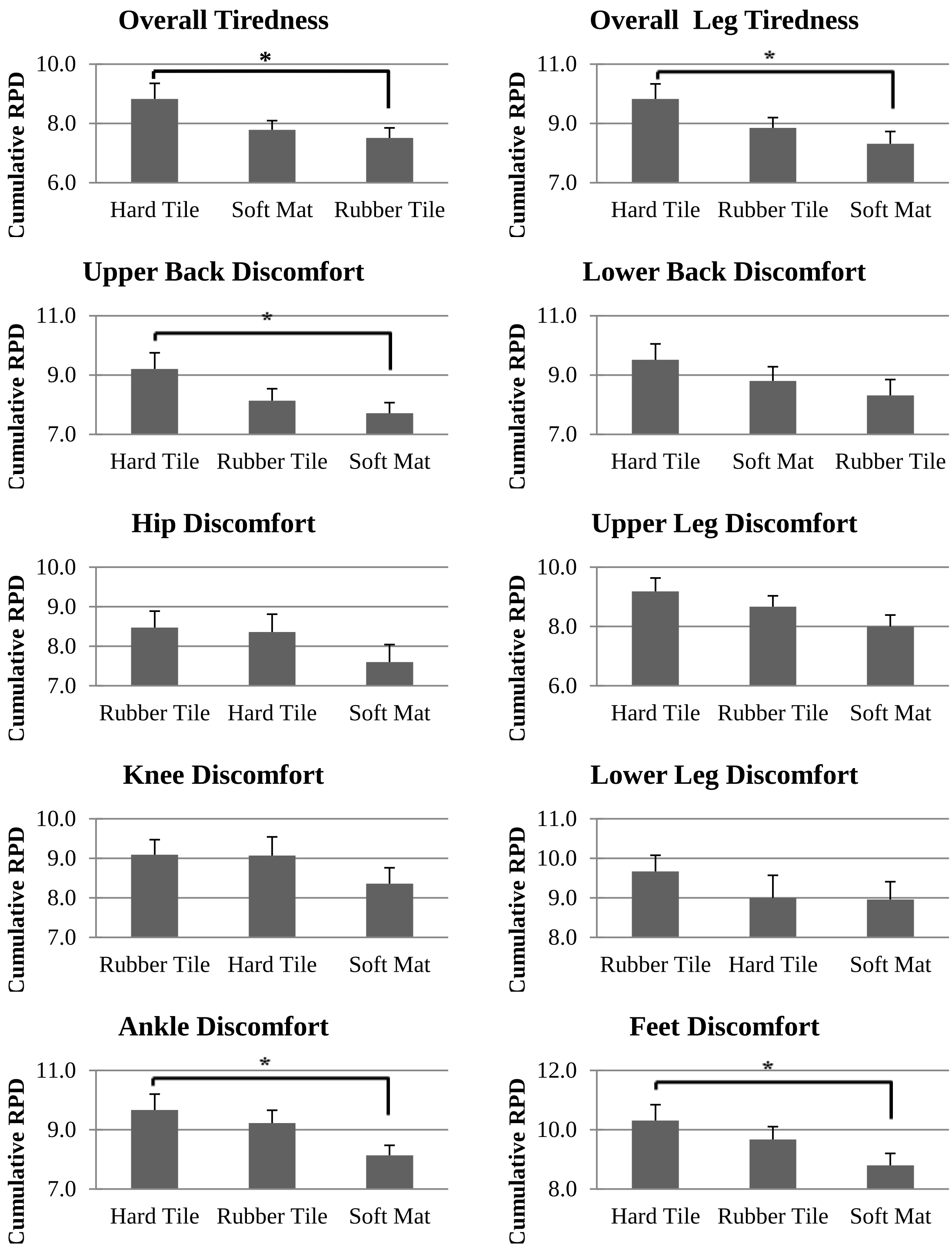


Figure 28: Cumulative subjective discomfort ratings over 2 hours of walking as a function of flooring surface. (Standard error bars)

6.3.2 NIRS measures

There was no interaction effect between flooring surface and time walking on muscle SO_2 and tHb. Separate ANOVA models were fit to determine the effect of time walking on muscle SO_2 and tHb by flooring surface. Walking significantly increased erector spinae and soleus SO_2 across all flooring conditions ($p < .0001$) compared to the muscle SO_2 during the baseline standing (walking time equal to 0 hours). The initial increase in SO_2 leveled off after the first half hour of walking. No changes in SO_2 were found at the walking periods analyzed for all flooring conditions.

Walking significantly increased erector spinae tHb compared to the resting tHb during baseline standing (walking time equal to 0 hours) for the soft mat ($p = .0003$) and rubber tile ($p = .0224$). No changes in erector spinae tHb compared to the resting tHb were found for the hard tile. Soleus tHb tended to increase from the seated baseline to the standing baseline at the beginning of the walking protocol. Thereafter, walking time had a significant effect on soleus tHb for the hard tile ($p = .0003$), soft mat ($p < .0001$), and rubber tile ($p = .0022$). Soleus tHb tended to initially decrease at the start of the walking protocol and gradually increase back to resting values.

Separate ANOVA models were fit to investigate the effect of flooring condition on muscle SO_2 and tHb by walking time. Flooring surface had no impact on muscle SO_2 and tHb at each period analyzed throughout the walking protocol (Figures 29, 30).

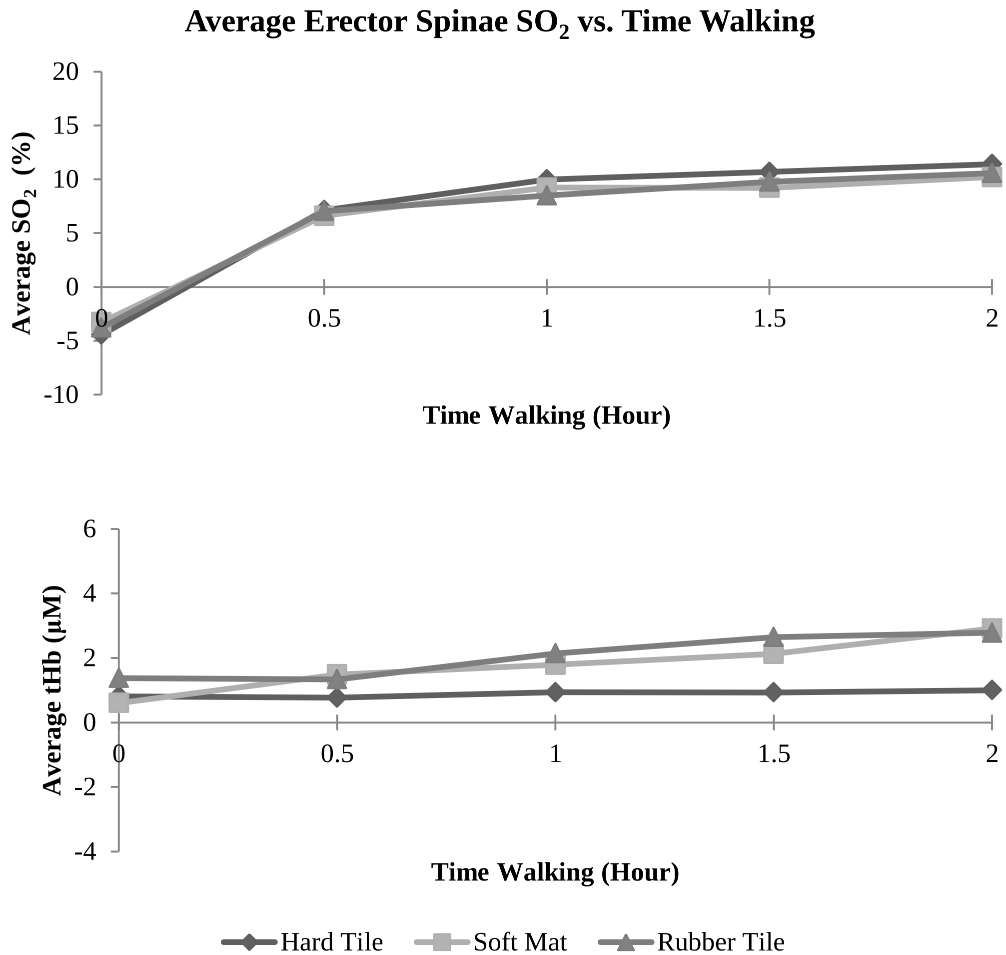


Figure 29: The effect of flooring on average erector spinae SO_2 (top) and tHb (bottom) across time walking. No significant differences were found across flooring surfaces at each analysis period.

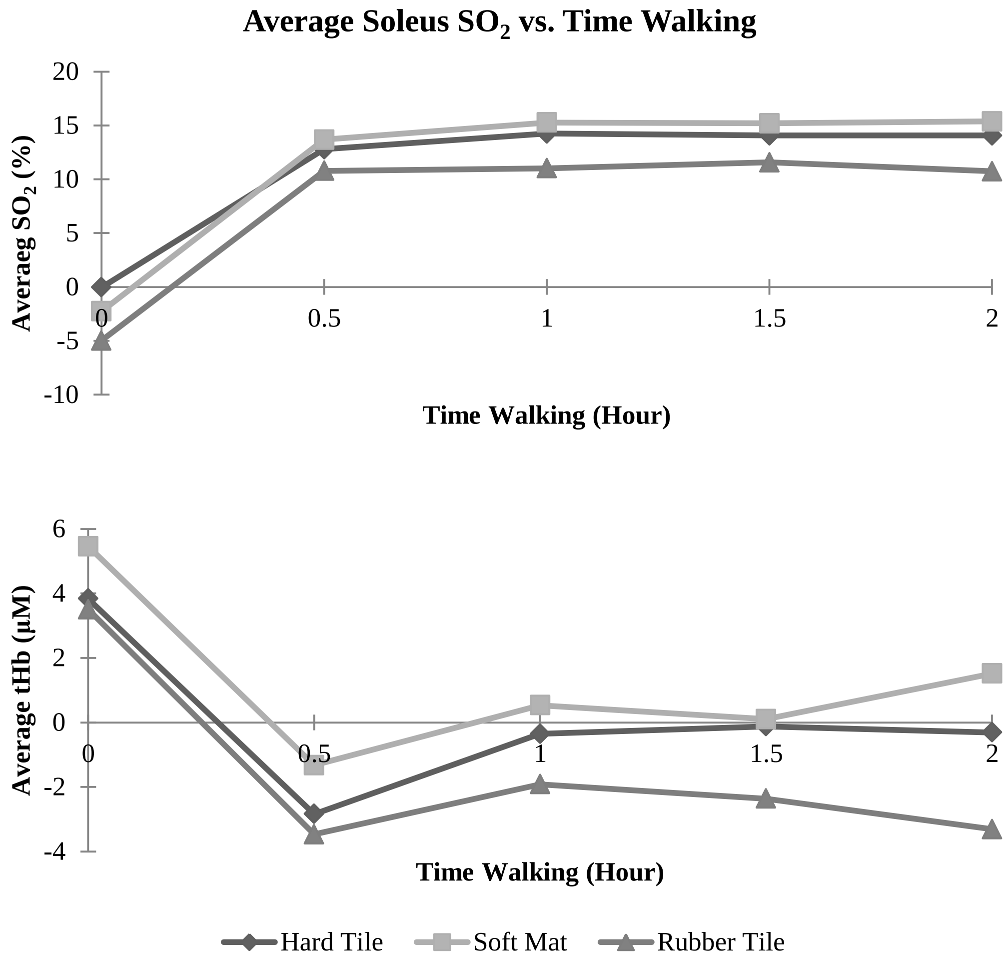


Figure 30: The effect of flooring on average soleus SO_2 (top) and tHb (bottom) across time walking. No significant differences were found across flooring surfaces at each analysis period.

A correlation analysis was performed to investigate the relationship between muscle SO_2 and subjective discomfort ratings during long-term walking. Soleus and erector spinae SO_2 were compared to subjective discomfort ratings for the lower leg and lower back regions, respectively. Pearson coefficients were estimated from the correlations for each flooring surface (Table 11).

Table 11: Relationship between muscle SO_2 and subjective discomfort during long-term walking. Erector spinae SO_2 was compared to lower back discomfort and soleus SO_2 was compared to lower leg discomfort. (* indicates a significant relationship).

Pearson coefficient (r)		Muscle SO_2		
		Hard Tile	**Soft Mat**	**Rubber Tile**
Body Region	**Lower Back Discomfort**	r = .34*	r = .50*	r = .57*
	Lower Leg Discomfort	r = .18	r = .02	r = .59*

Significant relationships were found between erector spinae SO_2 and lower back discomfort during long-term walking on all flooring surfaces. An increase in lower back discomfort corresponded to an increase in erector spinae SO_2. Similarly, an increase in lower leg discomfort corresponded to an increase in soleus SO_2 during long-term walking on the rubber tile. No relationship was found for walking on the hard tile or soft mat.

In summary, muscle SO_2 was impacted by time walking. A gradual increase in muscle SO_2 was observed during the first 30 minutes of the walking protocol and eventually plateaued. Flooring surface had no effect on the change in muscle SO_2 and tHb observed during the walking periods.

7.0 DISCUSSION

This study investigated the effect of flooring surface on subjective and objective measures of fatigue during long-term standing and walking. The primary goal of this study was to determine the reliability of using muscle SO_2 as an objective measure of fatigue. The application of NIRS to monitor changes in muscle SO_2 provides insight to the physiological processes that occur within muscles throughout long-term standing. Understanding the association between perceived muscle fatigue and muscle SO_2 during long-term standing can benefit the evaluation process of anti-fatigue flooring. In addition to muscle SO_2, other objective measures of fatigue were quantified which included muscle activity and postural sway parameters. This project focused on how trends in these fatigue measures varied across time and flooring surface.

7.1 LONG-TERM STANDING ON A HARD SURFACE

Significant increases in subjective measures of discomfort were found over time standing on a hard surface. The most effected body regions were the feet, lower back, and lower legs. Erector spinae SO_2 and subjective discomfort ratings for the lower back region had a significant positive relationship although the correlation was not particularly strong ($r = .33$). Additionally, soleus SO_2 was poorly related to lower leg discomfort ($r = -.05$).

Contrary to previous research [34], the results from this study revealed significant increases in erector spinae SO_2 during standing on a hard surface. Large variations in erector spinae SO_2 were observed within each hour of standing but generally increased throughout the testing session. Callaghan et al. [34] reported no changes in erector spinae SO_2 during standing. A reason for the discrepancy could be that in the Callaghan et al. study, the duration of the standing protocol was only 2 hours whereas the duration of the standing protocol was 6 hours in the current study. Average erector spinae SO_2 at the end of the third and sixth hour was significantly higher than the SO_2 measured during the middle of the first hour.

Previous research has shown that lifting tasks performed at frequencies of 2 to 12 lifts/min and throughout an 8 hour workday are associated to large increases in erector spinae SO_2 [32]. It was suggested that the short and frequent muscle contractions experienced during the lifting task increased blood flow to the erector spinae. The increase in blood volume provided more oxygen to the muscle as demand for oxygen increased. In the current study, blood volume (tHb) generally remained similar to resting values but there was a gradual increase in erector spinae SO_2 over time standing. The frequent low intensity contractions that the erector spinae undergoes during standing may not be intense enough to induce large changes, as seen during repetitive lifting tasks. Instead, the frequent low intensity contractions help maintain a steady level of SO_2.

No significant changes in soleus SO_2 were found over time standing on the hard surface although trends were observed. Soleus SO_2 tended to initially decrease until the midway point of each hour of standing and then eventually level off or recover to resting value. Postural movements could give insight to the observed patterns in soleus SO_2 during standing. A relationship was found between COP path length and SO_2 during standing in which an increase in COP path length corresponded to an increase in soleus SO_2 (r = .20).

Outside of the current research study, two investigational short-term standing trials were conducted in order to further observe changes in soleus SO_2 in response to an increase in postural measures (see appendix B.4). In the first trial, soleus SO_2 consistently decreased during a 10 minute period of quiet stance where body-weight was equally distributed among both feet. The soleus sustained a low intensity static contraction during this period, which explains the decline in SO_2 [22]. Following this period of quiet stance, the volunteer was instructed to continually shift their body-weight at a constant rate for an additional 10 minute period. A gradual increase in SO_2 was observed due to the repeated low intensity muscle contractions as postural measures increased compared to quiet stance. A second trial was conducted to observe changes in soleus SO_2 in response to shifting body-weight to one side and maintaining it for 5 minute periods. Similar to the first trial, soleus SO_2 consistently decreased during a 10 minute period of quiet stance where body-weight was equally distributed among both feet. Body-weight was then shifted to one side and soleus SO_2, measured from the unloaded leg, began to recover over a 5 minute period. Soleus SO_2 continued to recover when body-weight was shifted to the other side and maintained for another 5 minute period. The recovery in oxygenation was not as extreme as the increase seen during the previous trial, but these observations indicate that even minor redistributions in body-weight still impact soleus SO_2.

Previous research has indicated muscle SO_2 decreases during a sustained static contraction [22–25]. Additionally, it has been shown that the reduction in SO_2 is proportional to the intensity of the contraction, with higher intensity contractions leading to greater reductions in SO_2 [22]. The soleus muscle is a primary contributor to standing posture and undergoes static low intensity contractions during stance. In the current study, postural movements are low during the beginning of each hour of standing and in general, the soleus muscle maintains a low intensity static contraction. This corresponds to the initial decrease observed in soleus SO_2 at the beginning of each hour. Then, as postural movements begin to increase to relieve fatigue brought on by long-term standing, the soleus muscle undergoes frequent low intensity contractions. The increase in postural movements corresponds to the general leveling off and recovery of soleus SO_2 observed during the later stages of each hour of standing. Therefore, postural movements during long-term standing help maintain a steady level of soleus SO_2.

Additionally, significant increases in the number of body-weight shifts were found over time standing. Significant relationships were found between body-weight shifts and subjective measures of discomfort. Increases in overall leg tiredness, lower leg discomfort, ankle discomfort and feet discomfort corresponded to increases in body-weight shifts. These results support previous findings that suggest there is an increase in the number of body-weight shifts as subjects become progressively tired throughout standing [39,42].

7.2 FLOORING EFFECT ON LONG-TERM STANDING

The methodologies of this study have been added to the updated review table which summarizes the methodologies of previous standing fatigue studies (Table 12).

Table 12: Summary of methodologies in standing fatigue studies [43]. (Updated with methodologies from the current study)

Researchers	**Madeleine et al., 1998** [37]	**Cham and Redfern, 2001** [39]	**King, 2002** [40]	**Orlando and King, 2004** [41]	**Wiggermann and Keyserling, 2011** [42]	**Haney, 2014**
Study type	lab study	lab study	field study	field study	lab study	lab study
Testing duration	2 hours	4 hours	8-hr shift/day	8-hr shift/day	4 hours	6 hours
Time	1 session/day	1 session/day	5 shifts/condition	5 shifts/condition	1 session/day	1 session/day
Number of subjects	13	10	22	16	10	5
Independent variables	1 hard floor 1 soft mat	1 hard floor 6 floor mats	1 hard floor 1 floor mat 1 shoe insole	1 wood block 1 floor mat 1 shoe insole	1 hard floor 4 floor mats	1 hard floor, 1 soft mat, 1 rubber tile
Dependent variables	subjective emg (leg) COP shank circumference ankle movement skin temperature	subjective emg (leg and back) leg volume skin temperature	subjective	subjective	subjective COP	subjective COP emg (leg and back) NIRS

7.2.1 Subjective discomfort

The results of this study showed flooring surface had a minimal effect on preventing the onset of subjective measures of discomfort during long-term standing. Overall, subjective discomfort increased over time for all flooring surfaces. Flooring surface had an effect on cumulative discomfort in the upper back and feet regions. Results from this study have been added to the updated review table (Table 13) which examines the statistically significant effect of floor and/or shoes on subjective measures of fatigue. In both cases, standing on the soft mat decreased cumulative discomfort over time compared to standing on the hard tile. No significant differences were found across flooring surfaces in overall fatigue, overall leg fatigue, lower back discomfort, hip discomfort, upper leg discomfort, knee discomfort, lower leg discomfort, or ankle discomfort. The similarities in lower extremity discomfort found across flooring conditions is contradictory to studies conducted by Cham [39] and Wiggermann[42]. However, the current study was limited by a small sample size and a small number of flooring surfaces investigated.

Table 13: Statistically significant effect ($p < .05$) of floor and/or shoes on subjective measures of fatigue [43]. (Updated with results from the current study)

Discomfort Region	**Madeleine et al., 1998** [37]	**Cham and Redfern, 2001** [39]	**King, 2002** [40]	**Orlando and King, 2004** [41]	**Wiggermann and Keyserling, 2011** [42]	**Haney, 2014**
overall fatigue	yes-floor	no	yes-floor/insert	no	no	no
overall leg fatigue	N/A	yes-floor	yes-floor/insert	no	yes-floor	no
upper back	N/A	no	yes-insert	no	N/A	yes-floor
lower back	N/A	yes-floor	yes-insert	no	yes-floor	no
hips	N/A	yes-floor	yes-insert	no	N/A	no
upper legs	N/A	yes-floor	no	no	no	no
knees	N/A	yes-floor	yes-insert	no	yes-floor	no
lower legs	N/A	yes-floor	no	no	yes-floor	no
ankles	N/A	yes-floor	no	no	N/A	no
feet	N/A	yes-floor	yes-floor/insert	no	yes-floor	yes-floor

Trends in cumulative discomfort were observed in body regions that produced non-significant findings. Standing on the soft mat produced the least cumulative discomfort in the lower back and knee regions in addition to the feet and upper back. Standing on the rubber tile produced the least cumulative discomfort in the hips, upper legs, lower legs, and ankles. These trends are in agreement with previous research that anti-fatigue flooring reduces discomfort during long-term standing [36,39,42].

Floor surface hardness had the biggest impact on feet discomfort. Standing on the soft mat significantly reduced cumulative discomfort compared to both the hard and rubber tiles. This can be explained by the patterns observed in postural movements during long-term standing. No significant increases in body-weight shifts were found during standing on the soft mat. Additionally, no differences in cumulative number of body-weight shifts were found across flooring surfaces. Thus, the number of body-weight shifts was consistently high throughout every 30 minute period of standing on the soft mat. A likely explanation for this result could be that subjects were relatively unstable while standing on the cushioned surface of the soft mat. As a result, they were more inclined to shift their body-weight resulting in a continual unloading and reloading of the feet that reduced underfoot pressure and discomfort.

7.2.2 Objective measures

The results from this study of the flooring effect on behavioral responses during long-term standing have been added to the updated review table which examines the effect of floor/shoes on objective measures of fatigue [43] (Table 14). Muscle SO_2 has been added to the table as an objective measure of fatigue. In general, the results from this study show flooring surface had a minor effect on behavioral responses. A likely reason for this finding could be the similarities in subjective discomfort found across flooring surfaces. Additionally, as previously mentioned, this study was limited by a small sample size.

Table 14: Statistically significant effect ($p < .05$) of floor/shoes on objective measures of fatigue [43]. (Updated with results from the current study)

Objective Measure	**Madeleine et al., 1998** [37]	**Cham and Redfern, 2001** [39]	**Wiggermann and Keyserling, 2011** [42]	**Haney, 2014**
COP	yes-floor	yes-floor	yes-floor	yes-floor
EMG: legs RMS MPF	yes-floor yes-floor	 no	N/A	no no
EMG: back RMS MPF	N/A	 no	N/A	no no
leg volume	N/A	no	N/A	N/A
leg and/or foot dimensions	yes-floor	N/A	N/A	N/A
skin temperature	no	yes-floor		N/A
ankle movement	yes-floor	N/A	N/A	N/A
Performance	N/A	yes-floor	N/A	N/A
NIRS: legs SO_2	N/A	N/A	N/A	no
NIRS: back SO_2	N/A	N/A	N/A	no

7.2.2.1 EMG fatigue measures

In this study flooring surface had no effect on erector spinae and soleus EMG fatigue measures (MPF and RMS). A trend in soleus EMG fatigue measures was observed for one subject (S10). Soleus MPF and RMS increased when standing on the hard tile compared to the rubber tile and soft mat. The increase in MPF can be explained by the increase in EMG amplitude experienced when standing on a hard surface compared to a softer surface [37]. A possible explanation for the increase in soleus muscle activity could be the increase in postural measures while standing on the hard tile for this particular subject. However, the trend in soleus EMG fatigue measures was not observed in other subjects. Additionally, no trend in erector spinae EMG fatigue measures between flooring surfaces was observed across subjects. It has been previously concluded that EMG is not capable of describing muscle fatigue during standing at which time muscles experience low levels of contractions [49].

Conclusions drawn from previous research investigating the effect of flooring on EMG fatigue measures are contradictory [43]. The findings from this study are in agreement with researchers who have concluded there is no flooring effect [35,39]. Though, the similarities between flooring surfaces in the subjective measures of discomfort could give insight to the current findings in EMG fatigue measures. No statistically significant differences were found in lower back discomfort and lower leg discomfort across flooring surfaces, which could explain the similarities in erector spinae and soleus EMG fatigue measures across flooring surfaces.

7.2.2.2 Postural measures

This study found a relationship between subjective measures and body-weight shifts during standing. The strongest correlations with body-weight shifts were seen with lower leg discomfort and feet discomfort. This supports previous findings that number of body-weight shifts is related to lower extremity subjective discomfort during standing [39,42]. People are likely to redistribute their body-weight in order to relieve lower extremity joint stress and muscle fatigue. A significant effect of flooring was found during long-term standing. Standing on the rubber tile increased body-weight shifts compared to the hard tile during the time period from 1.5 to 2 hours, but flooring surface did not impact weight distribution during any other time period. Additionally, no difference in cumulative body-weight shifts was found across flooring surfaces during long-term standing.

Interestingly, different trends in body-weight shifts over time standing were found between flooring surfaces, though cumulative number of shifts were the same. Body-weight shifts significantly increased over time standing on the hard and rubber tiles which signify there were less shifts earlier on in the sessions. Unlike the hard and rubber tiles, the soft mat generated a similar number of shifts throughout each 30 minute period of standing. This indicates that there were more shifts earlier on in the standing session, considering that the cumulative number of shifts were the same across flooring surfaces. As previously discussed, the difference in cumulative feet discomfort across floors likely explains this finding. The increase in shifts that were seen in the earlier periods of standing on the soft mat assisted in reducing feet discomfort.

Flooring surface had a minimal impact on body-weight shifts in this study. The cumulative number of shifts over time standing was similar across floors, as expected. However, different trends in the number of shifts over time were detected. This finding suggests that it is important to evaluate the effect of flooring surface on the development of body-weight shifts over time. Anti-fatigue flooring that generates frequent body-weight distribution in the earlier stages of long-term standing could assist in reducing the development of lower extremity discomfort.

7.2.2.3 NIRS measures

Subjective discomfort was poorly related to muscle SO_2 during long-term standing, though significant correlations were found. Increases in lower back discomfort corresponded to an increase in erector spinae SO_2 while standing on the hard tile. Interestingly, a negative correlation was found between lower back discomfort and erector spinae SO_2 for standing on the soft mat. Levels of oxygenation reached a maximum in the erector spinae at the end of the third hour of standing on the soft mat and then gradually decreased towards the end of the standing session. Lower back discomfort continued to increase throughout the entire standing session which explains the negative relationship. No relationship was found for standing on the rubber tile. Similarly, weak correlations were found between soleus SO_2 and lower leg discomfort. An increase in soleus SO_2 corresponded to an increase in lower leg discomfort while standing on the rubber tile. No relationships were found for standing on the hard tile and soft mat. These findings suggest muscle SO_2 is not easily related to subjective discomfort during long-term standing likely due to postural movements.

Time standing did not significantly affect muscle SO_2 and tHb for each of the flooring surfaces. Additionally, flooring surface did not affect muscle SO_2 and tHb across 6 hours of standing. The similarities in muscle SO_2 across flooring surfaces can be explained by the similarities in postural movements and discomfort. As previously discussed, flooring surface had a minor effect on body-weight shifts during standing. The frequent redistribution of body-weight during standing helps maintain a constant level of muscle SO_2. It has been previously shown that muscle SO_2 decreases during a sustained static contraction [22–25]. However, during long-term standing muscle activity in the soleus undergoes dynamic changes as a result of the frequent redistribution of body-weight. It experiences periods of relaxation when body-weight is distributed to the opposite side and it experiences periods of low level exertions when the same side is loaded. These frequent changes in muscle activity cause an influx of blood volume to the muscle which helps maintain constant saturation levels. Additionally, the repeated muscle contractions facilitate the venous blood pump mechanism which allows for venous return.

The relationship between body-weight distribution and changes in muscle SO_2 is seen in the correlations between ΔPL and soleus ΔSO_2 for each flooring surface. Across all flooring surfaces, a significant correlation was found that revealed a positive change in COP path length corresponded to a positive change in SO_2. Likewise, a negative change in COP path length corresponded to a negative change in SO_2. This result validates the theory that change in soleus SO_2 during standing is dependent on the postural movements. Therefore, it is difficult to determine if muscle SO_2 is a proper measure of fatigue during long-term standing due to the increase in postural movements. The question remains what the response in muscle SO_2 would be if participants were constrained to stand quietly and not shift their body-weight and how flooring surface would affect this response. A continual decline in oxygenation might be observed and the rate of desaturation might be dependent on the material properties of the flooring surface.

To summarize, the results from this study suggest the relationship between muscle SO_2 and discomfort during long-term standing is more complicated than expected because the response of muscle SO_2 was affected by postural movements. As a result, muscle SO_2 experienced large variations despite increasing discomfort over time standing. In addition to this finding, the flooring surfaces examined in this study were found to have a minor effect on postural movements, EMG fatigue measures, and subjective discomfort. Therefore, it is difficult to form any conclusions on how flooring surface affects oxygenation due to these similarities.

7.3 FLOORING EFFECT ON LONG-TERM WALKING

7.3.1 Subjective discomfort

The effect of flooring on subjective discomfort during long-term walking showed similar trends to long-term standing. Increases in subjective measures were reported throughout the walking session. Walking on the rubber tile reduced cumulative overall tiredness compared to walking on the hard tile. The soft mat had the greatest impact on reducing body region discomfort compared to the hard tile. Significant reductions in cumulative discomfort were reported in overall leg tiredness, upper back discomfort, ankle discomfort and feet discomfort. It should be noted that significant reductions in subjective discomfort were seen after just 1 hour of long-term walking which suggests flooring surface has a greater impact on subjective discomfort during walking compared to standing.

Flooring surface had a greater impact on subjective discomfort during long-term walking likely due to the increase in physical exertion compared to standing. Muscles are more likely to experience fatigue when walking due to the repeated contractions over a long period of time. The body is more sensitive to changes in flooring surface when muscles experience greater amounts of fatigue. Furthermore, larger ground reaction forces are being transmitted to the feet during walking compared to standing [53]. The increase in reaction forces is a likely reason why flooring surface has a greater impact on subjective discomfort during long-term walking.

The impact of flooring surface on ground reaction forces estimated from in-shoe pressure measurement systems has been previously investigated [54]. Reductions in peak and mean ground reaction forces during gait were found while walking on inner-room floor mats compared to walking on a harder surface. The decrease in load distributed to the feet while walking on softer mats corresponds to less underfoot pressure. This can ultimately reduce strain on lower extremity joints and muscles and limit fatigue [54]. Though underfoot pressure was not estimated in the current study, it is expected the softer mat reduced peak ground reaction forces during gait seeing as how walking on the soft mat reduced subjective feet discomfort compared to the hard and rubber tiles.

7.3.2 NIRS measures

Lower back discomfort was related to erector spinae SO_2 during long-term walking. The results revealed moderate correlations for each flooring surface with an increase in lower back discomfort corresponding to an increase in erector spinae SO_2. Furthermore, a moderate positive correlation was found between lower leg discomfort and soleus SO_2. Though significant relationships were found, it cannot be concluded that increases in muscle SO_2 is the cause of subjective discomfort. Instead, the increase in subjective discomfort is likely a result of the large ground reaction forces being transmitted to the feet during walking, as previously discussed. Previous research has shown poor agreement between subjective discomfort and muscle SO_2 during long-term standing [34]. The results of the standing protocol from this study revealed a few weak correlations between subjective discomfort and muscle SO_2 across the different flooring surfaces which indicates changes in muscle SO_2 does not necessarily induce a sensation of discomfort. Additionally, the positive relationship contradicts previous conclusions that muscle SO_2 decreases during fatigue from a sustained isometric contraction [22–25].

Flooring surface did not affect changes in muscle SO_2 and tHb throughout the walking protocol. A consistent pattern was observed in both erector spinae and soleus SO_2 during walking. Muscle SO_2 gradually increased during the first 30 minute walking period and then generally remained constant throughout the remainder of the walking protocol. Erector spinae tHb increased compared to resting values at the initiation of walking. Over time it either gradually increased during walking or remained at a constant level. Dramatic decreases in soleus tHb were seen from the transition from standing to walking. Though, soleus tHb gradually increased throughout each walking period. The initiation of muscle contractions, during the transition from standing to walking, caused blood vessel compression which explains the dramatic decrease in soleus tHb. Inflow of blood volume to the muscle was then facilitated by the repeated muscle contractions experienced during the walking periods [28].

The trend in muscle SO_2 observed during walking differs from findings that researched sustained isometric contractions [22–25]. Occluded blood flow to the muscle is responsible for the reductions in muscle SO_2 as a result of an increase in intramuscular pressure. It has previously been reported that intramuscular pressure is lower during dynamic muscle contractions compared to static contractions [55]. Though intramuscular pressure was not measured in the current study, it is predicted that it is decreased during the walking periods and blood volume increased as a result. The increase in muscle SO_2 is explained by the increase in blood volume throughout the walking period measured at the muscle.

It is likely that flooring surface had a minimal impact on the intensity of muscle activations experienced during long-term walking. As a result, no significant changes in muscle SO_2 were found across flooring conditions. The findings from this study suggest, though flooring surface has an impact on subjective discomfort, it does not affect changes in muscle SO_2 during gait.

8.0 LIMITATIONS

The questionnaire and scoring system used to assess subjective discomfort during long-term standing and walking could potentially be inaccurate at quantifying a subject's true response. Asking subjects to rate their development of "discomfort" instead of "pain" or "fatigue" in body regions could factor in to creating an overestimation or underestimation of the responses given [34]. Additionally, it is impossible to determine if there was a bias in the subjective responses considering that subjects were prompted to rate fatigue every 30 minutes. This could be avoided by administering discomfort surveys every 1 hour to increase the time between ratings.

The reliability of using NIRS to measure muscle oxygenation has been validated [16]. However, the NIRS recordings are very sensitive to changes in probe placement on the surface of the skin. Subjects returned for multiple visits throughout the study so replacing the NIRS probes in the same location was crucial. Measurements were taken from anatomical landmarks to the location of the probes to verify the correct placement for each testing session but the accuracy in replacing the probe in the same location was difficult to determine considering the possibility for measurement errors. Another difficulty that arose in the placement of the NIRS probes was verifying that the light emitting diodes and detectors were in contact with the skin. This was more of a problem for the erector spinae muscle than it was for the soleus, because of the curvature of the lower back. The probes were taped down to the skin and covered with a dark fabric to prevent the detector from recording noise from ambient light which appeared to fix this problem.

The method used in this study for estimating the number of body-weight shifts has been used in previous research [42]. The method defined a shift in body-weight based on the percentage of body-weight distributed to each foot. Shifts in body-weight have also been described by monitoring excursions in COP [37,39]. The difference in methods for describing postural measures between researchers makes it difficult to compare findings across studies. Furthermore, counting the number of body-weight shifts may not be the best way to describe changes in body-weight distribution during standing. It is impossible to determine whether subjects would shift their body-weight due to feelings of discomfort or for other reasons like an inadvertent external cue from the testing environment or as a result of a task that the subject was performing. The method was unable to differentiate between reasons for a shift in body-weight.

The large variation in body-weight shifts seen across subjects is another limiting factor for quantifying postural movements (see Appendix C.1). A proportion of the total body-weight shifts in each 30 minute interval to the cumulative number of shifts counted over the entire 6 hours of standing could be estimated instead of an absolute total. This would account for the natural tendencies for some participants to frequently redistribute their body-weight at a greater rate.

The greatest limiting factor of this study was that it seems muscle SO_2 is dependent on postural movements. This finding has made it difficult to make conclusions on the effect of flooring on muscle SO_2 during long-term standing. Future investigations could eliminate any effect of postural movements on muscle SO_2 by limiting participants from redistributing their body-weight. Finally, this study was limited by a small sample size. The impact of flooring surface on subjective discomfort and objective measures of fatigue might become significant with a larger sample of the population studied.

9.0 CONCLUSIONS

This research confirms that periods of long-term standing and walking are associated to the development of general tiredness and subjective discomfort. A gradual increase in erector spinae SO_2 was found over 6 hours of long-term standing but large variations within each hour were observed. In general, oxygenation levels in the erector spinae were similar to resting values. Likewise, the soleus muscle tended to maintain similar levels of SO_2 compared to resting values during long-term standing. Subjective discomfort appeared to be unrelated to changes in levels of muscle SO_2. The behavior of muscle SO_2 during long-term standing did not follow the same pattern as seen in sustained isometric contractions. It was determined that the frequent redistribution of body-weight created a cycle of muscle relaxation and exertion. The frequent low intensity contractions experienced during this period were likely to have decreased intramuscular pressure and allowed for muscles to maintain a steady level of oxygenation.

In this study, flooring surface appeared to have a small effect on subjective measures of fatigue. This finding makes it difficult to draw conclusions on how flooring surface affects behavioral responses during long-term standing. However, there were no differences in behavioral responses among flooring surface which could be a result of there being no difference in subjective discomfort. The results of this research showed flooring surface had a minimal impact on postural measures during 6 hours of standing. The absence in flooring effect on muscle oxygenation can be explained by the similar patterns observed in body-weight distribution across flooring surface.

Long-term walking resulted in an increase in muscle SO_2 that eventually plateaued after 30 minutes. Increases in muscle SO_2 corresponded to increases in subjective discomfort. Conclusions cannot be drawn on whether or not the increase in muscle SO_2 was the cause for the discomfort because this relationship was not observed during long-term standing and previous research findings relating muscle fatigue to decreases in muscle SO_2 during a sustained isometric contraction. The increase in muscle SO_2 can be associated to the gradual increase in blood volume measured at the muscle throughout the walking periods. This is a result of the likely decrease in intramuscular pressure during repeated dynamic contractions compared to a sustained static contraction. In addition, the results of this study show flooring surface does not impact the changes in muscle SO_2 observed during long-term walking.

In conclusion, previous research has shown flooring surface can have a major impact on subjective measures of discomfort and behavioral responses during long-term standing and walking. The cause of discomfort and fatigue during long-term standing and walking is still unclear. Similarities were found in subjective discomfort measures across flooring surfaces in this research, which could explain the similarities observed in behavioral responses. No conclusions could be derived on the effect of flooring due to these findings. Findings from this research suggest sensations of discomfort are more skeletal than physiological. Further investigation is necessary to determine factors that influence muscle fatigue and discomfort.

APPENDIX A

DISCOMFORT SURVEYS

A.1 STANDING

Surveys were administered to subjects throughout the standing sessions to monitor RPDs. The RPDs were based on the nonlinear CR10-Borg scale which ranged from 0 (no discomfort at all) – 10 (extremely stressful). Values of 11, "~" and "▪" were also a scaling option that represented maximum stress levels. A baseline questionnaire was administered during the first 5 minutes of standing in the overall session. Subsequent questionnaires were administered halfway through and at the end of each hour of standing to accumulate to a total of 13 ratings. Ratings for overall tiredness, overall leg tiredness, upper and lower back, hip, upper leg, knee, lower leg, ankle, and feet discomfort were quantified throughout standing. The RPDs were transformed to a linear scale that ranged from 6-23. The responses were normalized to the first survey.

The following table includes a list of subjects that completed the testing protocol for each flooring condition and whether or not they were included in the analysis.

Table 15: Subjects who completed testing protocol

	Flooring Condition			**Included in Analysis**	
Subject	**Hard Tile**	**Soft Mat**	**Rubber Tile**	**Standing on Hard Tile**	**Standing on all Flooring Conditions**
S04	✓	✓	✓	✓	✓
S05	✓	×	✓	✓	×
S06	✓	✓	✓	✓	✓
S08	✓	×	×	✓	×
S10	✓	✓	✓	✓	✓
S11	✓	✓	✓	✓	✓
S12	✓	✓	✓	✓	✓
S13	✓	✓	✓	✓	×
S14	✓	✓	✓	×	×
S15	✓	✓	✓	✓	×

A.1.1 Hard Tile

Table 16: Overall tiredness RPD: standing on hard tile

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	7	8	7	11	11	12	12	13	14	15	16	16
S05	6	11	11	11	13	11	11	13	13	13	13	13	14
S06	6	6	6	6	9	9	7	7	7	9	7	12	7
S08	6	7	7	7	7	9	8	7	8	9	9	9	10
S10	6	6	6	7	8	9	9	10	10	10	11	11	12
S11	6	6	6	6	6	9	6	9	6	9	9	9	11
S12	6	6	6	6	6	6	6	7	8	8	8	6	6
S13	6	7	9	10	11	12	12	12	12	13	13	15	15
S14	6	3	6	6	6	6	6	7	8	8	8	8	8
S15	6	6	7	6	6	7	7	6	6	6	5	6	6
Mean	6.0	6.5	7.2	7.2	8.3	8.9	8.4	9.0	9.1	9.9	9.8	10.5	10.5
SD	0.0	2.0	1.7	1.8	2.6	2.1	2.5	2.6	2.7	2.6	3.1	3.5	3.7

Table 17: Overall leg tiredness RPD: standing on hard tile

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	7	10	11	11	11	11	12	13	15	15	16	16
S05	6	7	8	11	9	11	11	11	11	11	13	13	14
S06	6	8	11	11	13	13	13	13	13	13	13	13	13
S08	6	10	10	11	12	12	14	13	13	13	13	14	14
S10	6	7	7	8	8	9	10	10	10	10	11	11	12
S11	6	6	6	11	9	9	11	11	6	9	13	13	11
S12	6	9	10	9	11	11	11	10	12	12	13	12	12
S13	6	11	13	13	14	15	16	16	16	17	18	18	18
S14	6	9	9	9	9	9	10	10	12	11	11	11	11
S15	6	7	8	8	9	9	9	8	9	9	9	10	9
Mean	6.0	8.1	9.2	10.2	10.5	10.9	11.6	11.4	11.5	12.0	12.9	13.1	13.0
SD	0.0	1.6	2.0	1.6	2.0	2.0	2.1	2.2	2.7	2.6	2.4	2.4	2.6

Table 18: Upper back RPD: standing on hard tile

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	6	8	8	11	11	12	12	13	14	14	15	15
S05	6	6	6	6	6	6	6	6	6	10	12	13	11
S06	6	6	9	11	11	11	11	11	11	11	11	12	13
S08	6	6	6	6	9	9	13	11	11	12	11	11	12
S10	6	6	6	8	9	11	11	12	13	14	14	15	14
S11	6	6	9	11	11	11	11	11	11	11	11	12	11
S12	6	9	9	9	9	9	9	10	11	11	12	9	11
S13	6	6	6	6	6	6	11	6	6	6	11	13	13
S14	6	6	6	6	6	6	6	6	6	6	6	6	6
S15	6	6	6	6	6	6	6	6	6	6	6	8	8
Mean	6.0	6.3	7.1	7.7	8.4	8.6	9.6	9.1	9.4	10.1	10.8	11.4	11.4
SD	0.0	0.9	1.4	2.1	2.2	2.4	2.7	2.7	3.0	3.1	2.8	3.0	2.7

Table 19: Lower back RPD: standing on hard tile

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	6	7	7	10	10	11	11	12	13	13	14	14
S05	6	6	6	6	6	6	6	6	6	11	12	13	12
S06	6	6	10	11	11	10	11	12	13	13	14	14	14
S08	6	3	9	6	11	11	11	10	11	12	13	12	13
S10	6	11	12	13	15	15	16	16	16	17	17	17	17
S11	6	6	11	13	11	13	11	13	13	13	13	13	13
S12	6	9	9	9	12	9	13	12	13	11	11	11	11
S13	6	7	6	10	10	11	12	12	12	12	13	13	13
S14	6	6	6	6	9	9	9	11	12	11	10	10	9
S15	6	11	13	11	12	11	11	11	11	13	12	13	12
Mean	6.0	7.1	8.9	9.2	10.7	10.5	11.1	11.4	11.9	12.6	12.8	13.0	12.8
SD	0.0	2.5	2.6	2.8	2.3	2.4	2.6	2.5	2.5	1.8	1.9	1.9	2.1

Table 20: Hip RPD: standing on hard tile

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	7	8	9	12	11	12	12	13	14	14	15	15
S05	6	6	6	6	6	6	6	6	6	8	11	11	9
S06	6	6	9	10	9	9	11	13	13	12	13	14	13
S08	6	6	6	6	9	6	6	6	6	6	6	6	6
S10	6	4	4	6	7	9	10	11	12	12	12	13	12
S11	6	6	11	6	9	9	9	11	11	9	11	12	11
S12	6	9	9	10	12	12	12	12	12	12	12	11	11
S13	6	6	6	6	6	6	6	11	12	13	14	14	15
S14	6	6	6	6	6	6	6	9	9	9	9	9	9
S15	6	6	6	6	6	6	6	6	6	6	6	6	6
Mean	6.0	6.2	7.1	7.1	8.2	8.0	8.4	9.7	10.0	10.1	10.8	11.1	10.7
SD	0.0	1.2	2.1	1.8	2.4	2.3	2.7	2.8	3.0	2.9	2.9	3.2	3.2

Table 21: Upper leg RPD: standing on hard tile

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	6	8	8	12	12	12	12	13	14	14	15	15
S05	6	6	6	6	6	9	6	6	6	6	8	9	8
S06	6	8	9	11	12	12	12	12	11	12	12	12	13
S08	6	9	8	11	11	11	6	12	11	12	14	13	11
S10	6	7	8	9	7	7	10	10	10	10	11	11	11
S11	6	6	11	9	11	11	11	11	11	11	11	13	13
S12	6	10	10	10	12	12	10	12	12	12	12	12	12
S13	6	6	6	6	6	6	11	11	13	13	13	13	13
S14	6	6	6	6	6	6	6	9	9	10	9	10	10
S15	6	6	7	8	8	8	8	7	8	8	8	8	8
Mean	6.0	7.0	7.9	8.4	9.1	9.4	9.2	10.2	10.4	10.8	11.2	11.6	11.4
SD	0.0	1.5	1.7	2.0	2.7	2.5	2.5	2.2	2.2	2.4	2.3	2.1	2.3

Table 22: Knee RPD: standing on hard tile

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	8	10	11	11	12	12	13	14	15	15	16	16
S05	6	6	8	6	6	9	6	6	6	6	6	6	6
S06	6	7	11	12	12	12	12	12	13	13	12	14	13
S08	6	10	6	9	9	10	10	11	11	11	11	11	11
S10	6	6	6	7	7	9	10	11	11	11	11	12	12
S11	6	6	6	6	11	6	11	6	6	13	13	13	11
S12	6	8	9	11	9	11	9	9	10	12	12	12	11
S13	6	6	11	11	12	12	12	12	12	12	13	13	14
S14	6	9	9	9	9	9	9	10	10	10	10	10	9
S15	6	6	6	9	11	11	11	10	11	12	13	12	12
Mean	6.0	7.2	8.2	9.1	9.7	10.1	10.2	10.0	10.4	11.5	11.6	11.9	11.5
SD	0.0	1.5	2.1	2.2	2.1	1.9	1.9	2.4	2.6	2.4	2.4	2.6	2.7

Table 23: Lower leg RPD: standing on hard tile

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	7	10	11	12	12	13	13	14	15	15	16	16
S05	6	6	9	11	8	13	11	11	13	14	11	12	13
S06	6	8	9	11	12	13	11	11	11	12	12	14	12
S08	6	8	9	10	11	12	12	11	11	11	12	11	13
S10	6	7	8	9	8	9	9	10	9	11	11	12	12
S11	6	11	11	13	13	13	14	13	14	14	14	15	15
S12	6	6	8	10	9	9	10	9	10	11	11	10	12
S13	6	6	8	10	11	11	11	12	11	11	12	12	13
S14	6	9	10	9	9	11	10	11	11	11	11	11	11
S15	6	8	9	10	10	10	9	8	10	8	8	9	10
Mean	6.0	7.6	9.1	10.4	10.3	11.3	11.0	10.9	11.4	11.8	11.7	12.2	12.7
SD	0.0	1.6	1.0	1.2	1.8	1.6	1.6	1.6	1.7	2.0	1.9	2.2	1.8

Table 24: Ankle RPD: standing on hard tile

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	7	10	11	12	12	12	12	12	14	15	16	16
S05	6	6	9	13	11	11	11	13	13	13	13	13	13
S06	6	6	9	11	11	11	11	11	12	12	13	13	13
S08	6	6	5	6	5	5	8	9	9	9	8	8	8
S10	6	8	8	9	11	11	11	13	15	15	13	14	13
S11	6	6	9	9	6	6	9	13	13	11	11	12	11
S12	6	8	8	8	8	8	8	9	10	9	8	9	10
S13	6	8	10	10	12	12	13	12	12	14	14	15	15
S14	6	6	9	9	9	9	9	9	9	9	9	9	9
S15	6	8	8	8	9	10	9	9	9	11	9	10	11
Mean	6.0	6.9	8.5	9.4	9.4	9.5	10.1	11.0	11.4	11.7	11.3	11.9	11.9
SD	0.0	1.0	1.4	2.0	2.5	2.5	1.7	1.8	2.1	2.3	2.6	2.8	2.6

Table 25: Feet RPD: standing on hard tile

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	8	9	11	11	11	12	12	12	14	14	15	15
S05	6	14	16	15	15	15	15	16	16	16	16	16	17
S06	6	7	11	12	14	15	16	16	17	18	18	18	19
S08	6	9	10	11	13	13	14	14	14	14	15	15	15
S10	6	11	12	13	14	13	14	15	15	15	16	15	16
S11	6	11	13	13	13	13	15	14	14	15	15	16	16
S12	6	6	7	7	7	7	8	8	8	8	8	9	8
S13	6	8	10	10	11	12	12	13	13	13	14	15	15
S14	6	11	11	12	11	12	12	13	13	12	13	12	12
S15	6	10	12	12	13	12	13	12	14	12	12	12	14
Mean	6.0	9.5	11.1	11.6	12.2	12.3	13.1	13.3	13.6	13.7	14.1	14.3	14.7
SD	0.0	2.4	2.4	2.1	2.3	2.3	2.3	2.4	2.5	2.7	2.7	2.6	3.0

A.1.2 Soft Mat

Table 26: Overall tiredness RPD: standing on soft mat

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	6	6	7	8	8	10	9	10	11	12	13	14
S05	-	-	-	-	-	-	-	-	-	-	-	-	-
S06	6	6	9	9	9	9	9	10	11	12	11	11	13
S08	-	-	-	-	-	-	-	-	-	-	-	-	-
S10	6	6	9	11	10	11	12	14	14	14	15	16	17
S11	6	1	1	4	8	8	9	10	9	10	10	10	11
S12	6	6	6	6	6	6	6	6	6	6	6	6	6
S13	6	6	8	9	8	9	10	13	13	14	15	15	15
S14	6	6	6	6	6	6	6	6	6	6	6	6	6
S15	6	6	6	7	7	7	7	7	6	8	8	8	8
Mean	6.0	5.4	6.4	7.4	7.8	8.0	8.6	9.4	9.4	10.1	10.4	10.6	11.3
SD	0.0	1.8	2.6	2.2	1.4	1.7	2.1	3.0	3.2	3.2	3.6	3.9	4.2

Table 27: Overall leg tiredness RPD: standing on soft mat

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	6	7	7	9	8	10	9	11	11	12	14	14
S05	-	-	-	-	-	-	-	-	-	-	-	-	-
S06	6	5	7	9	9	11	10	11	12	11	12	13	14
S08	-	-	-	-	-	-	-	-	-	-	-	-	-
S10	6	8	11	12	11	12	13	14	15	15	16	17	18
S11	6	11	13	13	13	14	15	16	15	16	16	16	16
S12	6	7	8	7	7	7	7	7	7	7	7	7	7
S13	6	8	8	9	10	10	12	13	14	15	14	15	15
S14	6	8	9	9	11	12	11	11	14	14	14	14	14
S15	6	8	8	9	9	9	9	9	9	10	10	10	10
Mean	6.0	7.6	8.9	9.4	9.9	10.4	10.9	11.3	12.1	12.4	12.6	13.3	13.5
SD	0.0	1.8	2.1	2.1	1.8	2.3	2.5	3.0	2.9	3.1	3.1	3.3	3.5

Table 28: Upper back RPD: standing on soft mat

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	6	6	7	7	8	9	9	11	10	12	13	14
S05	-	-	-	-	-	-	-	-	-	-	-	-	-
S06	6	6	9	11	11	11	11	12	13	12	12	13	13
S08	-	-	-	-	-	-	-	-	-	-	-	-	-
S10	6	6	6	6	6	6	6	11	13	13	13	13	13
S11	6	8	9	9	9	8	9	9	10	10	10	10	11
S12	6	6	6	6	6	6	6	6	6	6	6	6	6
S13	6	6	6	6	6	6	6	6	6	6	6	6	6
S14	6	6	6	6	6	6	6	6	6	6	6	6	6
S15	6	6	6	6	4	6	4	7	7	7	7	7	7
Mean	6.0	6.3	6.8	7.1	6.9	7.1	7.1	8.3	9.0	8.8	9.0	9.3	9.5
SD	0.0	0.7	1.4	1.9	2.2	1.8	2.3	2.4	3.1	2.9	3.1	3.4	3.6

Table 29: Lower back RPD: standing on soft mat

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	6	7	8	7	9	9	11	11	11	12	13	14
S05	-	-	-	-	-	-	-	-	-	-	-	-	-
S06	6	7	10	11	12	14	15	14	16	15	15	15	17
S08	-	-	-	-	-	-	-	-	-	-	-	-	-
S10	6	6	6	7	6	6	9	14	15	15	15	17	18
S11	6	6	11	13	15	13	15	15	16	16	16	15	16
S12	6	6	6	6	7	6	6	6	6	6	6	6	6
S13	6	6	6	6	9	9	10	11	11	12	12	14	13
S14	6	6	6	6	9	10	9	11	14	9	11	11	11
S15	6	6	6	6	5	5	5	5	5	6	6	6	6
Mean	6.0	6.1	7.3	7.9	8.8	9.0	9.8	10.9	11.8	11.3	11.6	12.1	12.6
SD	0.0	0.4	2.1	2.7	3.3	3.3	3.7	3.7	4.3	4.0	3.9	4.2	4.7

Table 30: Hip RPD: standing on soft mat

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	6	6	6	7	8	9	10	11	11	12	13	13
S05	-	-	-	-	-	-	-	-	-	-	-	-	-
S06	6	6	11	7	9	11	12	12	13	12	13	11	14
S08	-	-	-	-	-	-	-	-	-	-	-	-	-
S10	6	8	8	11	8	7	6	11	13	14	11	13	14
S11	6	6	11	13	13	11	11	11	13	13	13	13	13
S12	6	6	6	6	6	7	7	7	7	7	7	7	7
S13	6	6	6	6	6	6	9	11	11	11	11	11	11
S14	6	6	6	9	6	9	6	6	9	9	6	9	6
S15	6	6	6	6	6	6	6	6	6	6	6	6	6
Mean	6.0	6.3	7.5	8.0	7.6	8.1	8.3	9.3	10.4	10.4	9.9	10.4	10.5
SD	0.0	0.7	2.3	2.7	2.4	2.0	2.4	2.5	2.8	2.8	3.0	2.8	3.6

Table 31: Upper leg RPD: standing on soft mat

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	6	6	6	7	9	9	10	10	11	13	12	14
S05	-	-	-	-	-	-	-	-	-	-	-	-	-
S06	6	4	9	9	9	9	9	10	11	10	11	11	11
S08	-	-	-	-	-	-	-	-	-	-	-	-	-
S10	6	8	10	12	12	12	13	13	14	15	15	15	17
S11	6	11	13	14	14	13	13	14	14	16	15	14	15
S12	6	6	6	6	6	6	6	6	6	6	6	6	6
S13	6	6	6	6	8	9	10	9	10	10	10	12	12
S14	6	6	9	6	9	6	9	9	11	9	6	10	11
S15	6	7	8	9	7	10	8	10	9	10	10	9	9
Mean	6.0	6.8	8.4	8.5	9.0	9.3	9.6	10.1	10.6	10.9	10.8	11.1	11.9
SD	0.0	2.1	2.4	3.1	2.7	2.5	2.4	2.5	2.6	3.2	3.5	2.9	3.5

Table 32: Knee RPD: standing on soft mat

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	6	6	7	8	8	10	10	11	11	12	13	14
S05	-	-	-	-	-	-	-	-	-	-	-	-	-
S06	6	6	9	11	9	11	11	12	12	12	12	13	13
S08	-	-	-	-	-	-	-	-	-	-	-	-	-
S10	6	8	10	11	10	11	14	15	15	15	15	16	15
S11	6	8	9	9	10	9	10	9	10	10	11	11	12
S12	6	6	7	6	6	7	7	7	8	8	8	8	7
S13	6	8	8	8	9	9	11	10	10	11	13	11	11
S14	6	9	9	9	11	10	10	10	11	9	11	9	12
S15	6	6	7	8	7	7	8	8	8	8	8	9	9
Mean	6.0	7.1	8.1	8.6	8.8	9.0	10.1	10.1	10.6	10.5	11.3	11.3	11.6
SD	0.0	1.2	1.4	1.8	1.7	1.6	2.1	2.5	2.3	2.3	2.4	2.7	2.6

Table 33: Lower leg RPD: standing on soft mat

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	6	7	8	8	9	10	11	12	12	14	14	14
S05	-	-	-	-	-	-	-	-	-	-	-	-	-
S06	6	7	11	13	13	13	13	13	13	13	14	13	15
S08	-	-	-	-	-	-	-	-	-	-	-	-	-
S10	6	8	12	12	12	13	15	13	14	15	16	14	18
S11	6	13	14	16	16	16	17	16	16	17	17	17	18
S12	6	6	6	6	6	6	6	6	6	6	6	6	6
S13	6	6	6	8	8	9	9	10	11	11	12	12	12
S14	6	9	10	11	10	12	11	11	13	13	13	13	14
S15	6	7	8	8	8	9	9	10	9	9	10	9	10
Mean	6.0	7.8	9.3	10.3	10.1	10.9	11.3	11.3	11.8	12.0	12.8	12.3	13.4
SD	0.0	2.4	3.0	3.3	3.3	3.2	3.6	2.9	3.1	3.4	3.5	3.4	4.0

Table 34: Ankle RPD: standing on soft mat

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	6	6	8	8	9	11	11	11	11	13	13	13
S05	-	-	-	-	-	-	-	-	-	-	-	-	-
S06	6	6	8	10	11	12	12	13	12	15	13	13	14
S08	-	-	-	-	-	-	-	-	-	-	-	-	-
S10	6	7	10	11	11	13	14	14	14	14	15	16	16
S11	6	14	12	13	15	11	15	13	12	11	11	13	13
S12	6	6	6	6	6	6	6	6	6	6	6	6	6
S13	6	6	8	9	9	10	11	11	11	12	11	11	13
S14	6	9	9	9	10	9	10	11	11	11	12	13	13
S15	6	8	7	7	9	9	8	8	8	9	9	10	10
Mean	6.0	7.8	8.3	9.1	9.9	9.9	10.9	10.9	10.6	11.1	11.3	11.9	12.3
SD	0.0	2.8	2.1	2.2	2.6	2.2	2.9	2.7	2.5	2.8	2.8	2.9	3.0

Table 35: Feet RPD: standing on soft mat

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	6	7	9	9	10	11	12	13	13	14	14	15
S05	-	-	-	-	-	-	-	-	-	-	-	-	-
S06	6	6	8	9	10	11	11	12	13	13	14	15	15
S08	-	-	-	-	-	-	-	-	-	-	-	-	-
S10	6	8	11	12	12	13	15	13	14	14	15	15	16
S11	6	8	9	9	10	9	10	9	10	10	11	11	12
S12	6	8	8	8	8	8	10	10	9	9	10	10	9
S13	6	9	9	10	10	11	13	13	13	14	15	16	16
S14	6	13	11	12	12	12	12	13	14	15	15	15	16
S15	6	8	8	9	9	9	10	9	9	9	10	10	11
Mean	6.0	8.3	8.9	9.8	10.0	10.4	11.5	11.4	11.9	12.1	13.0	13.3	13.8
SD	0.0	2.2	1.5	1.5	1.4	1.7	1.8	1.8	2.2	2.4	2.3	2.5	2.7

A.1.3 Rubber Tile

Table 36: Overall tiredness RPD: standing on rubber tile

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	7	8	8	9	11	11	12	11	11	13	15	16
S05	6	8	8	8	8	8	9	9	8	10	10	11	13
S06	6	7	7	7	7	8	9	11	13	13	13	9	13
S08	-	-	-	-	-	-	-	-	-	-	-	-	-
S10	6	6	6	5	5	6	6	7	8	9	9	9	9
S11	6	6	9	9	9	11	11	11	13	11	14	13	15
S12	6	4	4	4	5	4	5	6	5	5	5	6	6
S13	6	4	6	7	8	8	8	8	11	11	11	11	12
S14	6	5	10	9	10	10	12	12	12	12	13	13	13
S15	6	5	5	5	5	6	6	7	6	7	7	7	6
Mean	6.0	5.8	7.0	6.9	7.3	8.0	8.6	9.2	9.7	9.9	10.6	10.4	11.4
SD	0.0	1.4	1.9	1.8	1.9	2.4	2.5	2.3	3.0	2.5	3.1	3.0	3.6

Table 37: Overall leg tiredness RPD: standing on rubber tile

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	7	8	8	10	11	12	13	13	12	14	15	15
S05	6	7	7	7	8	8	8	9	9	9	11	11	13
S06	6	6	8	9	11	11	11	14	15	15	13	14	13
S08	-	-	-	-	-	-	-	-	-	-	-	-	-
S10	6	6	8	8	9	9	10	10	10	12	12	12	12
S11	6	9	6	11	13	11	13	13	14	14	15	14	15
S12	6	9	9	10	10	11	11	12	11	11	11	12	11
S13	6	8	10	12	12	13	14	14	15	16	17	17	17
S14	6	8	11	10	10	11	13	13	13	13	14	14	14
S15	6	9	11	11	11	11	12	11	10	11	12	12	13
Mean	6.0	7.7	8.7	9.6	10.4	10.7	11.6	12.1	12.2	12.6	13.2	13.4	13.7
SD	0.0	1.2	1.7	1.7	1.5	1.4	1.8	1.8	2.3	2.2	2.0	1.9	1.8

Table 38: Upper back RPD: standing on rubber tile

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	7	8	9	10	10	12	13	13	13	13	14	14
S05	6	6	6	6	6	9	9	9	9	9	10	9	6
S06	6	6	9	9	11	11	11	11	13	12	13	11	13
S08	-	-	-	-	-	-	-	-	-	-	-	-	-
S10	6	6	6	9	11	11	13	12	13	13	13	14	14
S11	6	6	6	9	6	11	13	12	14	14	13	13	13
S12	6	6	6	6	7	6	6	6	6	7	8	7	6
S13	6	6	6	6	6	6	6	6	6	6	6	6	6
S14	6	6	6	6	6	6	6	6	6	6	7	6	6
S15	6	6	6	6	6	8	8	9	9	9	9	6	9
Mean	6.0	6.1	6.6	7.3	7.7	8.7	9.3	9.3	9.9	9.9	10.2	9.6	9.7
SD	0.0	0.3	1.1	1.6	2.3	2.2	3.0	2.8	3.4	3.2	2.9	3.5	3.8

Table 39: Lower back RPD: standing on rubber tile

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	6	7	9	9	11	12	12	13	13	14	14	15
S05	6	6	6	7	8	11	12	12	11	13	12	12	12
S06	6	7	11	9	12	13	13	13	14	16	17	17	17
S08	-	-	-	-	-	-	-	-	-	-	-	-	-
S10	6	9	11	14	15	16	17	17	18	18	18	18	18
S11	6	6	6	9	6	11	13	13	15	15	15	14	14
S12	6	6	6	6	6	6	6	6	8	9	9	9	8
S13	6	3	6	6	8	8	8	10	11	11	13	13	13
S14	6	5	5	5	5	5	7	7	7	7	6	6	7
S15	6	6	6	6	6	6	6	6	6	6	8	8	8
Mean	6.0	6.0	7.1	7.9	8.3	9.7	10.4	10.7	11.4	12.0	12.4	12.3	12.4
SD	0.0	1.6	2.3	2.8	3.3	3.7	3.8	3.7	4.0	4.1	4.1	4.0	4.0

Table 40: Hip RPD: standing on rubber tile

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	6	6	8	9	10	11	12	12	12	13	13	14
S05	6	6	6	6	6	6	6	6	6	6	6	6	6
S06	6	6	6	9	11	11	9	11	11	11	11	13	14
S08	-	-	-	-	-	-	-	-	-	-	-	-	-
S10	6	6	6	6	9	9	11	11	12	12	13	13	13
S11	6	6	6	6	6	9	11	11	13	11	11	11	13
S12	6	6	6	6	6	8	8	8	9	9	10	10	8
S13	6	6	6	6	6	6	11	11	12	13	13	13	13
S14	6	6	6	6	6	6	6	6	6	6	6	6	9
S15	6	6	6	6	6	6	6	6	6	6	6	6	6
Mean	6.0	6.0	6.0	6.6	7.2	7.9	8.8	9.1	9.7	9.6	9.9	10.1	10.7
SD	0.0	0.0	0.0	1.1	1.9	2.0	2.3	2.6	3.0	2.9	3.1	3.3	3.4

Table 41: Upper leg RPD: standing on rubber tile

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	6	6	8	9	10	11	12	12	13	13	14	14
S05	6	6	6	6	6	6	6	6	6	6	6	6	7
S06	6	6	9	11	11	13	13	13	13	14	13	14	13
S08	-	-	-	-	-	-	-	-	-	-	-	-	-
S10	6	6	8	9	9	9	12	11	12	12	12	12	13
S11	6	6	6	9	6	11	11	11	13	13	13	13	14
S12	6	7	6	7	7	8	8	8	8	10	9	9	8
S13	6	6	6	6	6	6	6	6	6	6	6	11	6
S14	6	6	11	9	9	10	9	9	9	9	6	9	9
S15	6	9	11	9	10	10	11	10	9	12	11	11	9
Mean	6.0	6.4	7.7	8.2	8.1	9.2	9.7	9.6	9.8	10.6	9.9	11.0	10.3
SD	0.0	1.0	2.2	1.6	1.9	2.3	2.5	2.5	2.8	3.0	3.2	2.6	3.2

Table 42: Knee RPD: standing on rubber tile

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	6	6	8	11	11	12	13	13	13	13	14	14
S05	6	6	6	6	6	6	6	8	6	8	9	8	8
S06	6	7	7	11	11	11	11	11	11	13	11	13	12
S08	-	-	-	-	-	-	-	-	-	-	-	-	-
S10	6	6	6	6	9	9	11	10	11	13	12	13	13
S11	6	6	11	9	6	13	11	11	13	13	13	13	14
S12	6	6	7	6	6	8	8	6	10	9	10	10	10
S13	6	6	6	8	8	9	9	8	10	11	11	11	10
S14	6	9	9	9	10	10	11	12	11	12	13	11	12
S15	6	7	8	8	10	8	8	10	11	10	9	9	9
Mean	6.0	6.6	7.3	7.9	8.6	9.4	9.7	9.9	10.7	11.3	11.2	11.3	11.3
SD	0.0	1.0	1.7	1.7	2.1	2.1	2.0	2.2	2.1	1.9	1.6	2.1	2.2

Table 43: Lower leg RPD: standing on rubber tile

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	7	7	9	11	12	13	13	14	14	14	15	15
S05	6	6	6	6	8	11	8	8	8	8	11	8	11
S06	6	6	8	10	11	11	12	12	12	13	11	13	11
S08	-	-	-	-	-	-	-	-	-	-	-	-	-
S10	6	8	8	10	10	10	12	11	11	12	13	12	12
S11	6	9	11	13	14	15	14	16	17	16	18	18	18
S12	6	6	6	6	7	7	9	7	8	8	9	9	10
S13	6	6	6	6	6	6	9	9	13	12	13	13	14
S14	6	12	14	11	13	13	14	13	13	13	14	14	14
S15	6	11	14	12	13	13	15	12	10	12	13	12	12
Mean	6.0	7.9	8.9	9.2	10.3	10.9	11.8	11.2	11.8	12.0	12.9	12.7	13.0
SD	0.0	2.3	3.3	2.7	2.8	2.9	2.5	2.8	2.9	2.6	2.5	3.0	2.5

Table 44: Ankle RPD: standing on rubber tile

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	7	8	9	11	13	12	14	14	15	15	15	16
S05	6	9	9	8	11	9	11	9	10	9	11	9	9
S06	6	6	6	9	9	12	13	13	13	13	13	14	11
S08	6	6	6	9	8	11	9	12	13	13	13	14	15
S10	-	-	-	-	-	-	-	-	-	-	-	-	-
S11	6	6	11	9	6	11	11	11	13	11	13	13	14
S12	6	6	6	6	7	6	6	7	6	6	7	8	8
S13	6	6	6	6	6	11	12	12	13	13	13	13	13
S14	6	14	12	9	12	12	11	13	12	13	15	11	13
S15	6	7	9	8	9	9	9	9	10	10	9	10	12
Mean	6.0	7.4	8.1	8.1	8.8	10.4	10.4	11.1	11.6	11.4	12.1	11.9	12.3
SD	0.0	2.7	2.3	1.3	2.2	2.1	2.1	2.3	2.5	2.7	2.7	2.5	2.6

Table 45: Feet RPD: standing on rubber tile

	Time of Survey (hour)												
Subject	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
S04	6	8	11	11	12	13	13	14	15	15	15	16	16
S05	6	11	11	12	12	12	11	13	12	13	14	14	13
S06	6	12	12	14	15	17	17	18	18	18	18	20	19
S08	-	-	-	-	-	-	-	-	-	-	-	-	-
S10	6	8	8	10	10	10	11	12	12	12	12	13	13
S11	6	11	13	14	14	16	15	17	18	18	18	19	19
S12	6	7	7	8	7	8	9	10	10	10	11	10	11
S13	6	9	12	12	13	13	14	15	15	16	17	17	18
S14	6	12	13	9	10	9	10	11	11	11	12	12	12
S15	6	12	14	12	14	14	15	13	13	14	15	16	16
Mean	6.0	10.0	11.2	11.3	11.9	12.4	12.8	13.7	13.8	14.1	14.7	15.2	15.2
SD	0.0	2.0	2.3	2.1	2.5	3.0	2.7	2.6	2.9	2.9	2.6	3.3	3.1

A.2 WALKING

Surveys were administered to subjects throughout the walking sessions to monitor ratings of perceived discomfort (RPDs). RPDs were based on the nonlinear CR10-Borg scale which ranged from 0 (no discomfort at all) – 10 (extremely stressful). Values of 11, "~" and "▪" were also a scaling option that represented maximum stress levels. The questionnaire included ratings for overall tiredness, overall leg tiredness, upper and lower back, hips, upper legs, knees, lower legs, ankles, and feet. Questionnaires were administered during the 5 minute standing baseline and the following 5 minute standing rest breaks for a total of 5 ratings. The RPDs were transformed to a linear scale that ranged from 6-23. The responses were normalized to the first survey.

The following table includes a list of subjects that completed the walking protocol for each flooring condition and whether or not they were included in the analysis.

Table 46: Subjects who completed testing protocol

	Completed Flooring Condition			**Included in Analysis**
Subject	**Hard Tile**	**Soft Mat**	**Rubber Tile**	**Walking on all Flooring Conditions**
S04	✓	✓	✓	✓
S05	✗	✗	✗	✗
S06	✓	✓	✓	✗
S08	✗	✗	✗	✗
S10	✓	✓	✓	✓
S11	✓	✓	✓	✓
S12	✓	✓	✓	✓
S13	✓	✓	✓	✓
S14	✓	✓	✓	✓
S15	✓	✓	✓	✓
S16	✓	✓	✓	✓
S17	✓	✓	✓	✓
S18	✓	✓	✓	✗

A.2.1 Hard Tile

Table 47: Overall tiredness RPD: walking on hard tile

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	7	14	16	17
S06	6	5	10	10	12
S10	6	7	4	7	7
S11	6	11	11	11	13
S12	6	5	6	6	7
S13	6	7	11	12	14
S14	6	6	9	10	10
S15	6	6	4	4	10
S16	6	10	13	15	16
S17	6	8	8	10	11
S18	6	6	6	6	6
Mean	6.0	7.1	8.7	9.7	11.2
SD	0.0	1.9	3.4	3.8	3.7

Table 48: Overall leg tiredness RPD: walking on hard tile

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	9	14	17	17
S06	6	6	9	9	13
S10	6	9	11	11	15
S11	6	6	11	13	13
S12	6	6	7	8	8
S13	6	6	12	13	13
S14	6	7	11	13	13
S15	6	10	12	12	16
S16	6	6	7	9	7
S17	6	11	11	11	13
S18	6	6	6	8	8
Mean	6.0	7.5	10.1	11.3	12.4
SD	0.0	1.9	2.5	2.7	3.3

Table 49: Upper back RPD: walking on hard tile

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	9	16	17	18
S06	6	9	9	11	12
S10	6	9	13	11	13
S11	6	11	11	11	13
S12	6	6	6	6	6
S13	6	6	6	6	6
S14	6	6	7	8	9
S15	6	6	6	8	7
S16	6	13	14	13	17
S17	6	11	13	11	11
S18	6	6	6	6	6
Mean	6.0	8.4	9.7	9.8	10.7
SD	0.0	2.5	3.8	3.4	4.3

Table 50: Lower back RPD: walking on hard tile

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	7	13	14	15
S06	6	9	9	11	12
S10	6	9	13	14	16
S11	6	6	13	13	13
S12	6	6	6	6	6
S13	6	6	9	11	11
S14	6	8	8	7	8
S15	6	6	8	9	8
S16	6	13	15	17	18
S17	6	9	11	11	11
S18	6	6	6	8	8
Mean	6.0	7.7	10.1	11.0	11.5
SD	0.0	2.2	3.1	3.3	3.8

Table 51: Hip RPD: walking on hard tile

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	11	14	17	17
S06	6	9	11	12	13
S10	6	6	9	11	11
S11	6	6	9	11	11
S12	6	7	7	8	10
S13	6	6	6	9	6
S14	6	6	7	8	9
S15	6	6	6	6	6
S16	6	6	6	9	8
S17	6	9	11	13	14
S18	6	6	6	6	6
Mean	6.0	7.1	8.4	10.0	10.1
SD	0.0	1.8	2.7	3.3	3.6

Table 52: Upper leg RPD: walking on hard tile

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	9	15	17	18
S06	6	6	11	12	13
S10	6	6	9	11	11
S11	6	11	13	9	13
S12	6	6	7	7	9
S13	6	6	9	11	11
S14	6	7	9	11	12
S15	6	7	9	11	13
S16	6	6	8	9	9
S17	6	9	9	11	11
S18	6	6	6	7	8
Mean	6.0	7.2	9.5	10.5	11.6
SD	0.0	1.7	2.6	2.7	2.7

Table 53: Knee RPD: walking on hard tile

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	11	15	17	17
S06	6	7	8	10	12
S10	6	6	9	11	13
S11	6	6	11	11	11
S12	6	6	6	6	7
S13	6	6	9	10	10
S14	6	6	8	9	9
S15	6	8	12	12	15
S16	6	6	8	13	12
S17	6	9	9	9	11
S18	6	11	11	9	13
Mean	6.0	7.5	9.6	10.6	11.8
SD	0.0	2.0	2.5	2.8	2.8

Table 54: Lower leg RPD: walking on hard tile

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	11	16	18	18
S06	6	9	9	11	14
S10	6	6	10	13	14
S11	6	-1	4	6	6
S12	6	6	6	6	7
S13	6	8	12	14	12
S14	6	8	10	11	12
S15	6	8	12	12	14
S16	6	6	8	9	9
S17	6	8	11	10	11
S18	6	6	6	8	8
Mean	6.0	6.8	9.5	10.7	11.4
SD	0.0	3.0	3.4	3.6	3.6

Table 55: Ankle RPD: walking on hard tile

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	11	16	19	19
S06	6	8	8	10	11
S10	6	9	9	13	13
S11	6	13	6	9	11
S12	6	6	6	6	8
S13	6	8	10	14	13
S14	6	7	9	11	10
S15	6	11	13	14	15
S16	6	6	8	11	11
S17	6	8	8	10	10
S18	6	11	11	14	15
Mean	6.0	8.9	9.5	11.9	12.4
SD	0.0	2.3	3.0	3.4	3.1

Table 56: Feet RPD: walking on hard tile

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	11	16	18	18
S06	6	6	8	10	12
S10	6	8	9	10	10
S11	6	13	11	13	14
S12	6	6	7	8	9
S13	6	7	11	12	13
S14	6	7	8	11	11
S15	6	10	12	14	16
S16	6	12	13	14	17
S17	6	9	10	11	11
S18	6	8	7	8	7
Mean	6.0	8.8	10.2	11.7	12.5
SD	0.0	2.4	2.8	2.9	3.4

A.2.2 Soft Mat

Table 57: Overall tiredness RPD: walking on soft mat

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	6	9	11	12
S06	6	6	6	6	6
S10	6	6	7	7	7
S11	6	11	11	11	11
S12	6	6	7	8	8
S13	6	6	7	10	12
S14	6	8	10	11	11
S15	6	6	6	6	6
S16	6	6	6	6	6
S17	6	7	9	10	9
S18	6	6	7	7	7
Mean	6.0	6.7	7.7	8.5	8.6
SD	0.0	1.6	1.7	2.2	2.5

Table 58: Overall leg tiredness RPD: walking on soft mat

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	8	11	11	14
S06	6	8	11	14	14
S10	6	8	10	11	11
S11	6	9	11	13	13
S12	6	6	7	7	8
S13	6	5	6	9	12
S14	6	4	4	9	10
S15	6	6	7	7	8
S16	6	6	6	7	7
S17	6	10	13	13	13
S18	6	6	7	7	8
Mean	6.0	6.9	8.5	9.8	10.7
SD	0.0	1.8	2.8	2.7	2.6

Table 59: Upper back RPD: walking on soft mat

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	9	11	13	14
S06	6	9	9	11	11
S10	6	6	9	12	13
S11	6	9	9	11	11
S12	6	6	6	6	6
S13	6	6	6	6	9
S14	6	6	6	6	6
S15	6	6	6	6	6
S16	6	6	8	9	9
S17	6	6	9	9	11
S18	6	8	8	9	9
Mean	6.0	7.0	7.9	8.9	9.5
SD	0.0	1.4	1.7	2.6	2.8

Table 60: Lower back RPD: walking on soft mat

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	9	9	12	14
S06	6	8	10	11	12
S10	6	11	14	14	15
S11	6	9	13	13	13
S12	6	6	6	6	6
S13	6	6	6	13	15
S14	6	6	6	7	7
S15	6	6	6	6	6
S16	6	8	10	10	12
S17	6	7	11	12	12
S18	6	8	13	13	14
Mean	6.0	7.6	9.5	10.6	11.5
SD	0.0	1.6	3.1	3.0	3.5

Table 61: Hip RPD: walking on soft mat

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	6	11	12	14
S06	6	11	11	13	13
S10	6	6	9	11	11
S11	6	9	11	11	13
S12	6	6	6	7	6
S13	6	6	6	6	6
S14	6	2	2	4	3
S15	6	6	6	6	6
S16	6	8	9	9	9
S17	6	8	12	12	13
S18	6	8	8	9	8
Mean	6.0	6.9	8.3	9.1	9.3
SD	0.0	2.3	3.0	3.0	3.7

Table 62: Upper leg RPD: walking on soft mat

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	6	11	13	15
S06	6	9	9	11	13
S10	6	6	9	11	11
S11	6	6	9	11	11
S12	6	5	5	5	5
S13	6	8	9	10	10
S14	6	6	8	11	9
S15	6	8	7	8	8
S16	6	7	6	6	6
S17	6	6	11	10	13
S18	6	6	8	9	9
Mean	6.0	6.6	8.4	9.5	10.0
SD	0.0	1.2	1.9	2.4	3.0

Table 63: Knee RPD: walking on soft mat

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	6	9	13	14
S06	6	6	8	10	11
S10	6	9	12	14	14
S11	6	6	9	11	11
S12	6	6	6	6	6
S13	6	6	9	11	11
S14	6	6	8	8	8
S15	6	6	8	8	8
S16	6	7	7	7	7
S17	6	8	12	12	13
S18	6	8	9	11	9
Mean	6.0	6.7	8.8	10.1	10.2
SD	0.0	1.1	1.8	2.5	2.8

Table 64: Lower leg RPD: walking on soft mat

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	7	10	13	15
S06	6	11	9	11	11
S10	6	6	11	14	14
S11	6	11	13	13	13
S12	6	6	6	7	6
S13	6	8	10	13	15
S14	6	7	7	10	12
S15	6	7	7	8	9
S16	6	7	7	7	7
S17	6	9	11	12	11
S18	6	8	8	9	10
Mean	6.0	7.9	9.0	10.6	11.2
SD	0.0	1.8	2.2	2.6	3.0

Table 65: Ankle RPD: walking on soft mat

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	7	11	12	14
S06	6	8	8	10	10
S10	6	9	11	11	11
S11	6	9	11	11	11
S12	6	6	7	6	6
S13	6	6	6	11	12
S14	6	6	7	8	8
S15	6	6	6	6	7
S16	6	7	8	8	9
S17	6	8	10	10	10
S18	6	13	13	14	15
Mean	6.0	7.7	8.9	9.7	10.3
SD	0.0	2.1	2.4	2.5	2.8

Table 66: Feet RPD: walking on soft mat

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	7	10	13	14
S06	6	8	9	10	11
S10	6	10	11	12	12
S11	6	11	13	13	14
S12	6	6	6	6	7
S13	6	6	6	11	12
S14	6	7	8	10	12
S15	6	6	8	9	11
S16	6	7	8	9	9
S17	6	7	10	10	11
S18	6	9	8	10	13
Mean	6.0	7.6	8.8	10.3	11.5
SD	0.0	1.7	2.1	2.0	2.1

A.2.3 Rubber Tile

Table 67: Overall tiredness RPD: walking on rubber tile

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	8	11	12	13
S06	6	3	3	3	1
S10	6	6	6	8	9
S11	6	6	11	11	13
S12	6	6	6	7	7
S13	6	7	8	9	8
S14	6	5	5	5	6
S15	6	4	6	8	7
S16	6	7	7	9	12
S17	6	6	8	8	9
S18	6	6	7	8	8
Mean	6.0	5.8	7.1	8.0	8.5
SD	0.0	1.4	2.4	2.5	3.5

Table 68: Overall leg tiredness RPD: walking on rubber tile

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	8	10	12	13
S06	6	9	10	13	12
S10	6	6	8	11	11
S11	6	9	11	11	14
S12	6	7	7	7	9
S13	6	8	8	9	10
S14	6	7	8	8	9
S15	6	7	12	12	13
S16	6	8	8	9	9
S17	6	10	11	11	13
S18	6	7	7	9	8
Mean	6.0	7.8	9.1	10.2	11.0
SD	0.0	1.2	1.8	1.9	2.1

Table 69: Upper back RPD: walking on rubber tile

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	11	12	13	15
S06	6	6	6	8	8
S10	6	6	8	11	11
S11	6	9	13	14	14
S12	6	6	6	7	9
S13	6	6	6	6	6
S14	6	8	7	7	8
S15	6	7	8	7	7
S16	6	6	6	7	8
S17	6	6	11	9	11
S18	6	6	8	9	9
Mean	6.0	7.0	8.3	8.9	9.6
SD	0.0	1.7	2.6	2.7	2.8

Table 70: Lower back RPD: walking on rubber tile

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	10	12	12	14
S06	6	7	9	11	11
S10	6	6	9	11	11
S11	6	6	11	13	13
S12	6	6	6	7	9
S13	6	6	12	13	14
S14	6	5	5	5	5
S15	6	3	2	2	2
S16	6	9	13	13	14
S17	6	8	11	11	11
S18	6	8	13	14	15
Mean	6.0	6.7	9.4	10.2	10.8
SD	0.0	2.0	3.6	3.8	4.1

Table 71: Hip RPD: walking on rubber tile

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	8	10	11	13
S06	6	8	8	8	10
S10	6	11	11	13	14
S11	6	6	11	13	11
S12	6	6	7	9	12
S13	6	6	6	11	10
S14	6	7	8	10	8
S15	6	4	4	4	4
S16	6	9	9	9	9
S17	6	9	10	11	13
S18	6	8	8	8	8
Mean	6.0	7.5	8.4	9.7	10.2
SD	0.0	1.9	2.2	2.6	2.9

Table 72: Upper leg RPD: walking on rubber tile

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	8	10	11	13
S06	6	8	8	8	10
S10	6	6	9	11	13
S11	6	6	12	11	13
S12	6	6	7	8	11
S13	6	9	8	11	8
S14	6	8	6	9	10
S15	6	5	7	8	8
S16	6	9	9	10	10
S17	6	9	12	12	13
S18	6	8	9	9	9
Mean	6.0	7.5	8.8	9.8	10.7
SD	0.0	1.4	1.9	1.5	2.0

Table 73: Knee RPD: walking on rubber tile

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	8	10	11	13
S06	6	6	8	8	9
S10	6	9	9	11	11
S11	6	11	11	13	11
S12	6	7	7	7	9
S13	6	6	13	14	14
S14	6	6	7	9	9
S15	6	6	8	8	9
S16	6	11	11	11	10
S17	6	10	11	11	13
S18	6	8	8	8	8
Mean	6.0	8.0	9.4	10.1	10.5
SD	0.0	2.0	2.0	2.3	2.0

Table 74: Lower leg RPD: walking on rubber tile

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	9	11	11	14
S06	6	6	8	8	9
S10	6	11	11	13	14
S11	6	9	13	13	13
S12	6	6	7	9	9
S13	6	12	11	12	14
S14	6	6	8	10	9
S15	6	9	10	11	13
S16	6	8	9	10	9
S17	6	9	11	13	14
S18	6	8	8	9	8
Mean	6.0	8.5	9.7	10.8	11.5
SD	0.0	2.0	1.8	1.8	2.6

Table 75: Ankle RPD: walking on rubber tile

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	9	11	13	15
S06	6	6	8	8	10
S10	6	9	9	13	11
S11	6	11	11	11	13
S12	6	7	6	7	8
S13	6	12	13	15	17
S14	6	6	6	9	10
S15	6	8	8	8	8
S16	6	9	9	11	10
S17	6	7	9	10	12
S18	6	8	12	13	14
Mean	6.0	8.4	9.3	10.7	11.6
SD	0.0	1.9	2.3	2.6	2.9

Table 76: Feet RPD: walking on rubber tile

	Time of Survey (hour)				
Subjects	**0**	**0.5**	**1**	**1.5**	**2**
S04	6	9	11	12	14
S06	6	8	9	11	12
S10	6	8	8	9	9
S11	6	13	13	15	15
S12	6	5	6	9	10
S13	6	12	11	12	14
S14	6	9	9	10	10
S15	6	7	8	10	11
S16	6	11	12	14	15
S17	6	8	10	10	12
S18	6	7	10	11	11
Mean	6.0	8.8	9.7	11.2	12.1
SD	0.0	2.4	2.0	1.9	2.1

APPENDIX B

NIRS DATA

B.1 STANDING: HARD TILE

The following data are NIRS measures for the soleus and erector spinae muscles. Muscle SO_2 and tHb were calculated using computer software (Matlab R2012a) for both detectors on each of the two probes. A 4^{th} order low-pass filter with a cutoff frequency of 0.15 Hz was applied to the signal before analysis. The output from one detector from each probe was chosen after visual comparison. Muscle SO_2 and tHb were normalized to the average SO_2 and tHb during the 2 minute seated baseline.

The following table represents subjects who completed the standing protocol on the hard tile and from whom NIRS data was collected and whether or not it was included in the analysis.

Table 77: NIRS data collection: Standing on hard tile

	Completed Testing Protocol	**Included in Analysis**	
Subject	**NIRS data collection**	**Erector Spinae**	**Soleus**
S04	✓	✓	✓
S05	✓	✗	✓
S06	✓	✓	✓
S08	✓	✓	✓
S10	✓	✓	✓
S11	✓	✓	✓
S12	✓	✓	✓
S13	✓	✓	✗
S14	✗	✗	✗
S15	✓	✓	✓

B.1.1 Erector Spinae

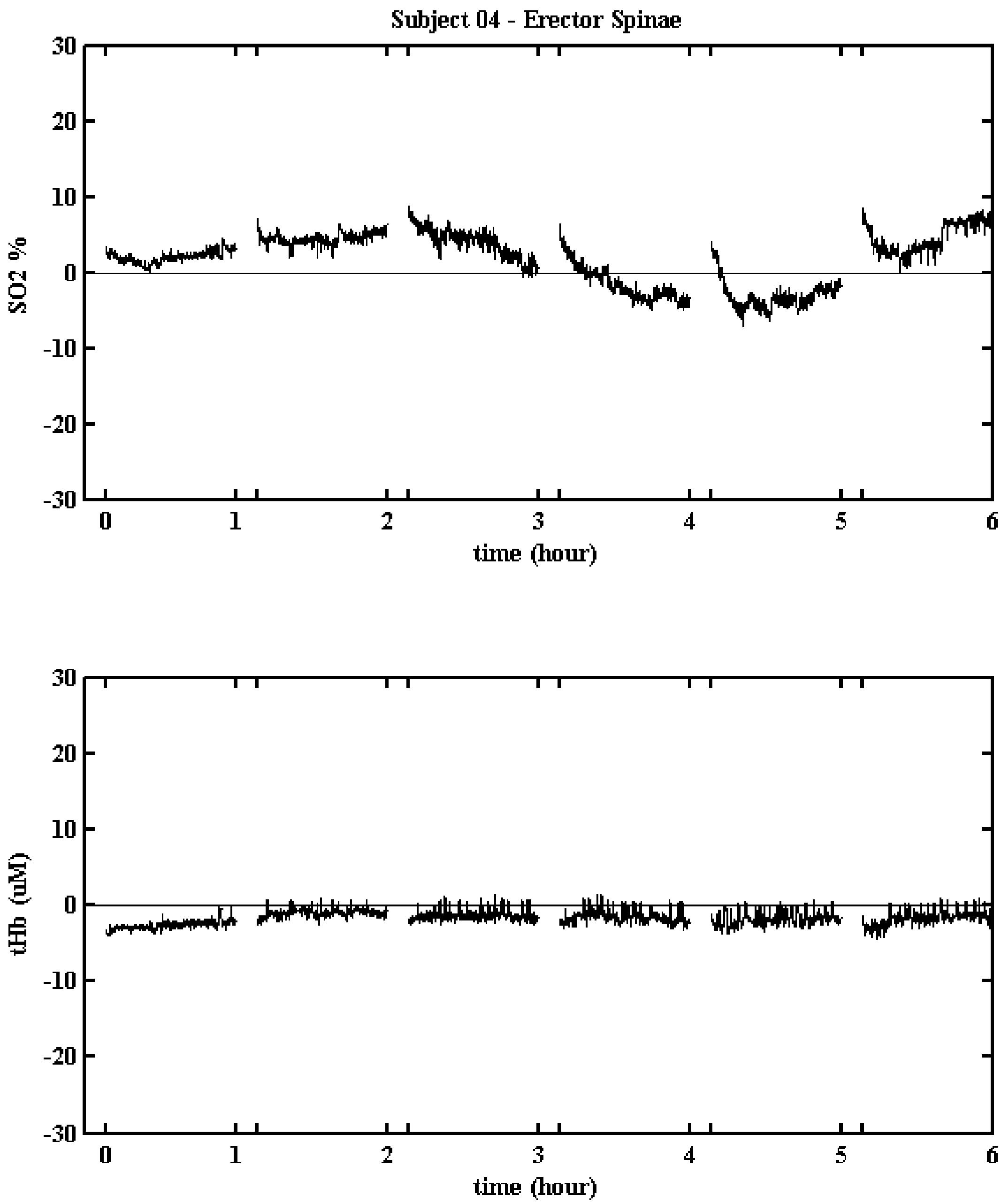


Figure 31: S04 erector spinae NIRS parameters while standing on hard tile

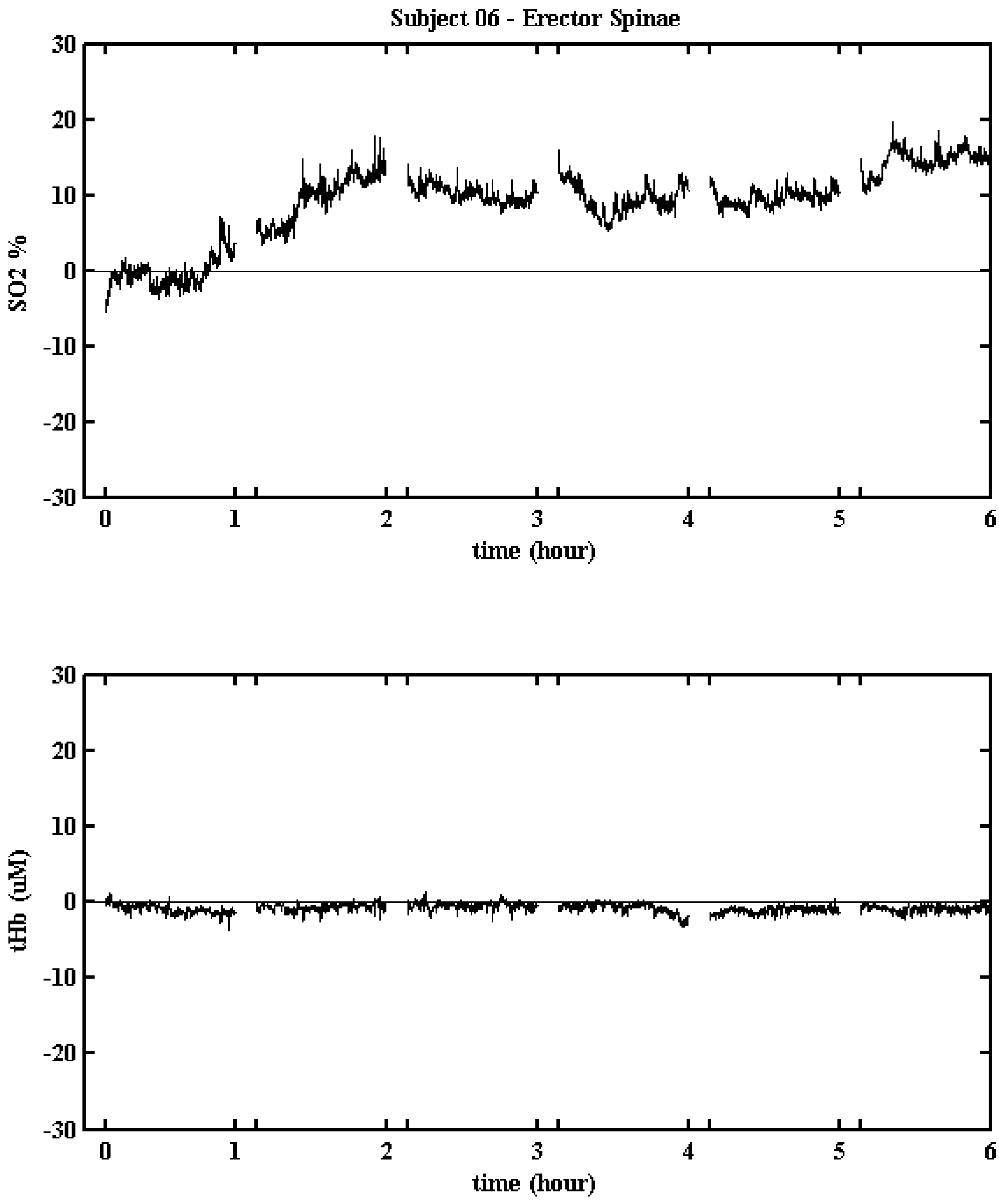


Figure 32: S06 erector spinae NIRS parameters while standing on hard tile

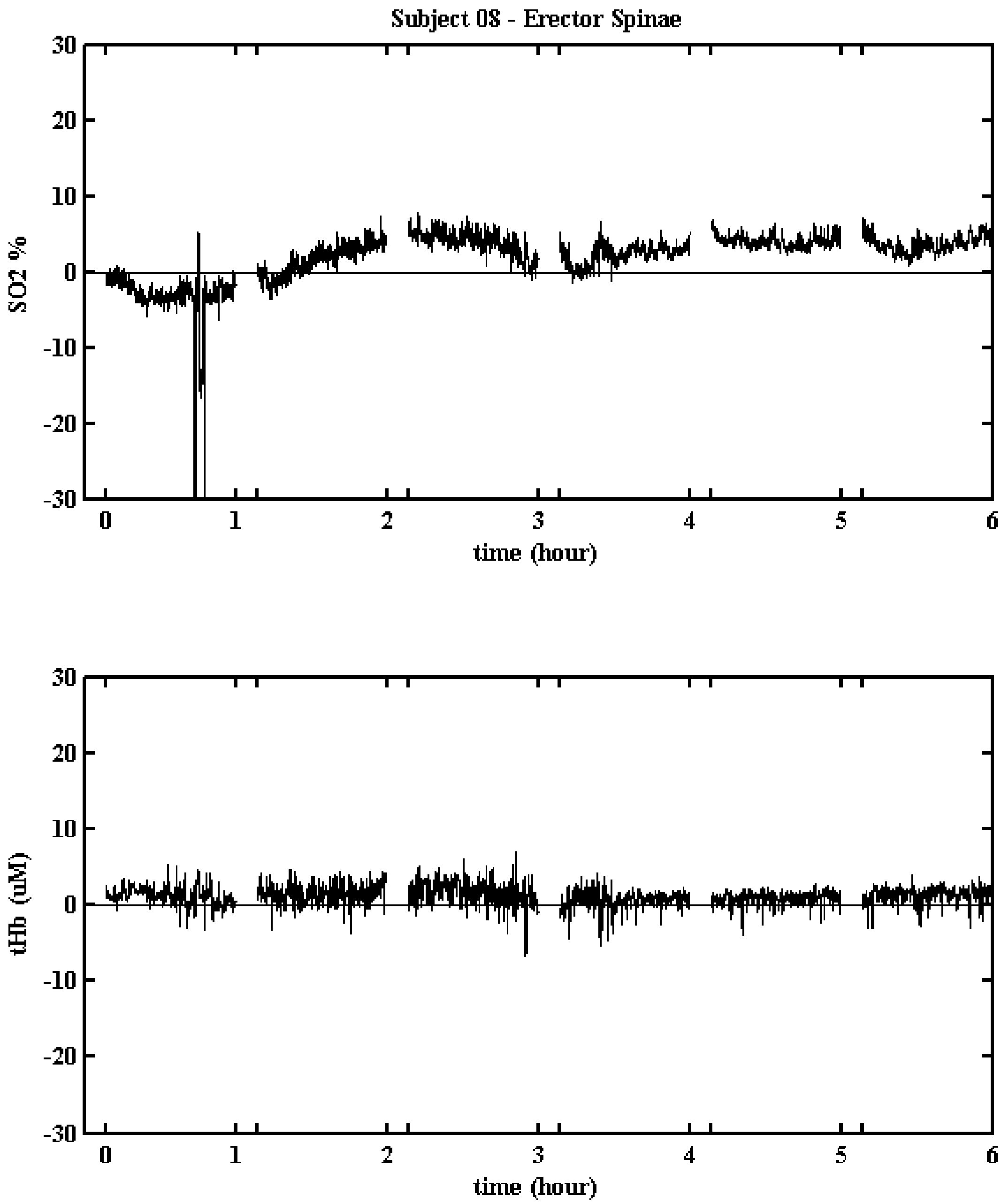


Figure 33: S08 erector spinae NIRS parameters while standing on hard tile

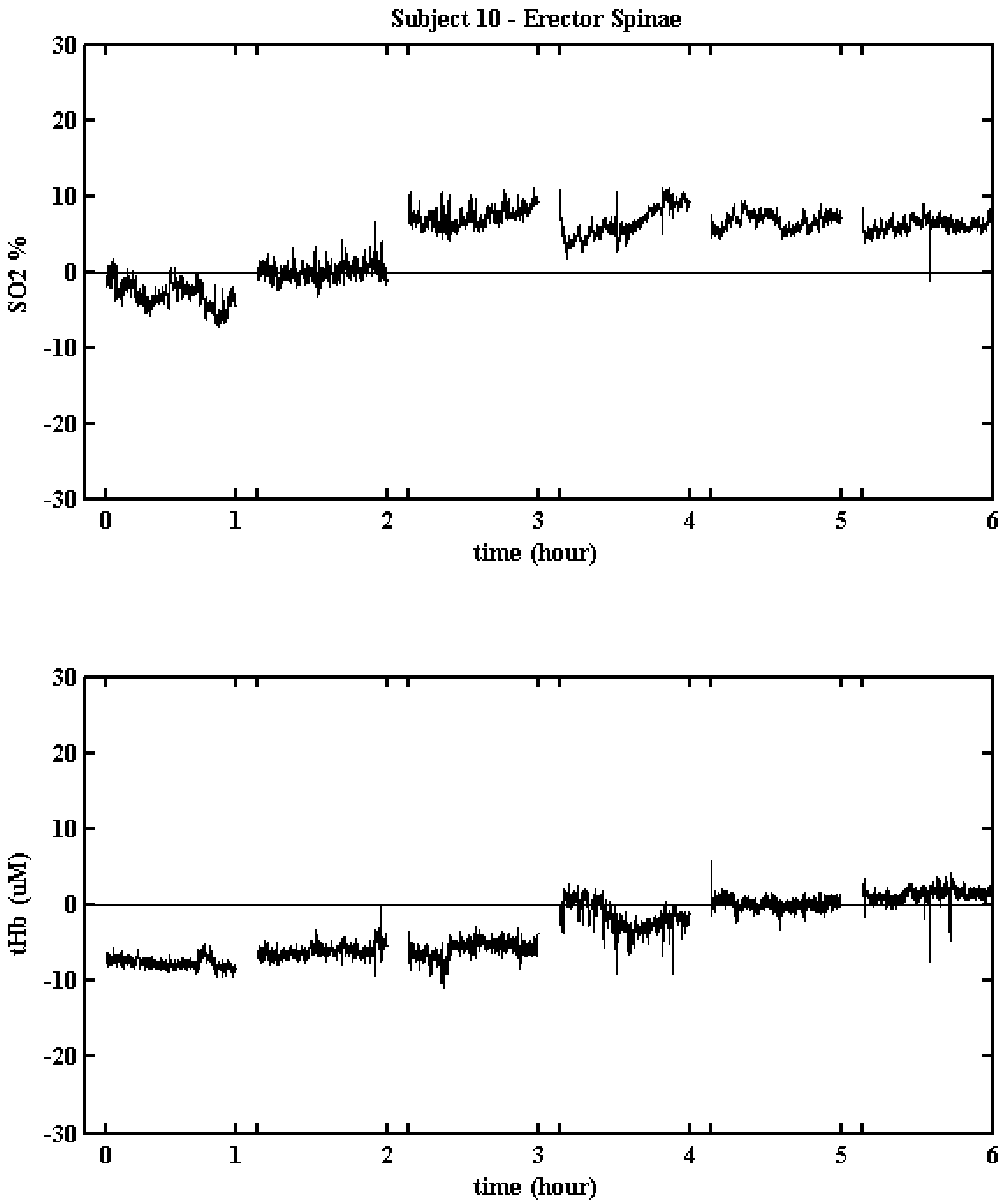


Figure 34: S10 erector spinae NIRS parameters while standing on hard tile

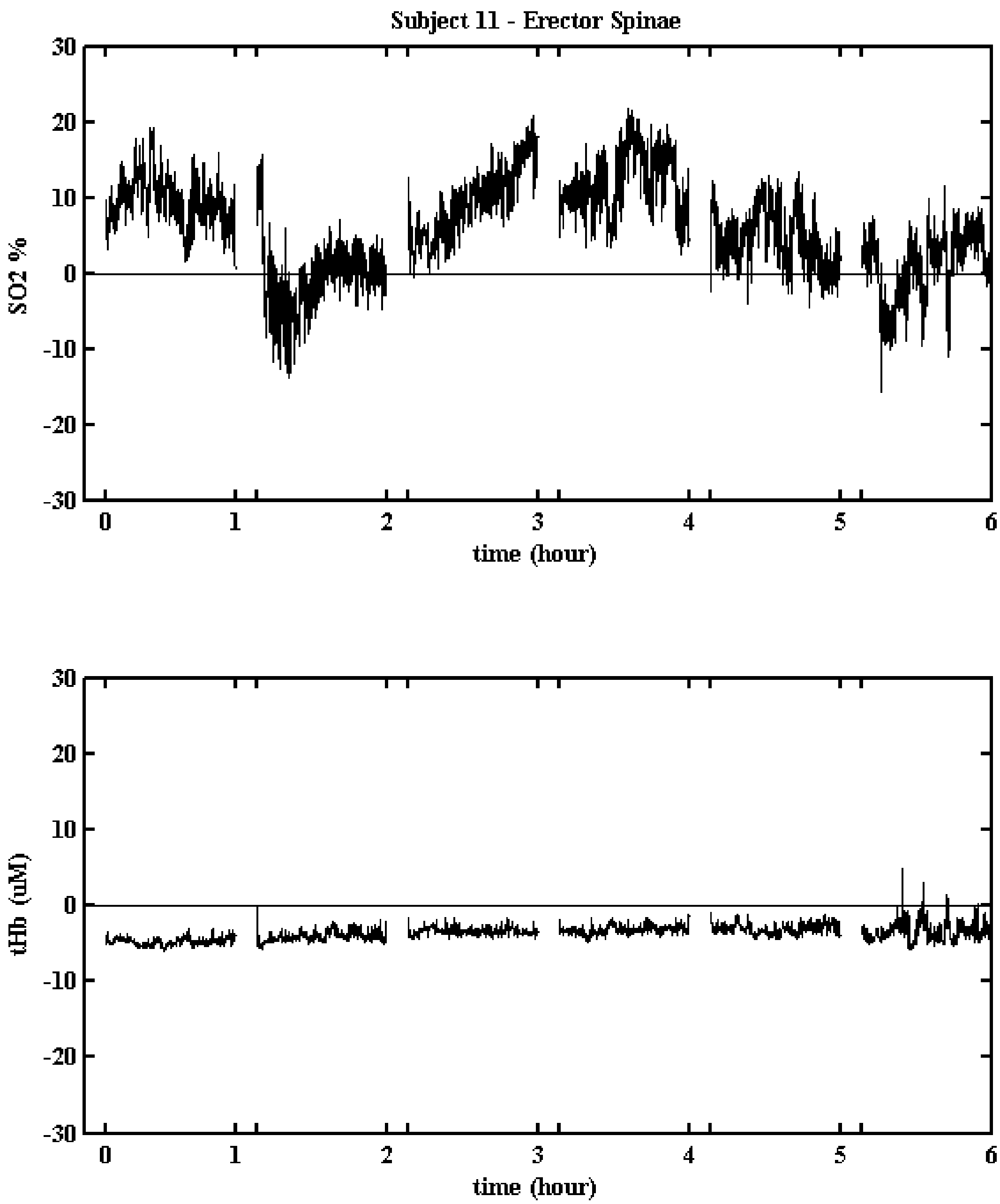


Figure 35: S11 erector spinae NIRS parameters while standing on hard tile

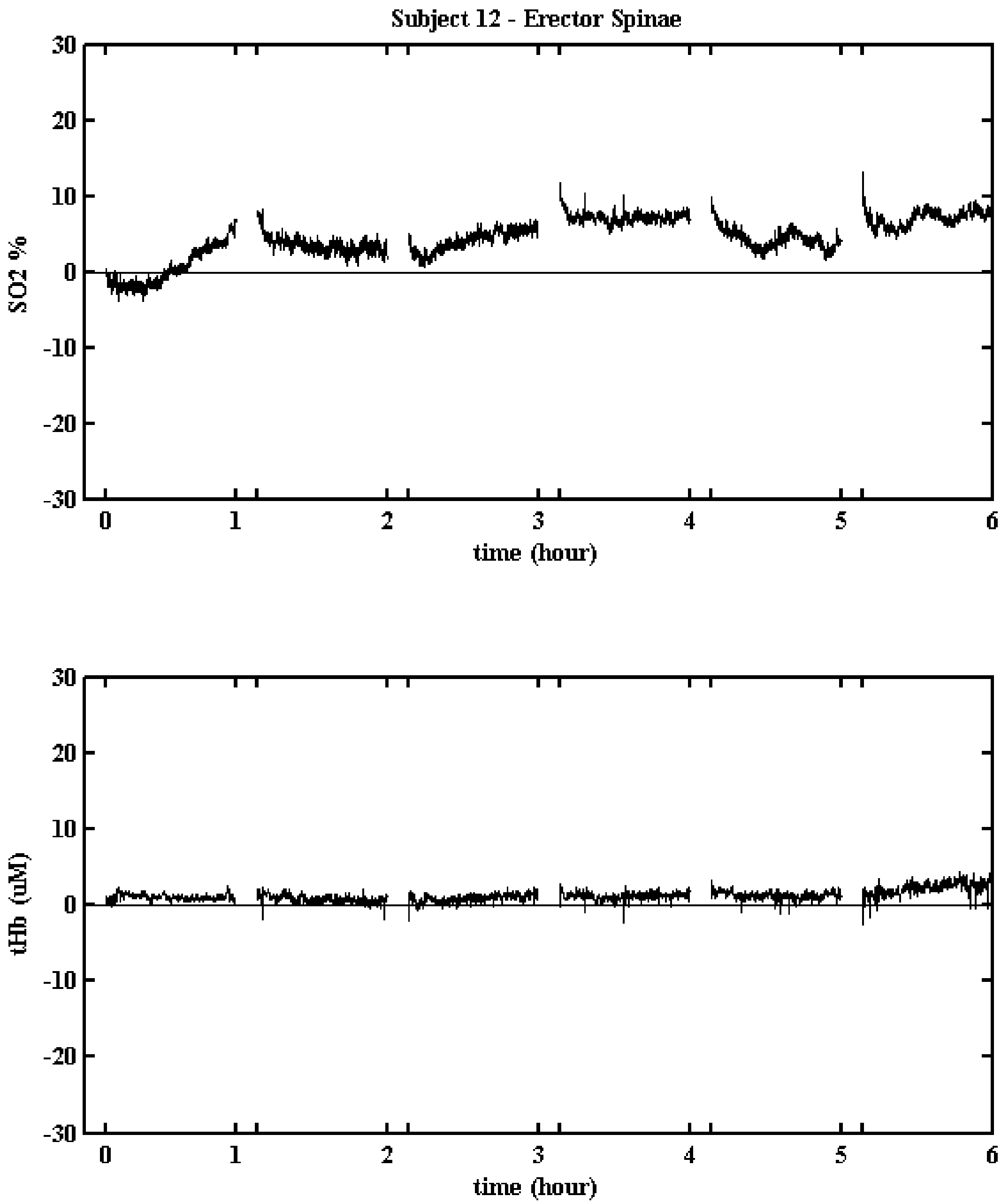


Figure 36: S12 erector spinae NIRS parameters while standing on hard tile

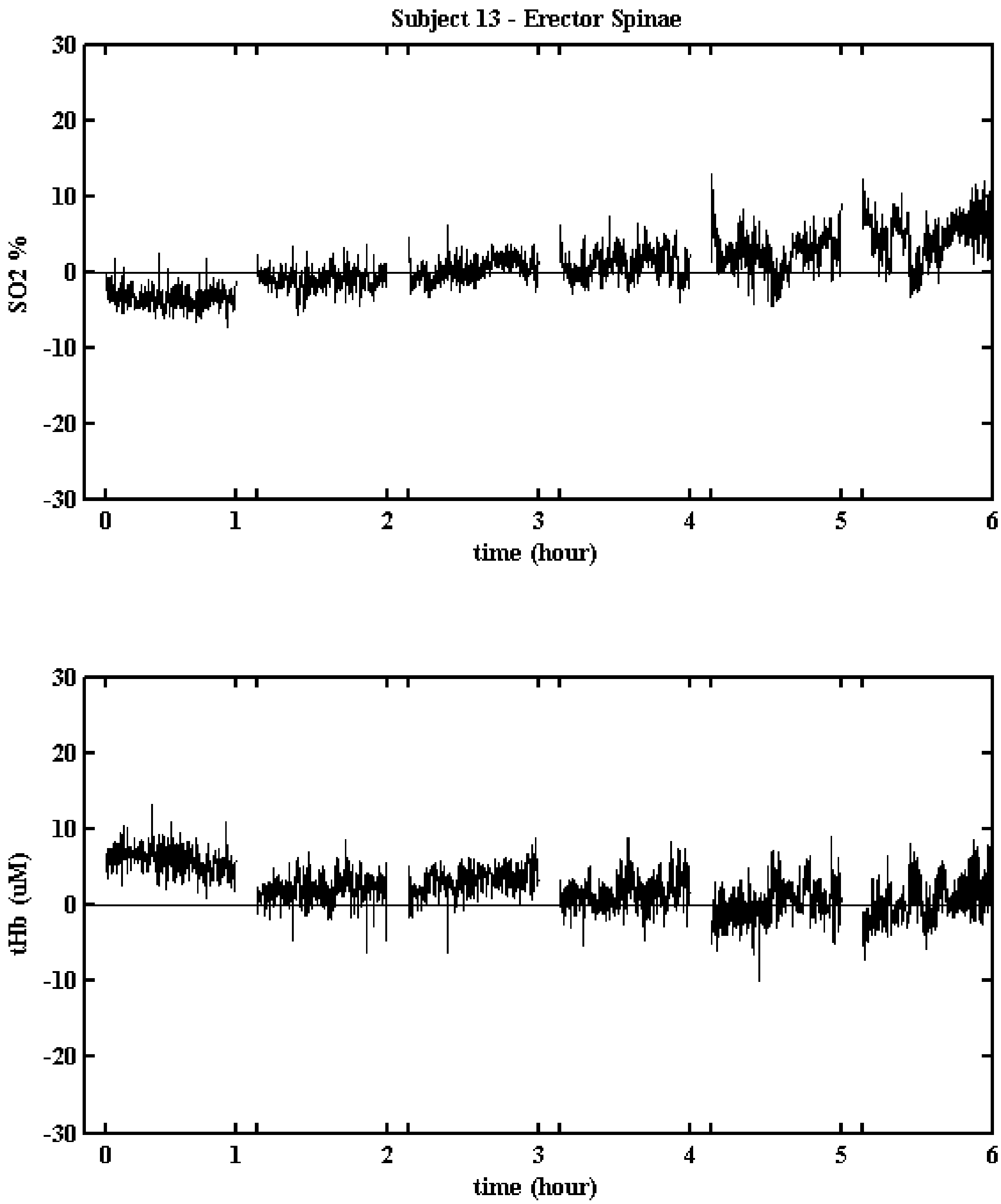


Figure 37: S13 erector spinae NIRS parameters while standing on hard tile

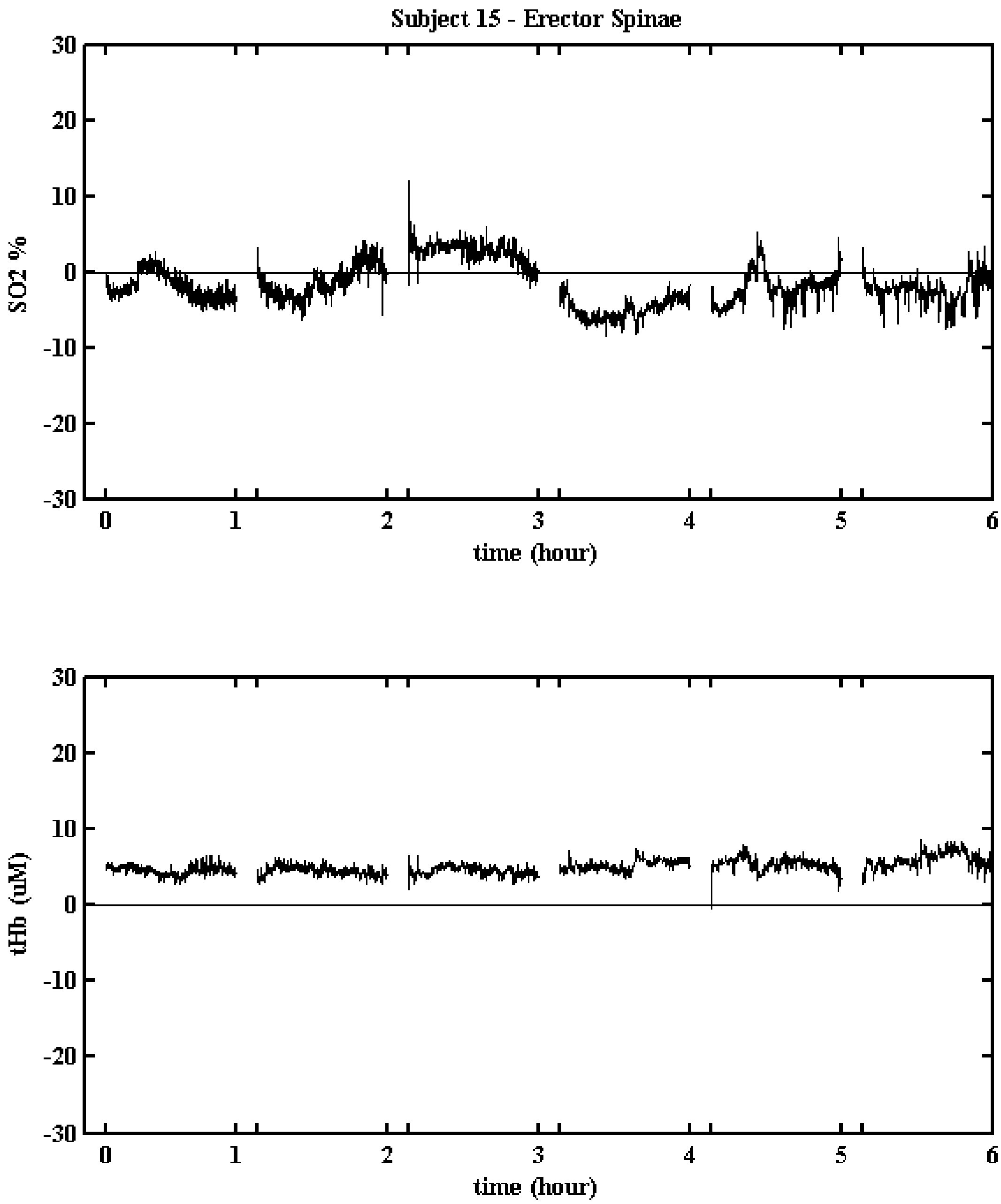


Figure 38: S15 erector spinae NIRS parameters while standing on hard tile

B.1.2 Soleus

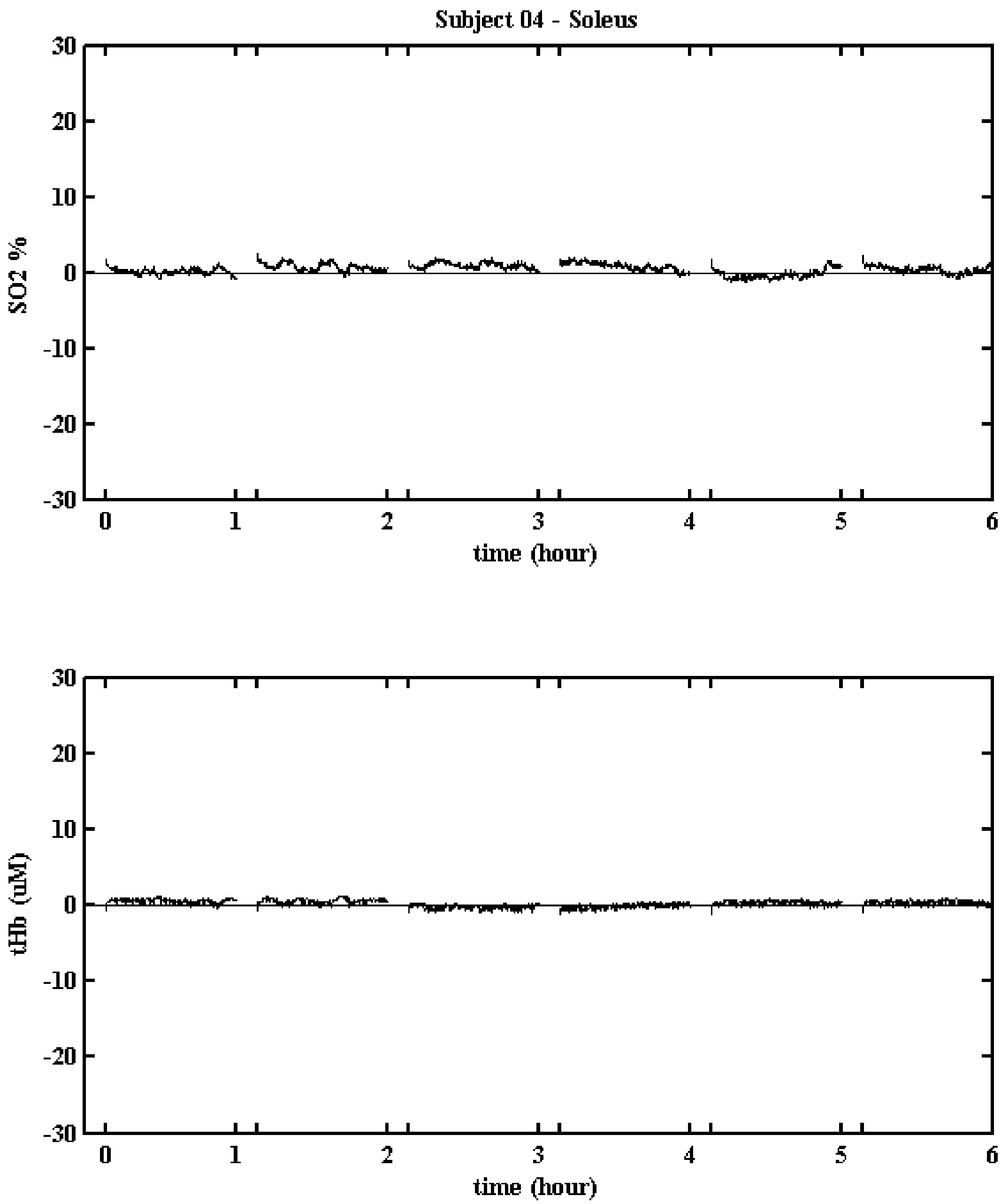


Figure 39: S04 soleus NIRS parameters while standing on hard tile

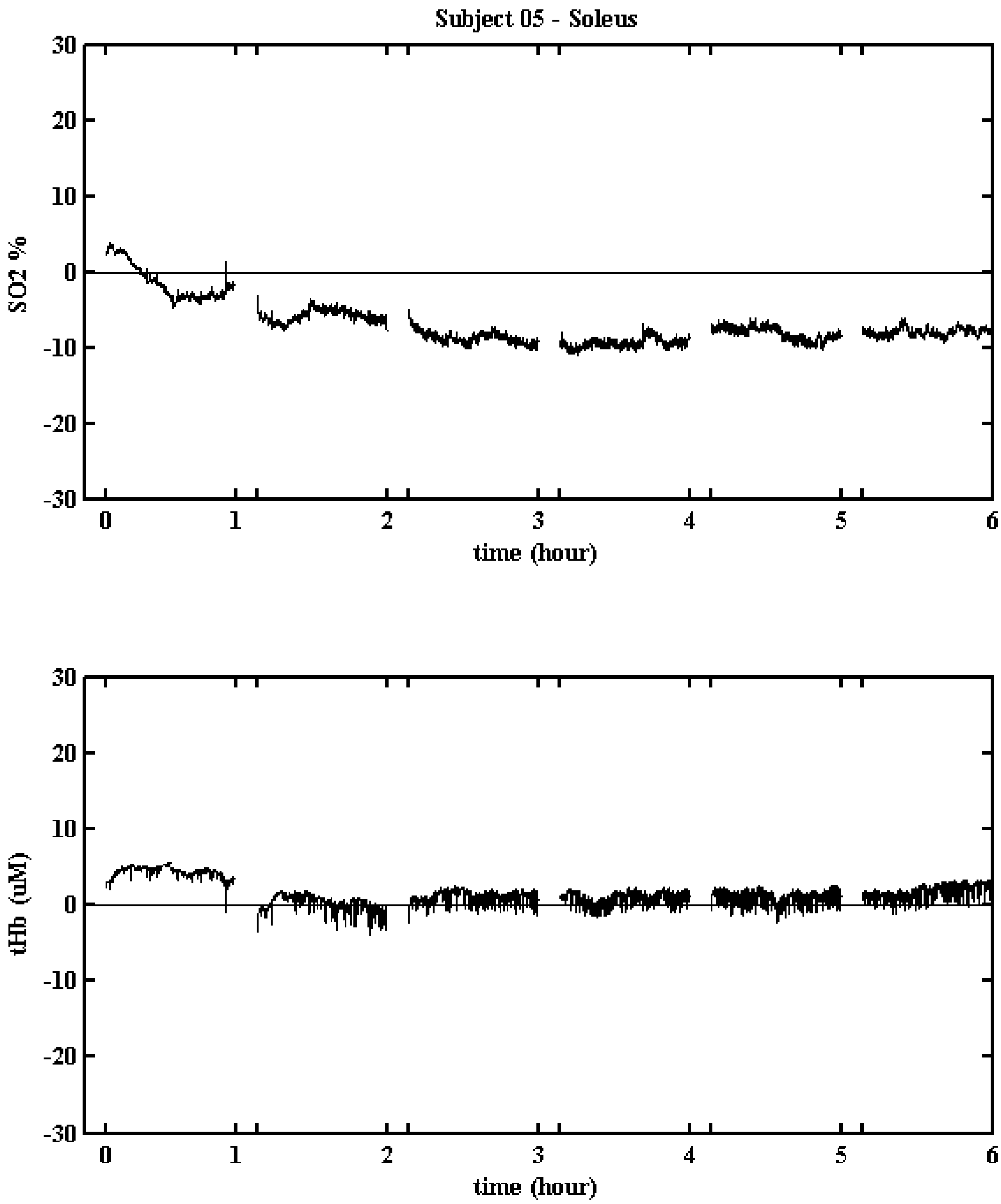


Figure 40: S05 soleus NIRS parameters while standing on hard tile

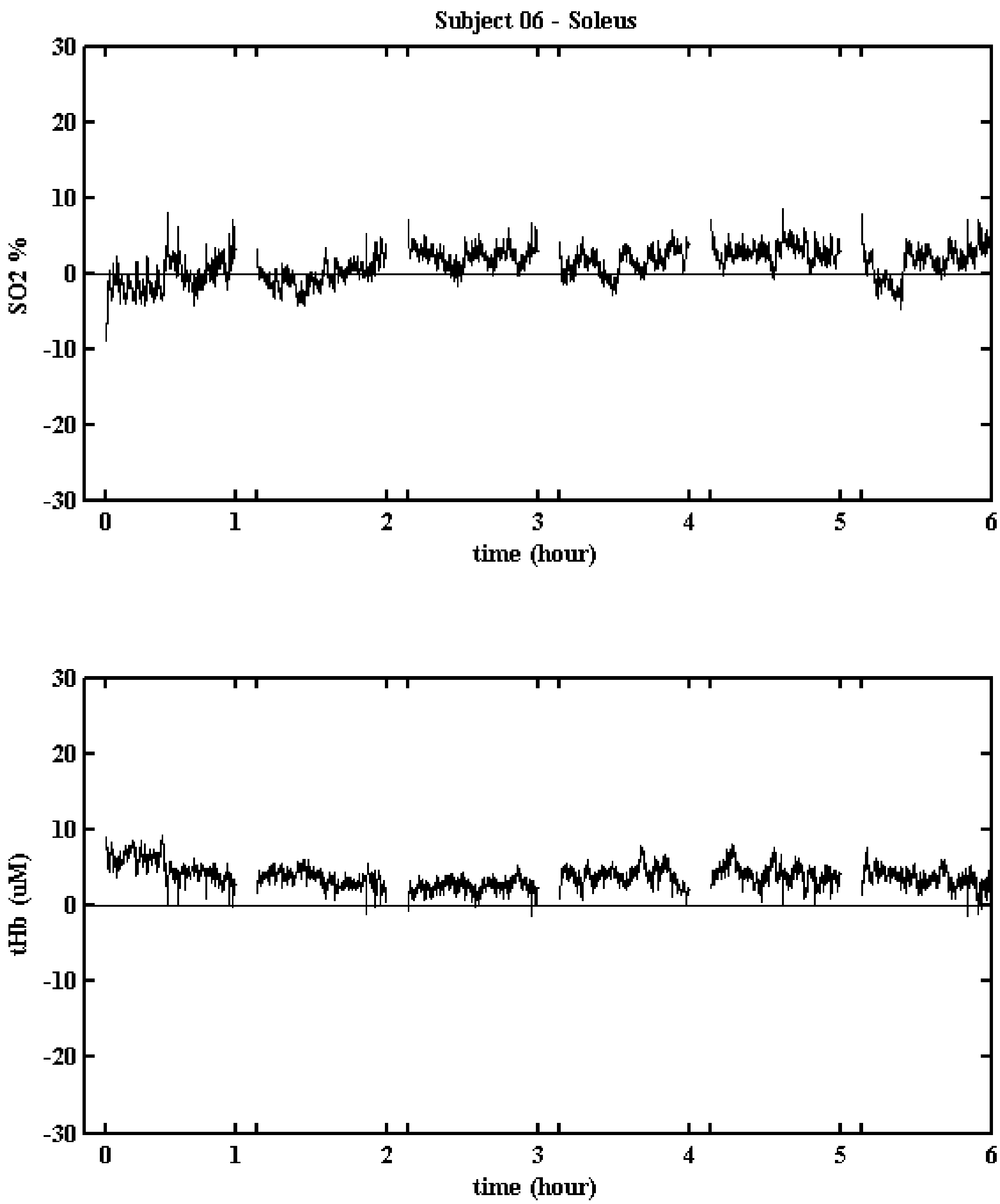


Figure 41: S06 soleus NIRS parameters while standing on hard tile

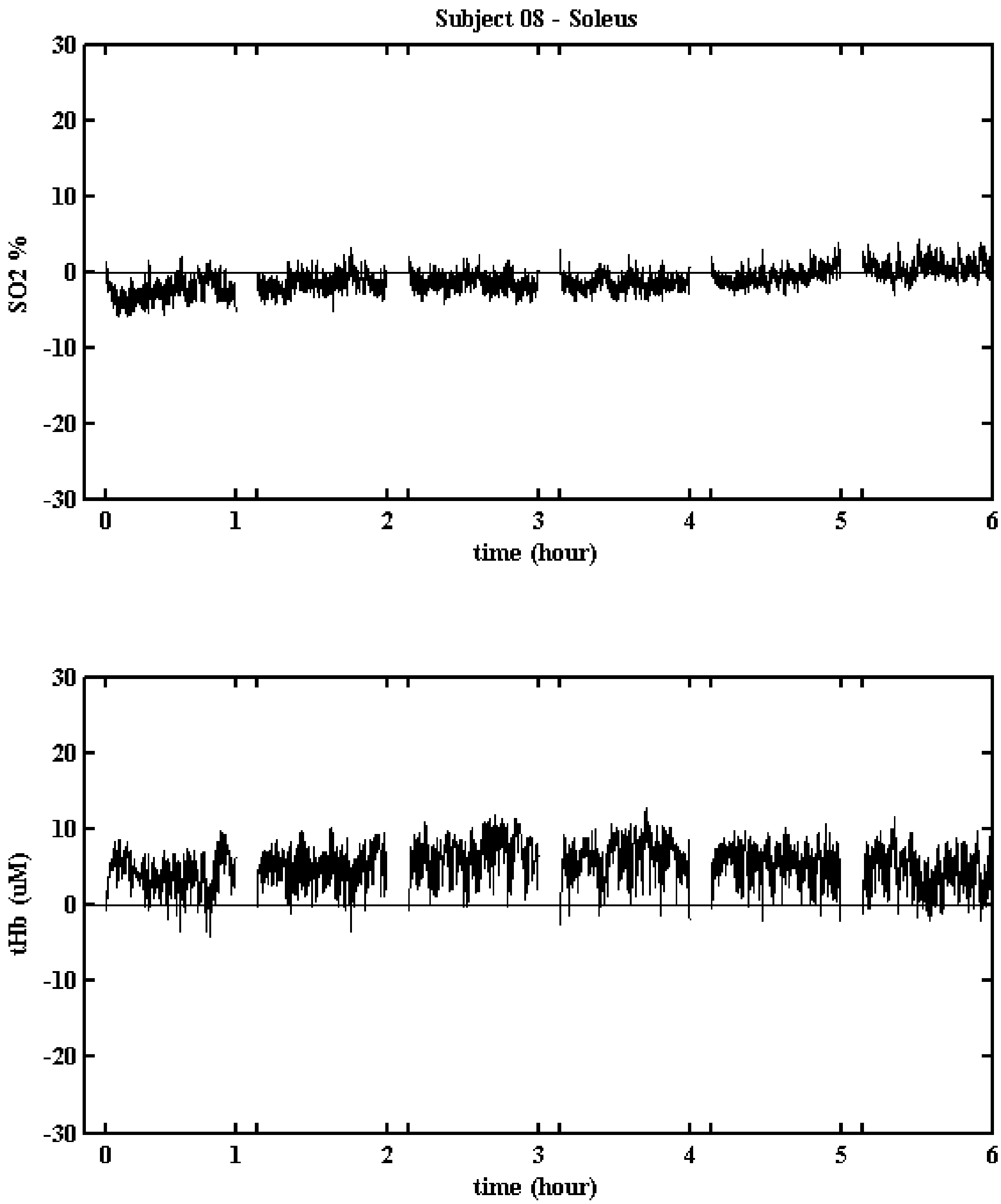


Figure 42: S08 soleus NIRS parameters while standing on hard tile

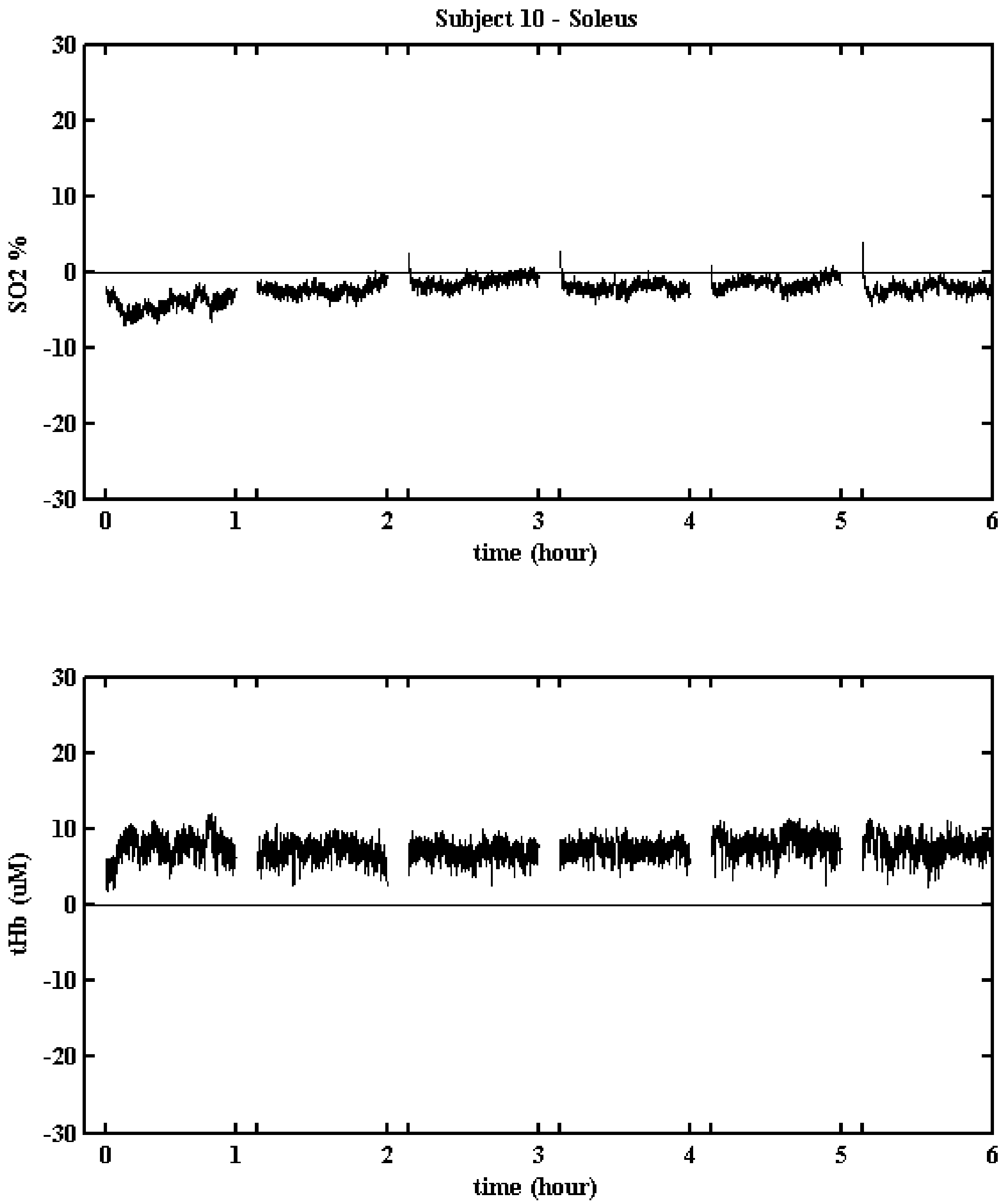


Figure 43: S10 soleus NIRS parameters while standing on hard tile

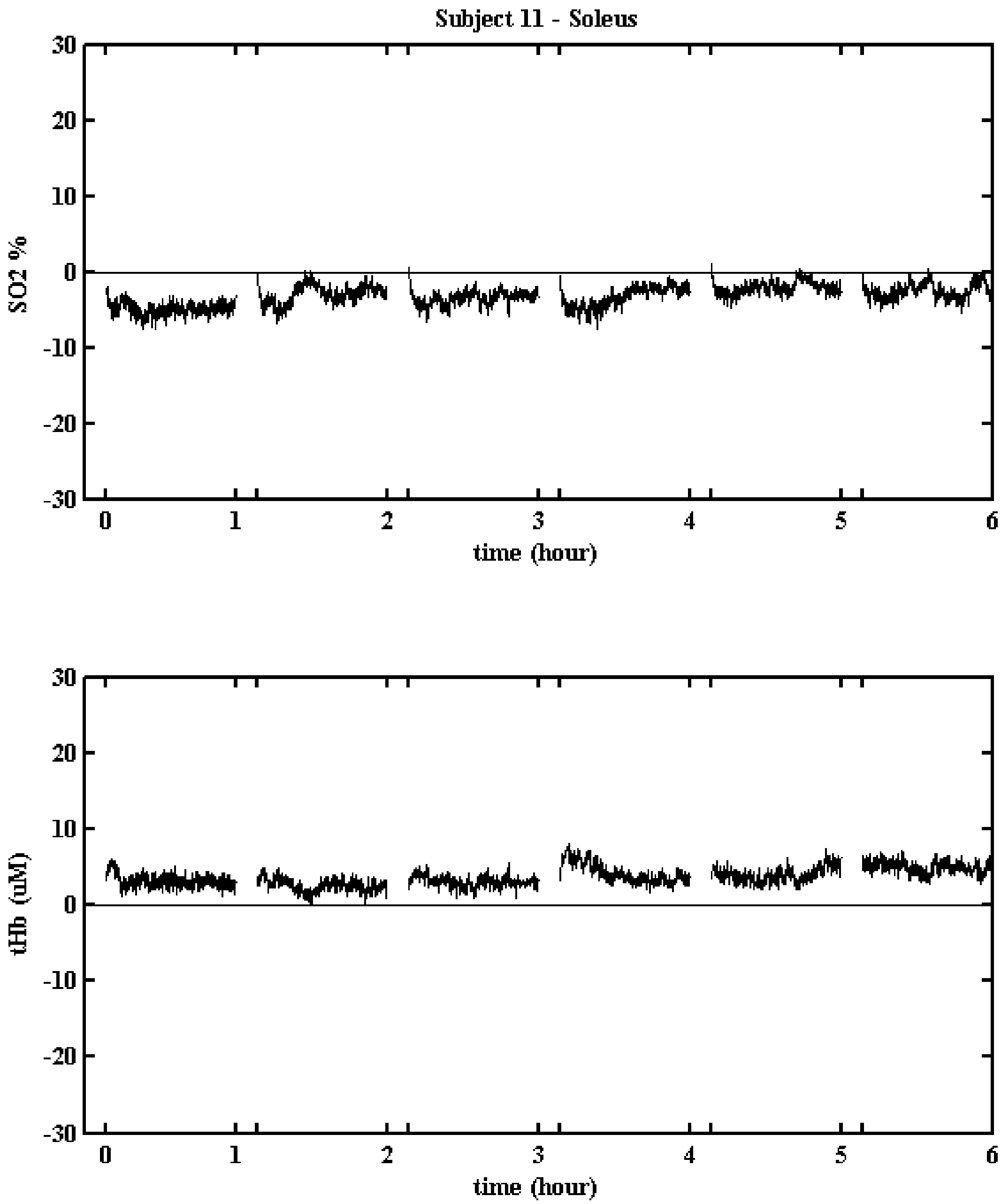


Figure 44: S11 soleus NIRS parameters while standing on hard tile

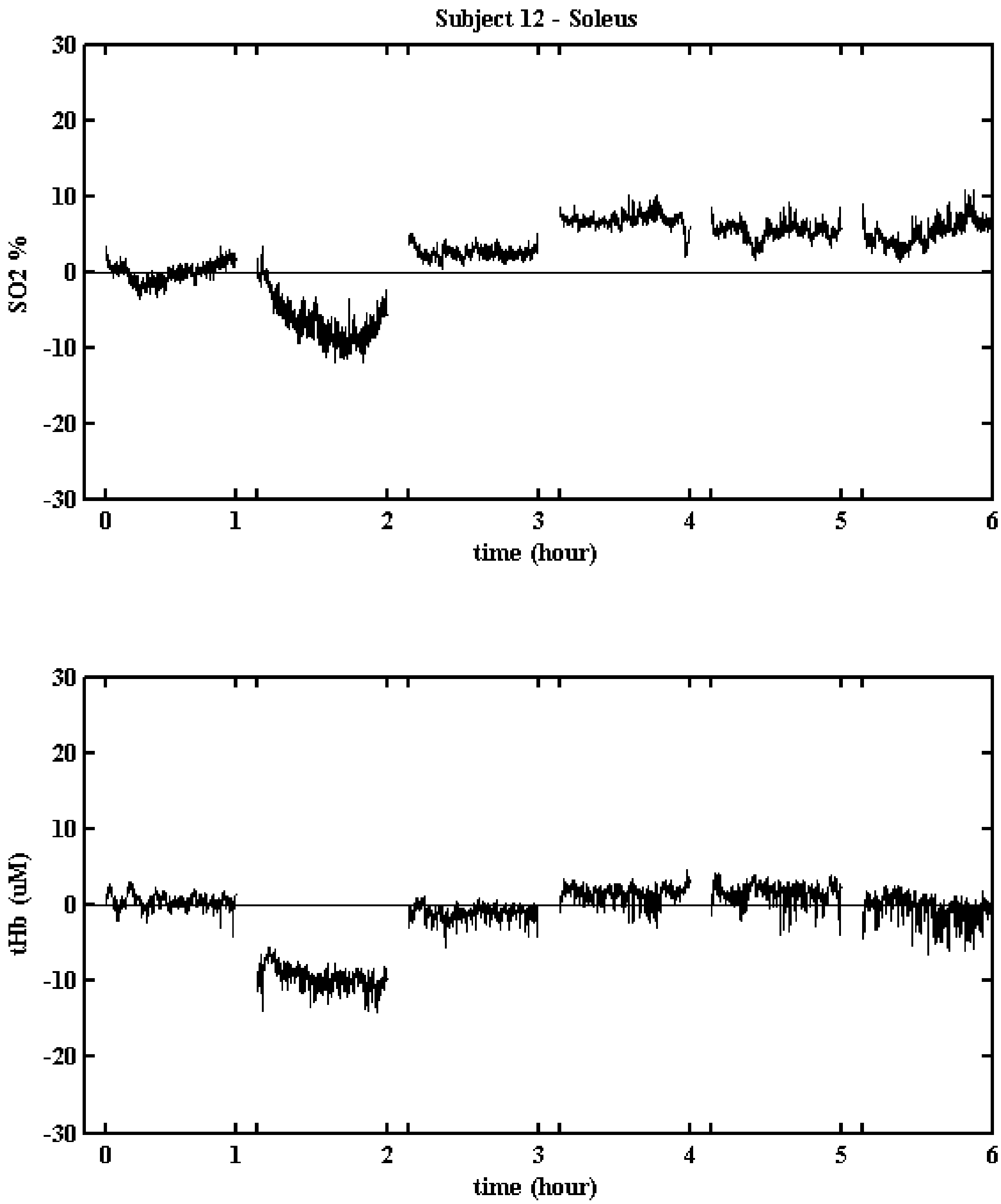


Figure 45: S12 soleus NIRS parameters while standing on hard tile

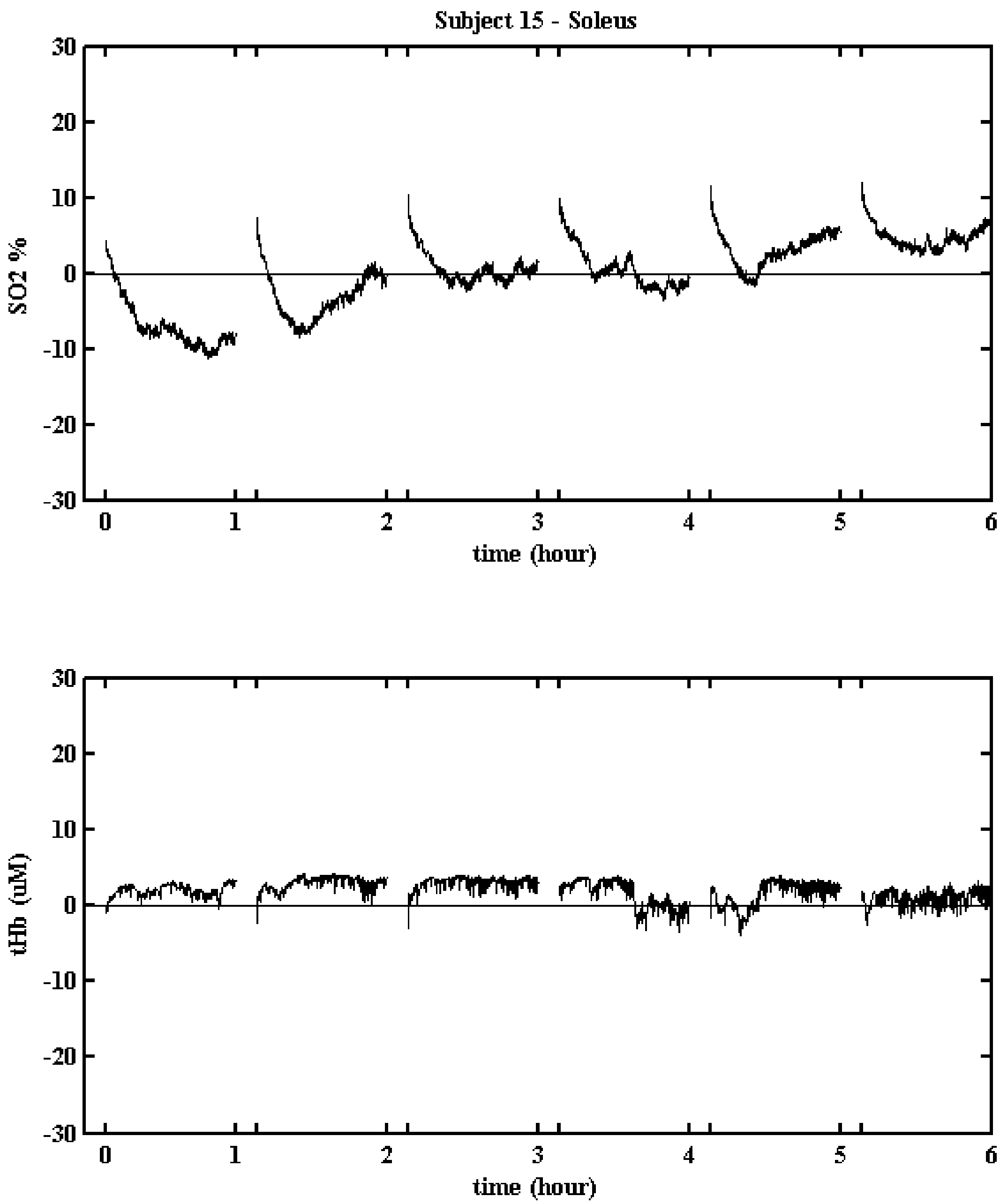


Figure 46: S15 soleus NIRS parameters while standing on hard tile

B.2 STANDING: ALL FLOORING CONDITIONS

The following data are NIRS outcomes for the soleus and erector spinae muscles. Muscle SO_2 and tHb were calculated using computer software (Matlab R2012a) for both detectors on each of the two probes. A 4^{th} order low-pass filter with a cutoff frequency of 0.15 Hz was applied to the signal before analysis. The output from one detector from each probe was chosen after visual comparison. Muscle SO_2 and tHb were normalized to the average SO_2 and tHb during the 2 minute seated baseline.

The following table describes which subjects completed the standing protocol for each flooring condition and whom NIRS data was collected and whether or not it was included in the analysis.

Table 78: NIRS data collection: Standing on each flooring condition

	NIRS data collection			**Included in Analysis**	
Subject	**Hard Tile**	**Soft Mat**	**Rubber Tile**	**Erector Spinae**	**Soleus**
S04	✓	✓	✓	✓	✓
S05	✓	✗	✗	✗	✗
S06	✓	✓	✓	✓	✓
S08	✓	✗	✗	✗	✗
S10	✓	✓	✓	✓	✓
S11	✓	✓	✓	✓	✓
S12	✓	✓	✓	✓	✓
S13	✓	✗	✗	✗	✗
S14	✗	✗	✓	✗	✗
S15	✓	✗	✓	✗	✗

B.2.1 Erector Spinae

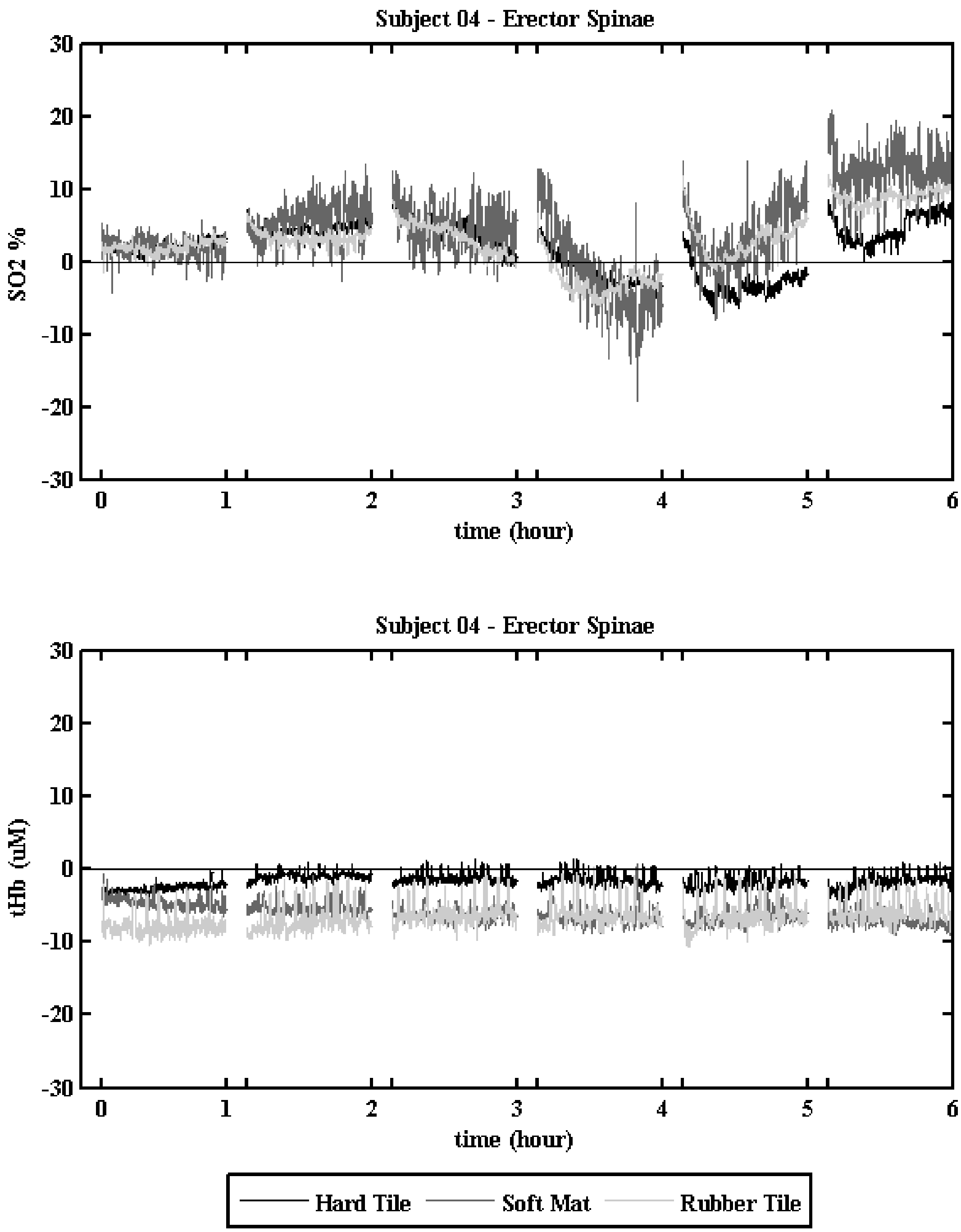


Figure 47: S04 erector spinae NIRS parameters while standing

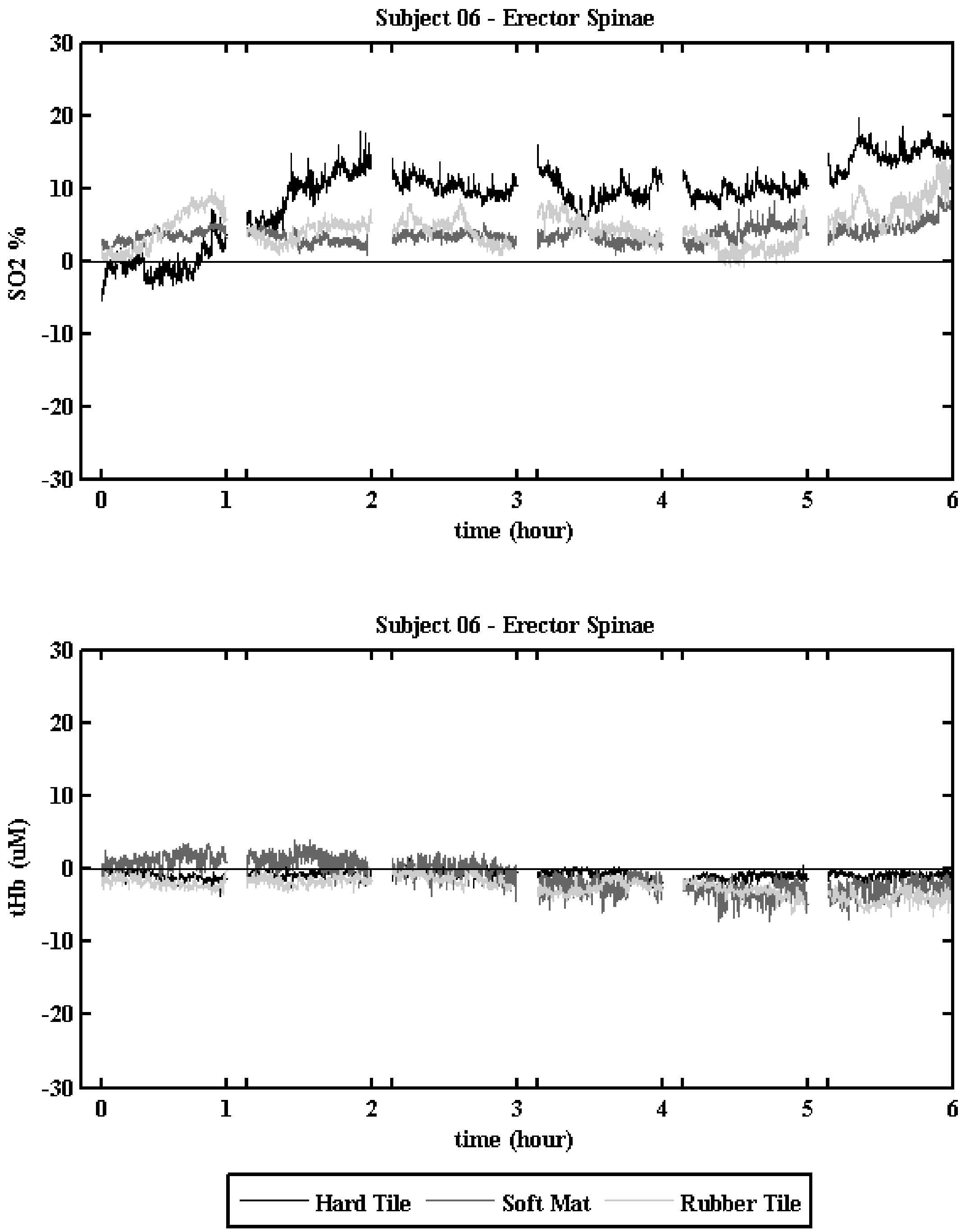


Figure 48: S06 erector spinae NIRS parameters while standing

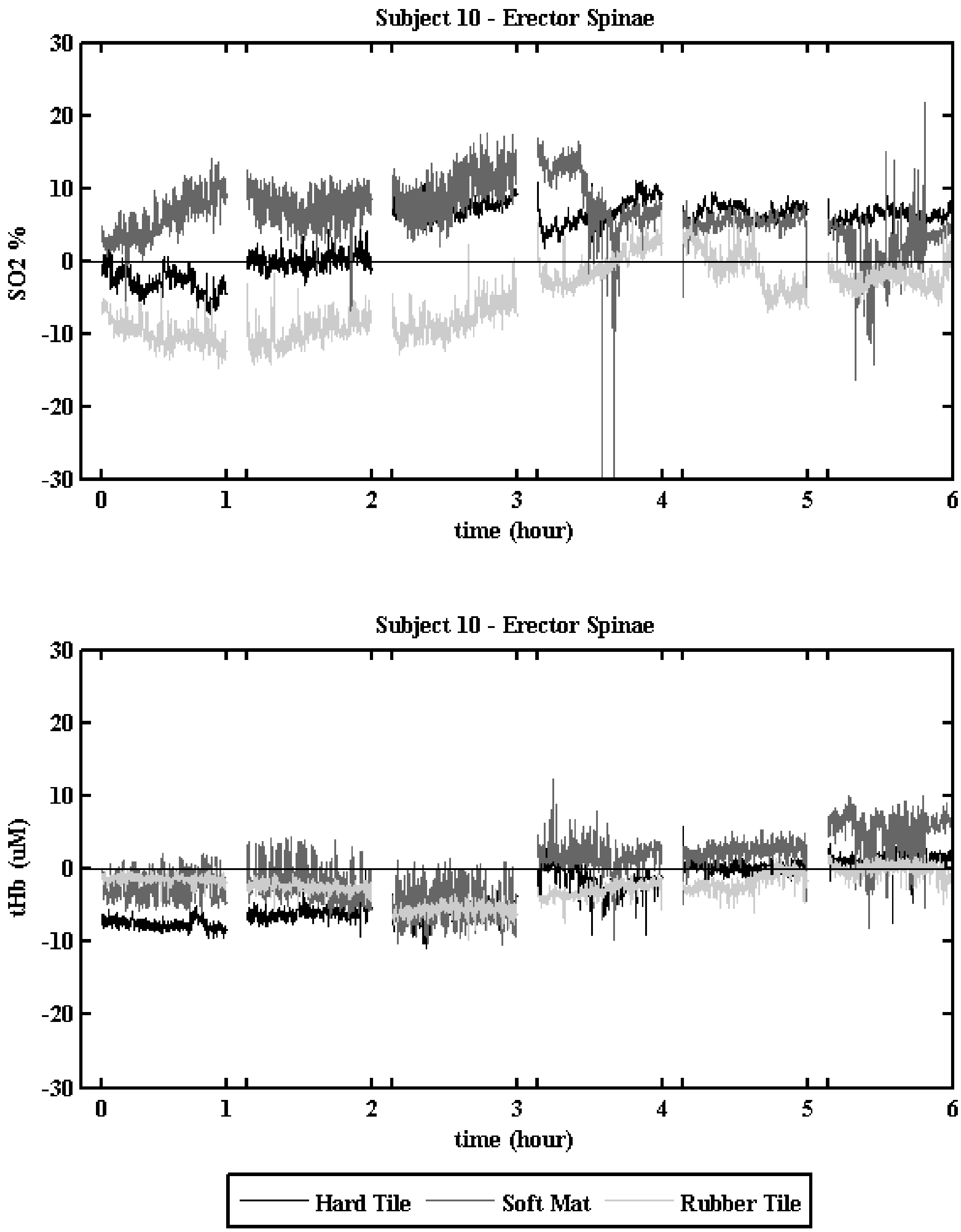


Figure 49: S10 erector spinae NIRS parameters while standing

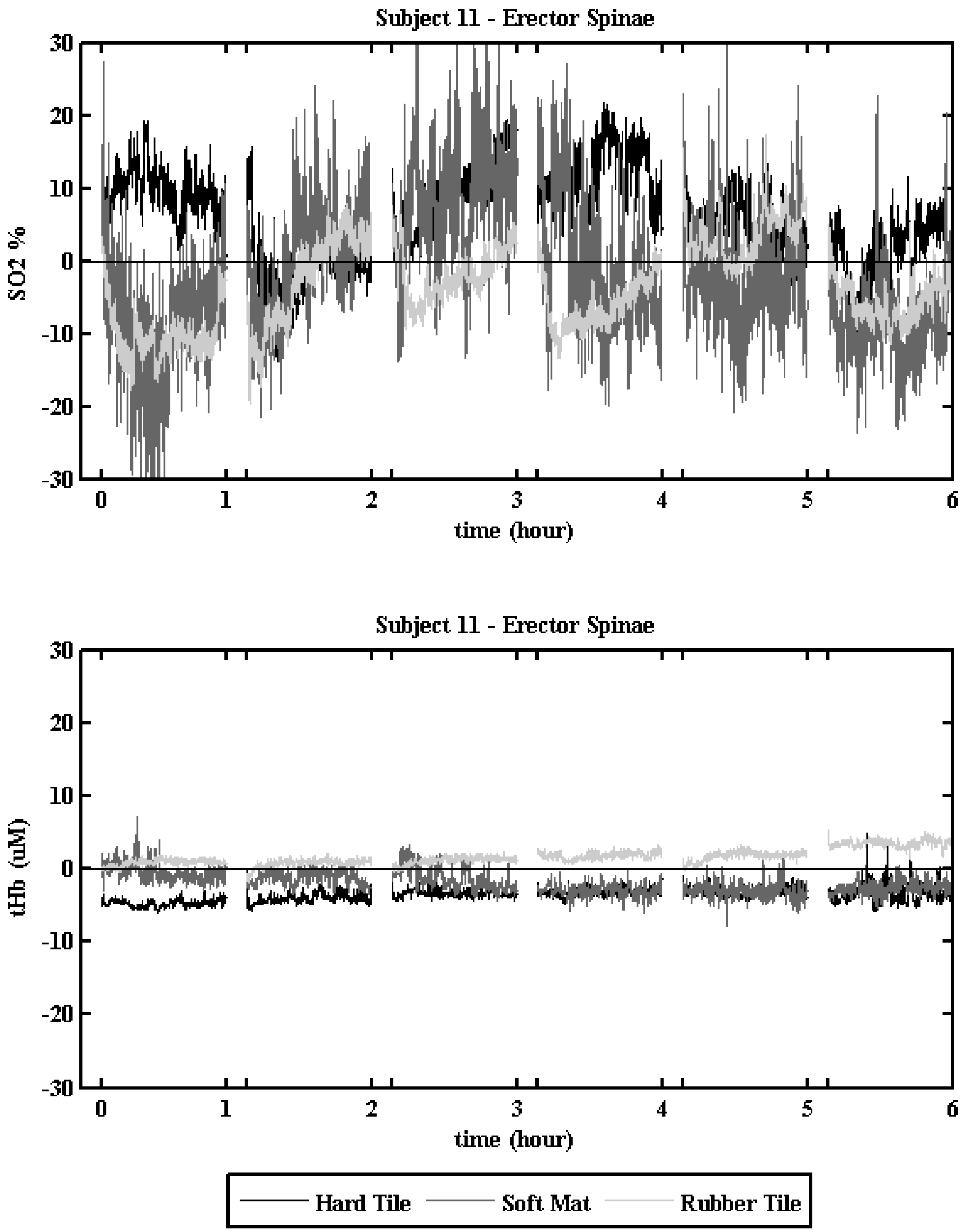


Figure 50: S11 erector spinae NIRS parameters while standing

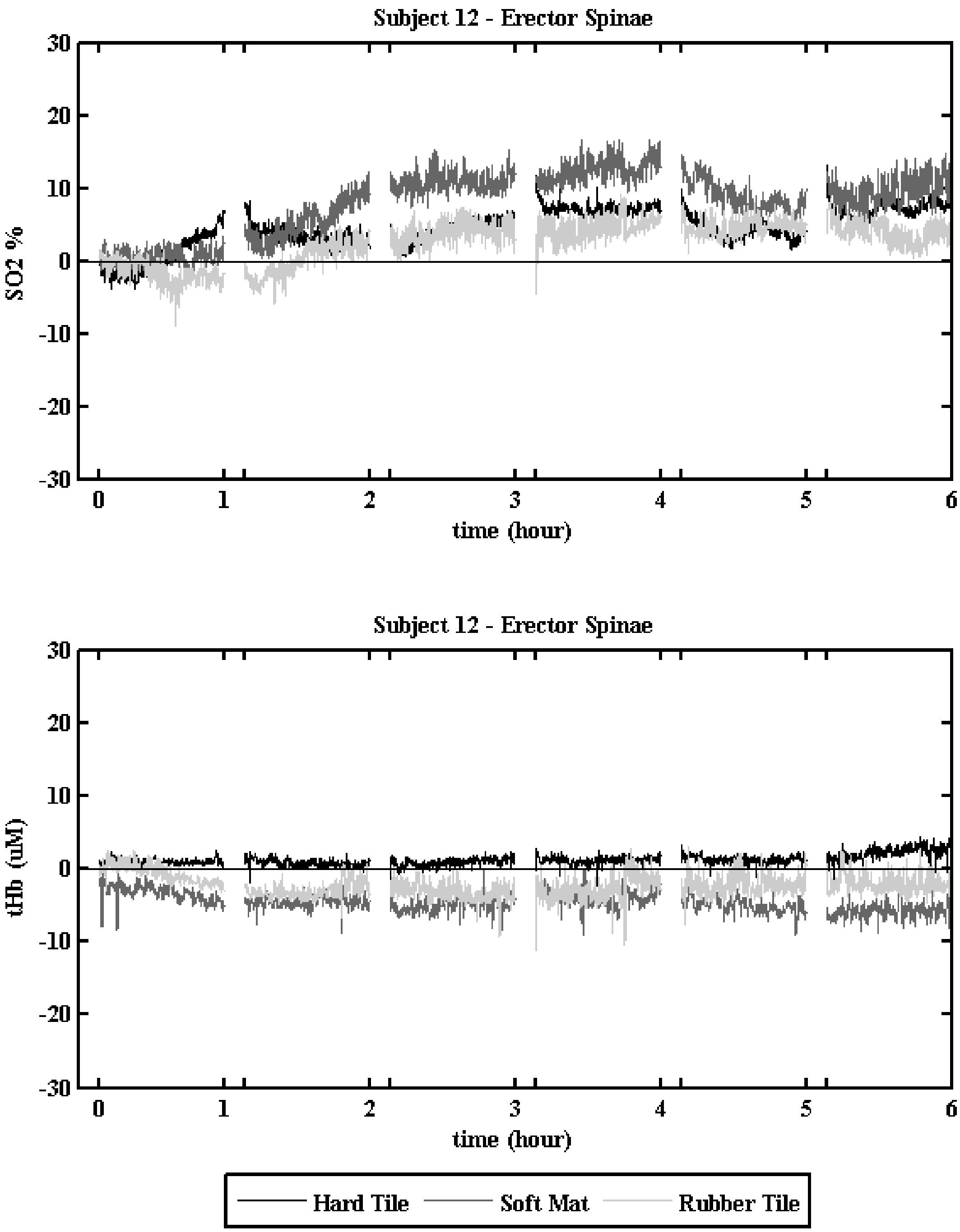


Figure 51: S12 erector spinae NIRS parameters while standing

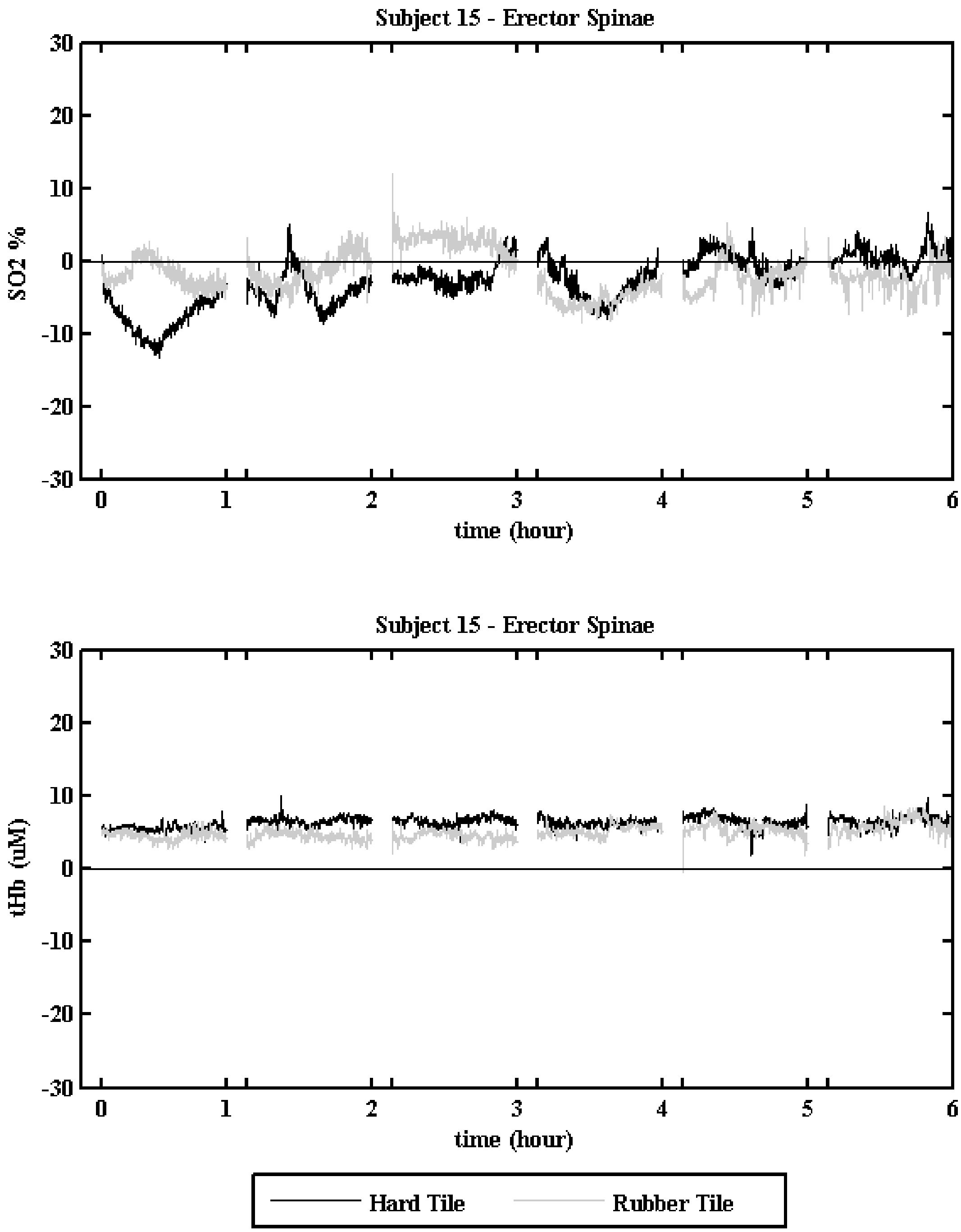


Figure 52: S15 erector spinae NIRS parameters while standing

B.2.2 Soleus

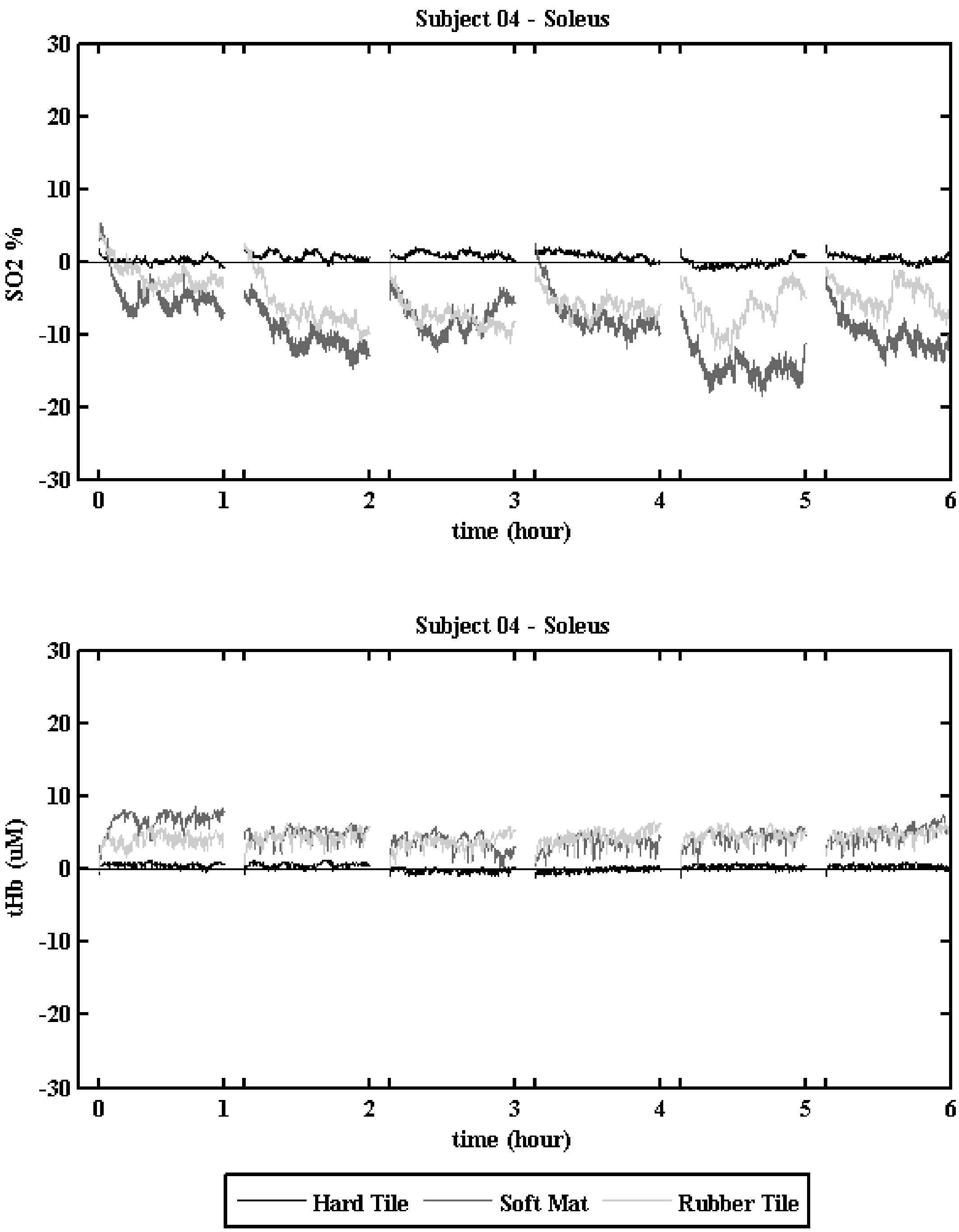


Figure 53: S04 soleus NIRS parameters while standing

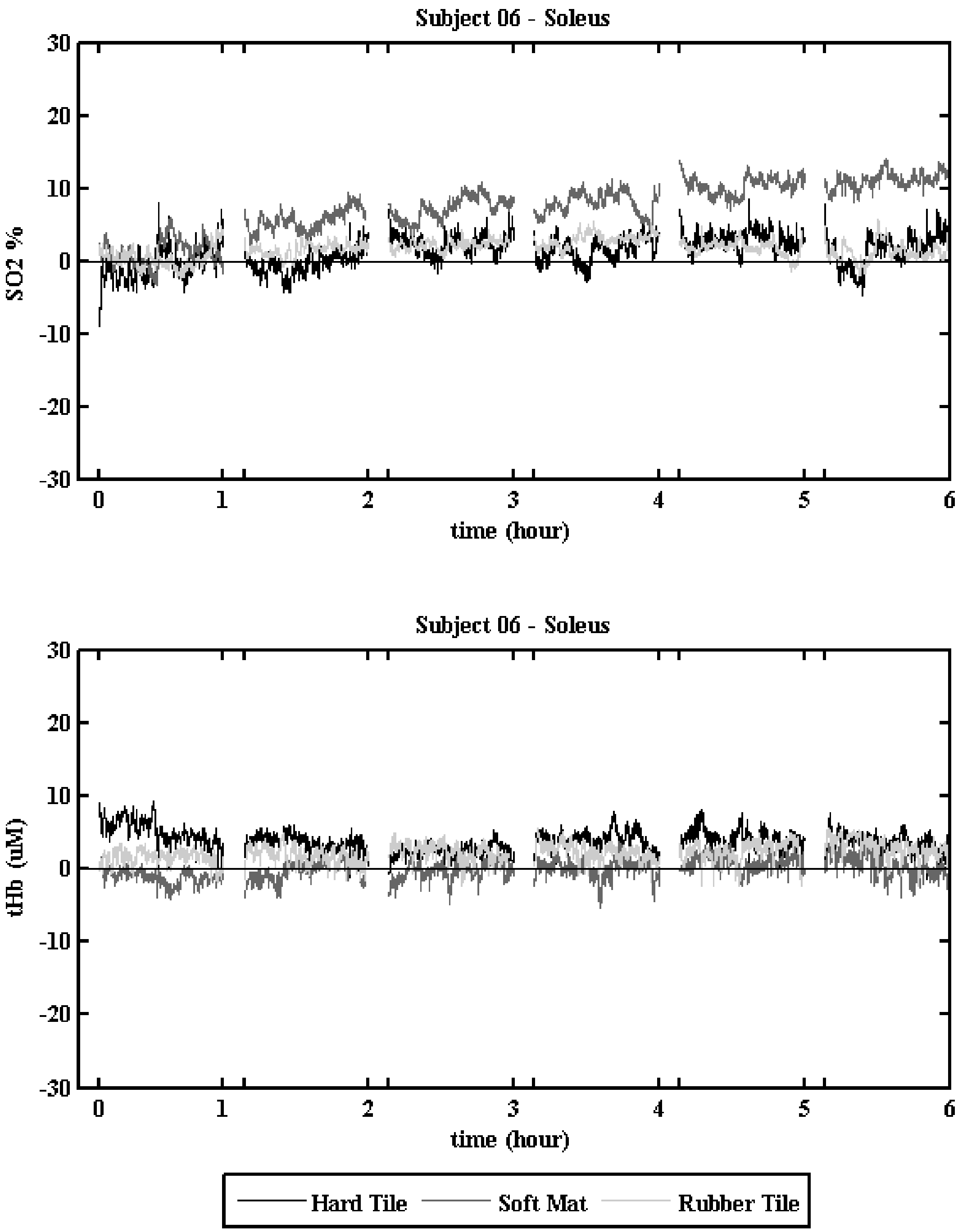


Figure 54: S06 soleus NIRS parameters while standing

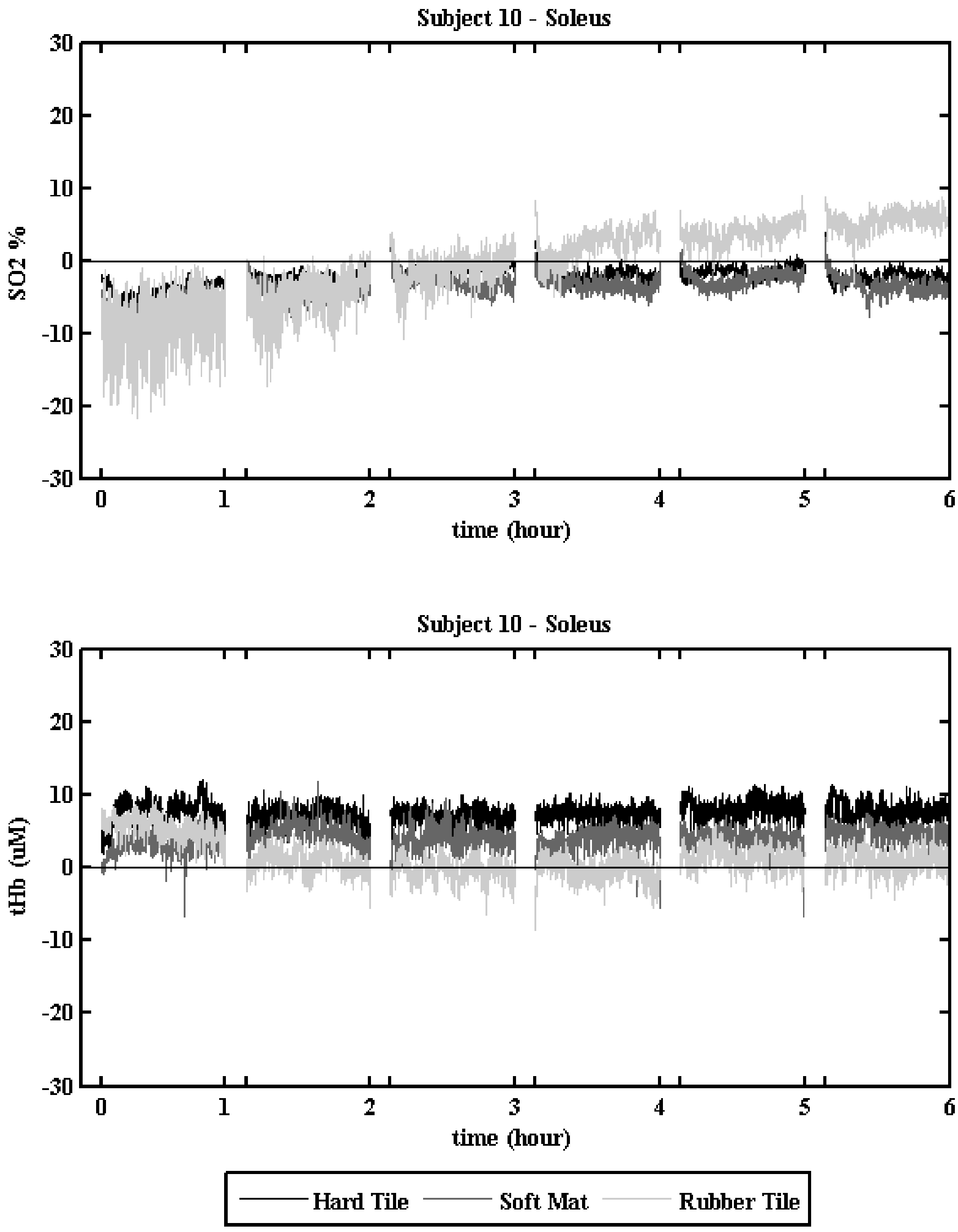


Figure 55: S10 soleus NIRS parameters while standing

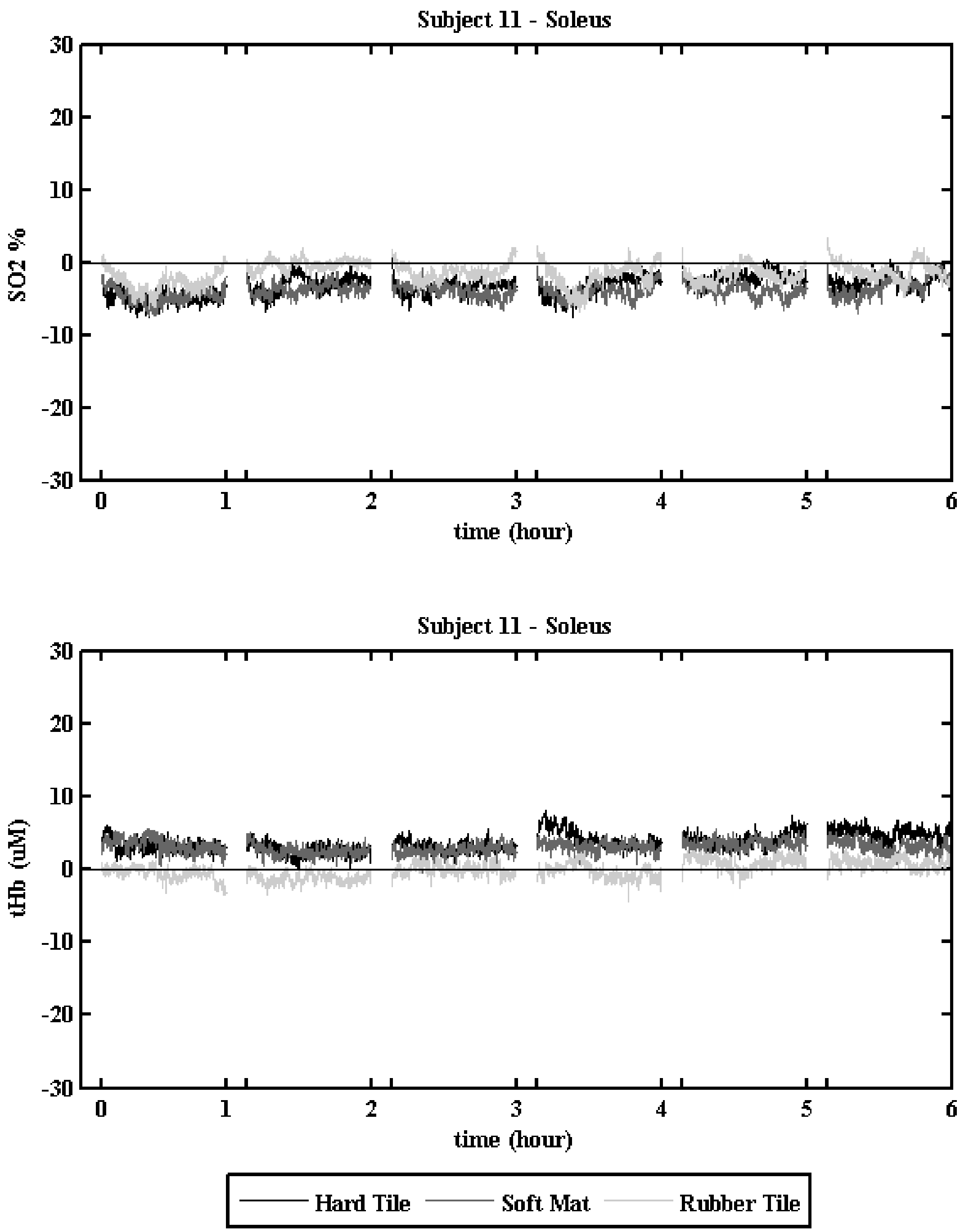


Figure 56: S11 soleus NIRS parameters while standing

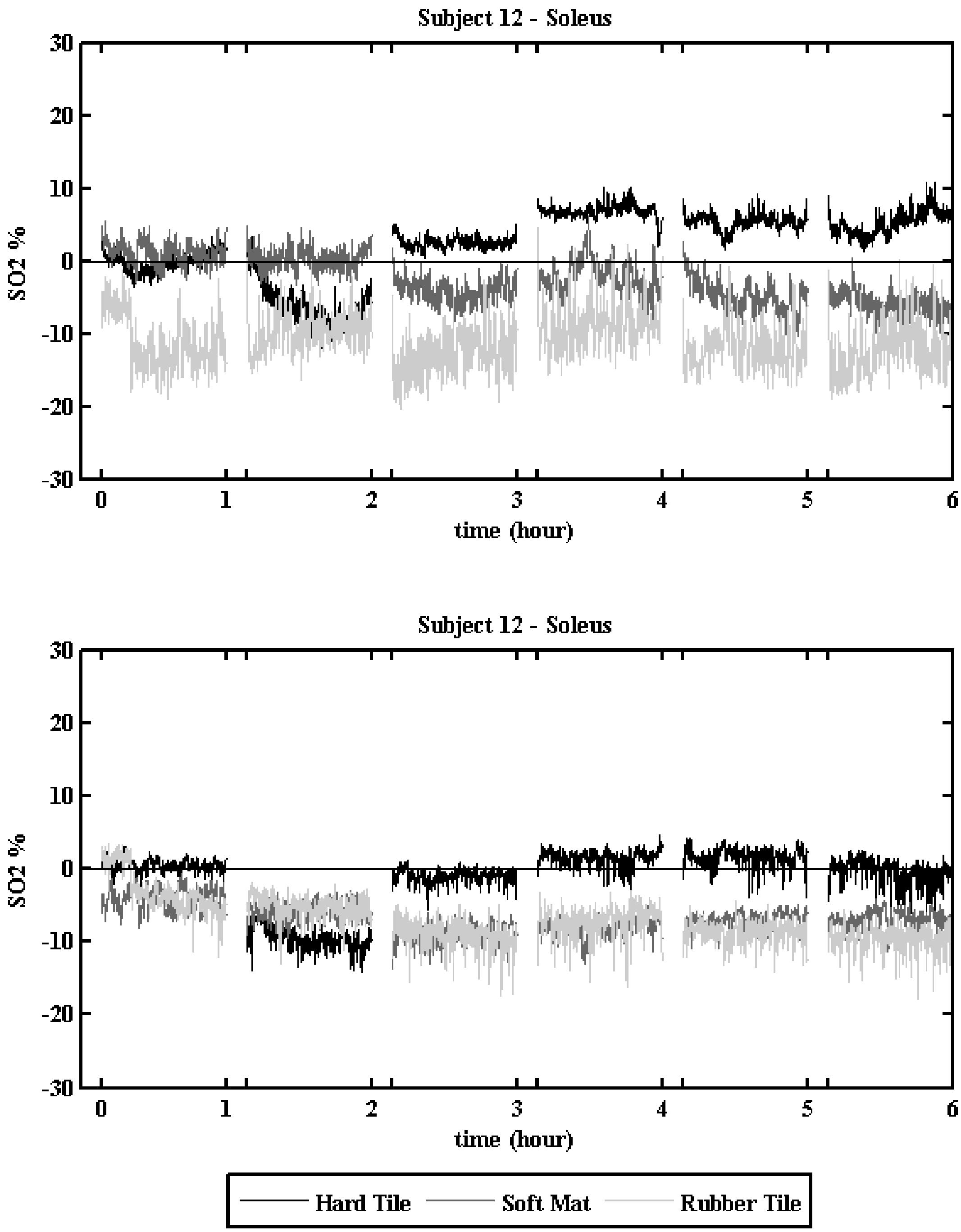


Figure 57: S12 soleus NIRS parameters while standing

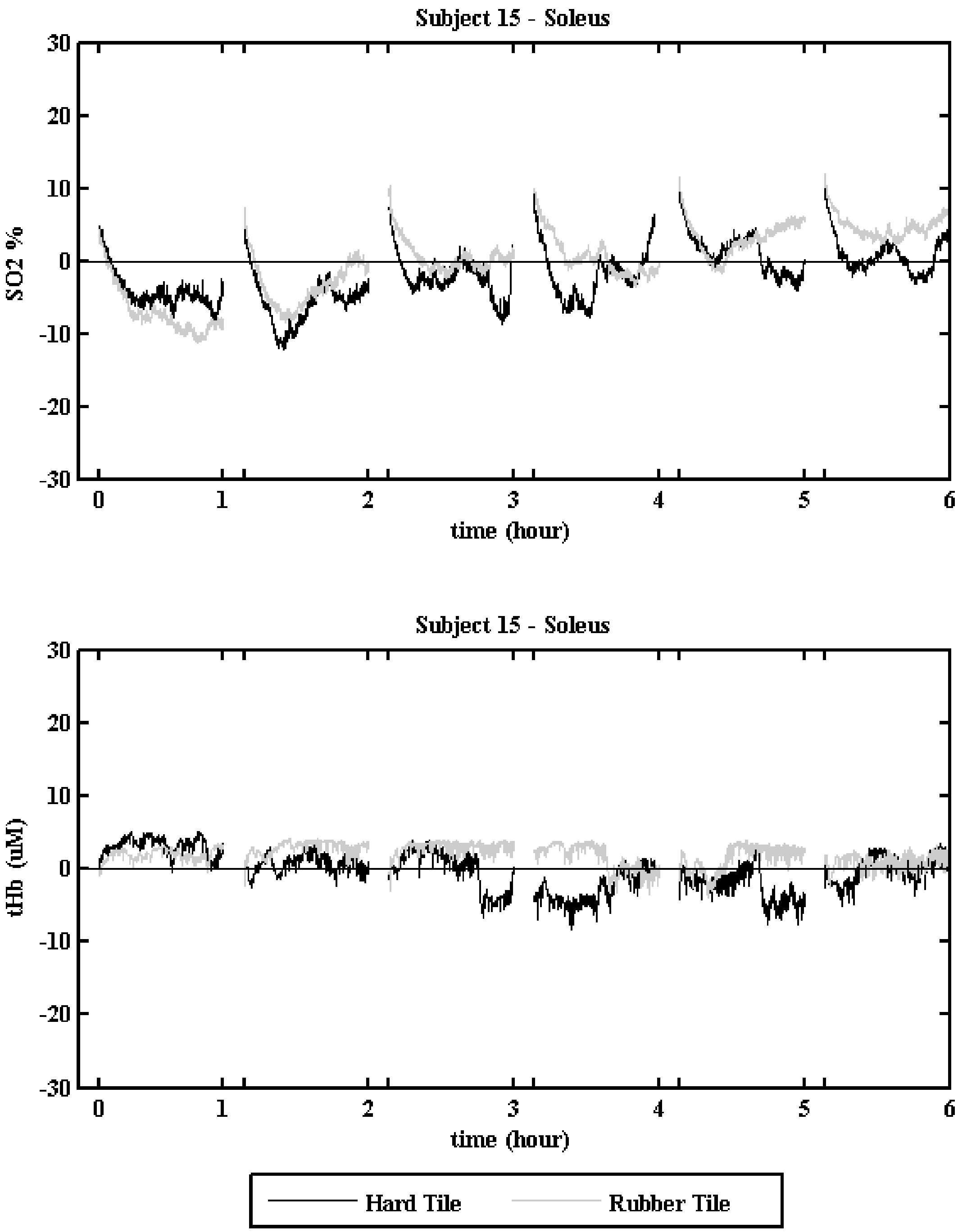


Figure 58: S15 soleus NIRS parameters while standing

B.3 WALKING: ALL FLOORING CONDTIONS

The following data are NIRS outcomes for the soleus and erector spinae muscles during the walking protocol. Muscle SO_2 and tHb were calculated using computer software (Matlab R2012a) for both detectors on each of the two probes. A 4^{th} order low-pass filter with a cutoff frequency of 0.15 Hz was applied to the signal before analysis. The output from one detector from each probe was chosen after visual comparison. Muscle SO_2 and tHb were normalized to the average SO_2 and tHb during the 2 minute seated baseline. The dotted vertical lines represent the 5 minute standing breaks after every 30 minutes of walking.

The following table describes which subjects completed the walking protocol for each flooring condition and whom NIRS data was collected and whether or not it was included in the analysis.

Table 79: NIRS data collection: Walking on each flooring condition

	NIRS data collection			Included in Analysis	
Subject	**Hard Tile**	**Soft Mat**	**Rubber Tile**	**Erector Spinae**	**Soleus**
S04	✓	✓	✓	✓	✓
S05	✗	✗	✗	✗	✗
S06	✓	✓	✗	✗	✗
S08	✗	✗	✗	✗	✗
S10	✓	✓	✓	✓	✓
S11	✓	✓	✓	✗	✓
S12	✓	✓	✓	✓	✓
S13	✓	✓	✓	✓	✗
S14	✓	✓	✓	✓	✓
S15	✓	✓	✓	✗	✓
S16	✓	✓	✓	✓	✓
S17	✓	✓	✓	✓	✓
S18	✓	✗	✗	✗	✗

B.3.1 Erector Spinae

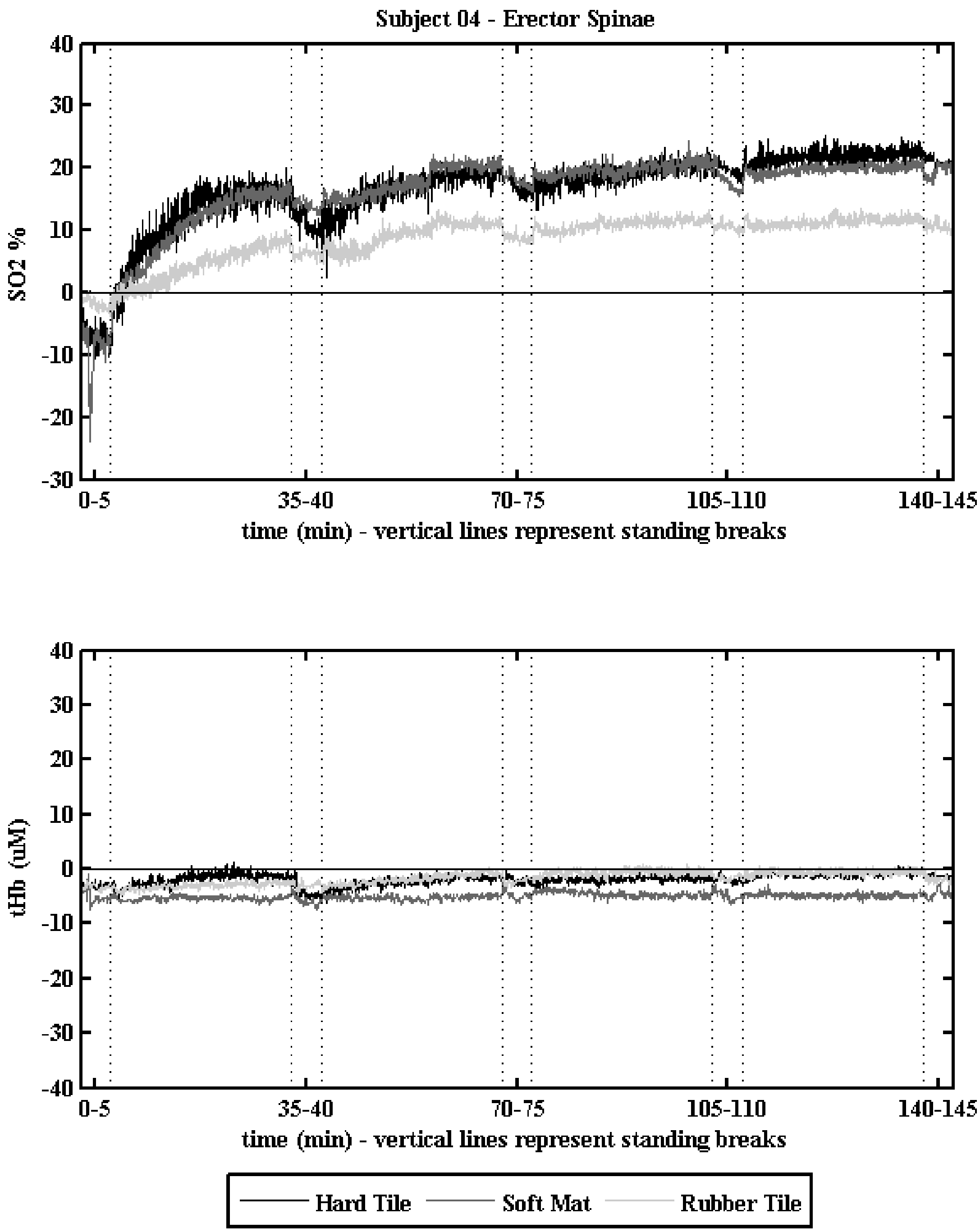


Figure 59: S04 erector spinae NIRS parameters while walking

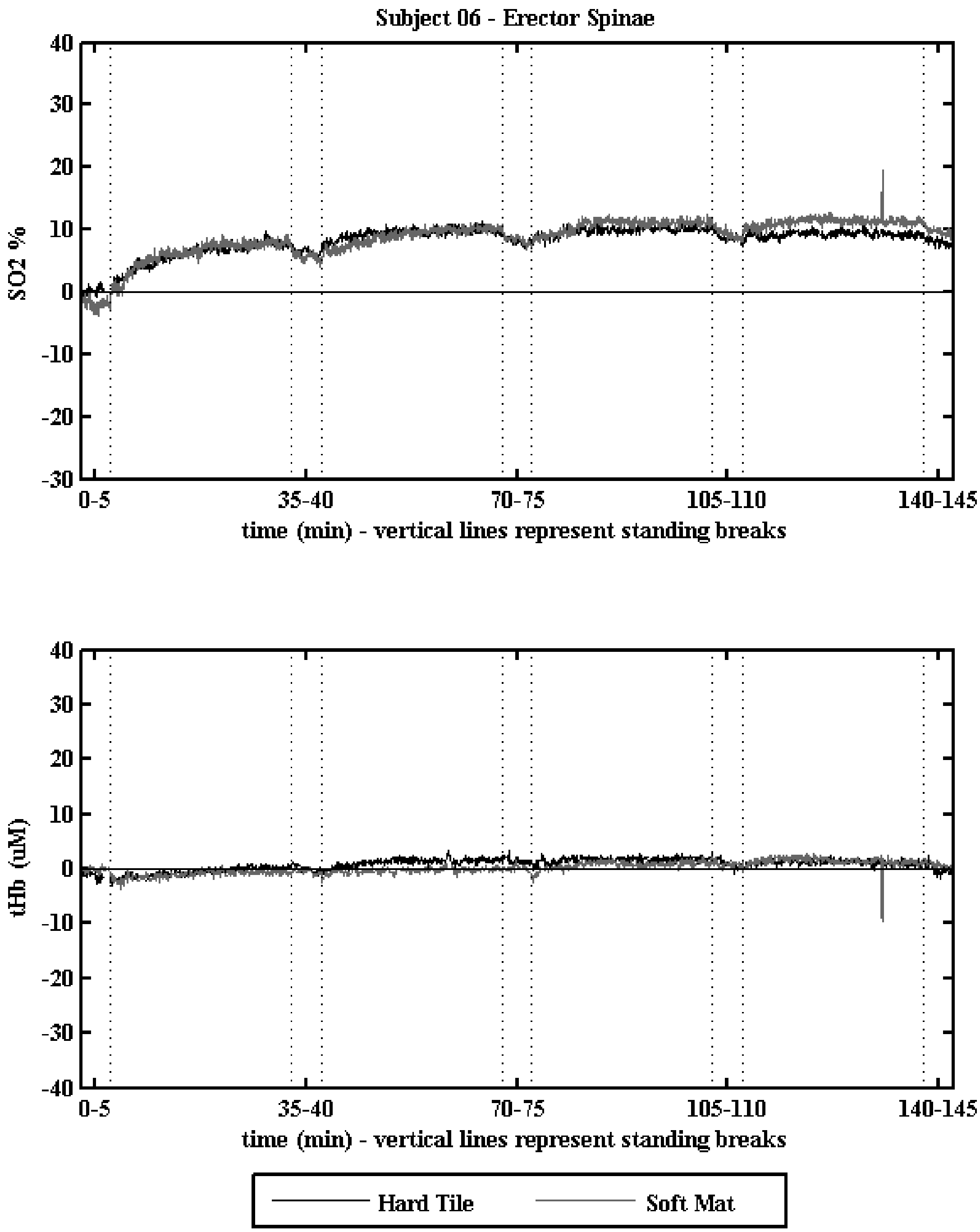


Figure 60: S06 erector spinae NIRS parameters while walking

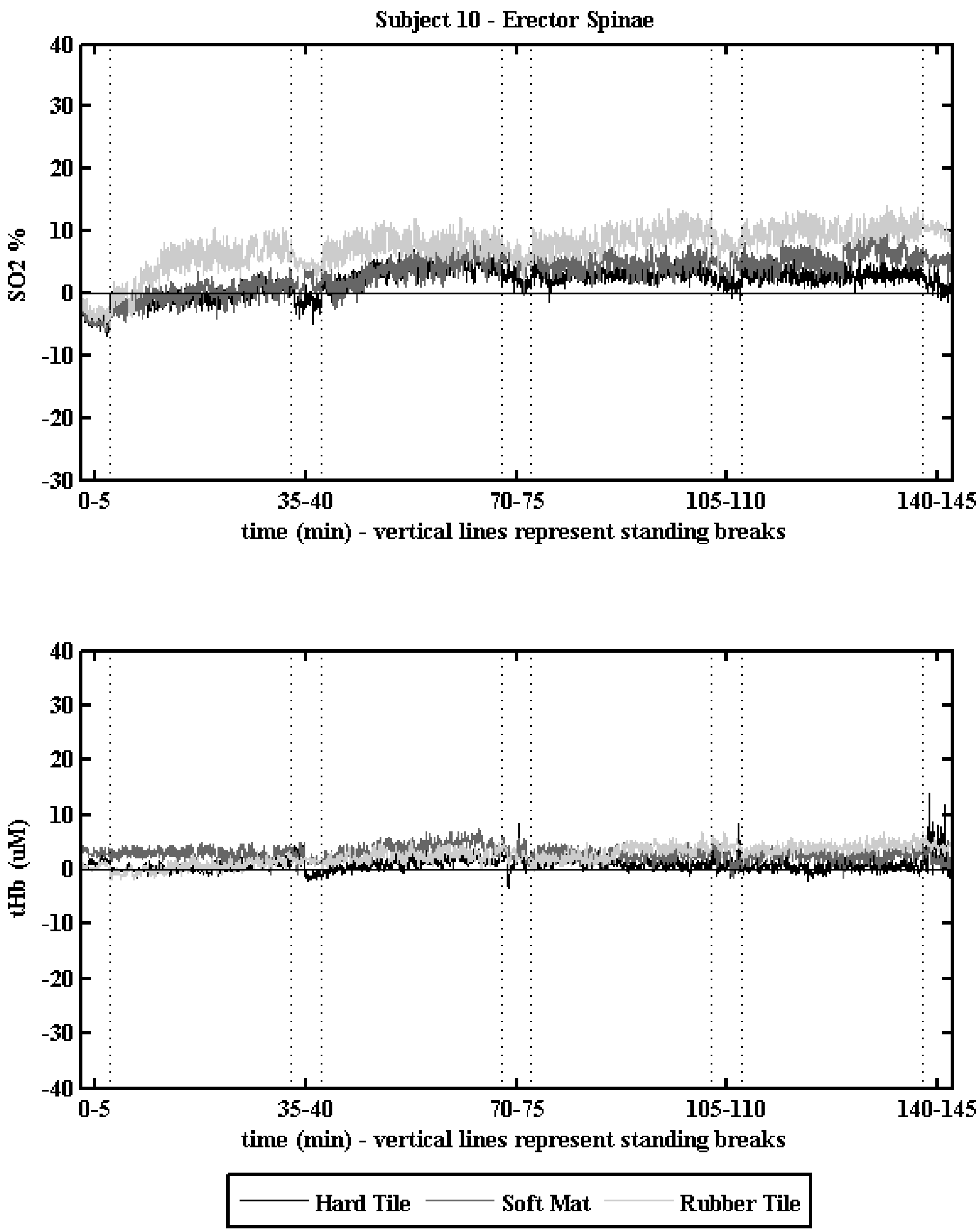


Figure 61: S10 erector spinae NIRS parameters while walking

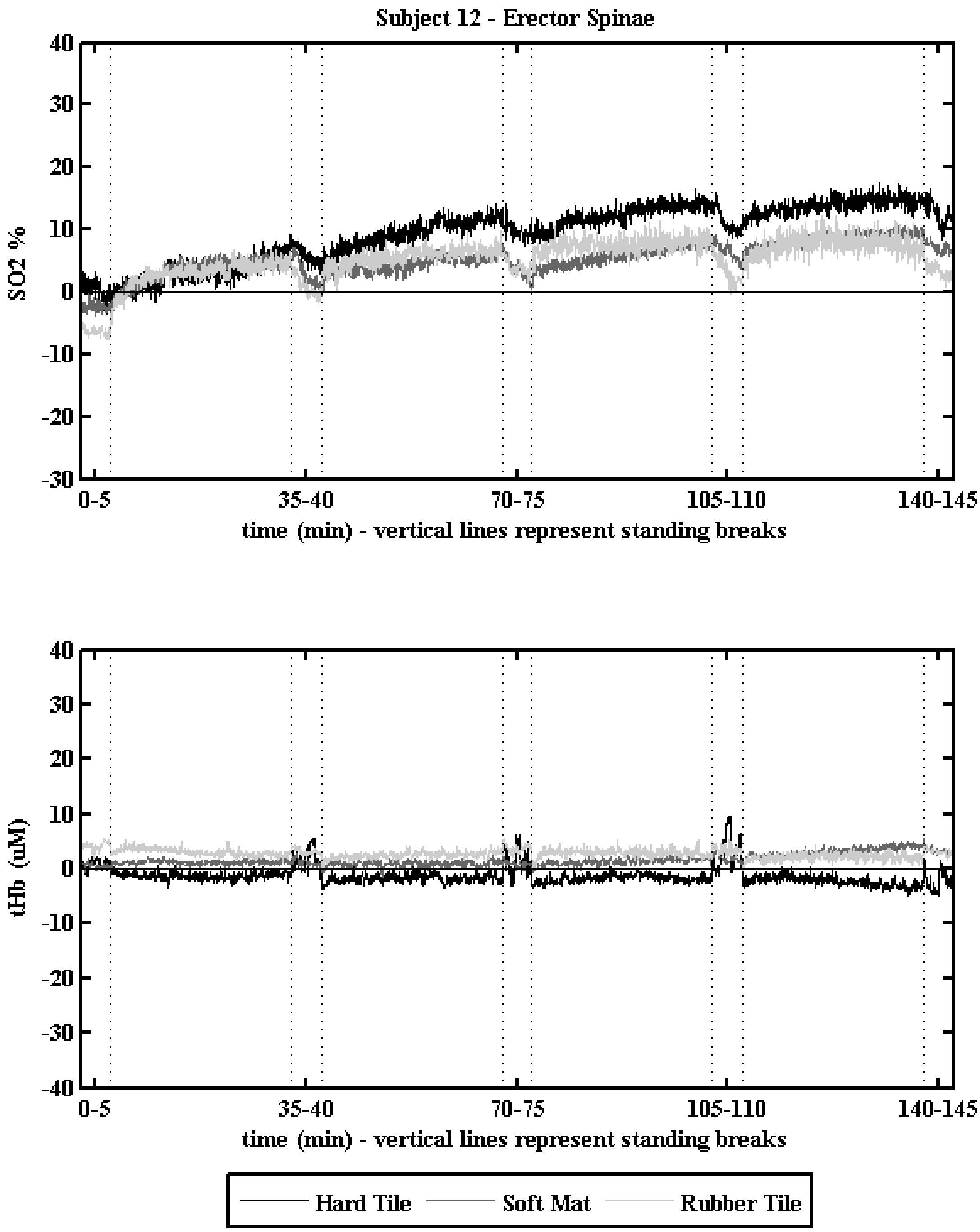


Figure 62: S12 erector spinae NIRS parameters while walking

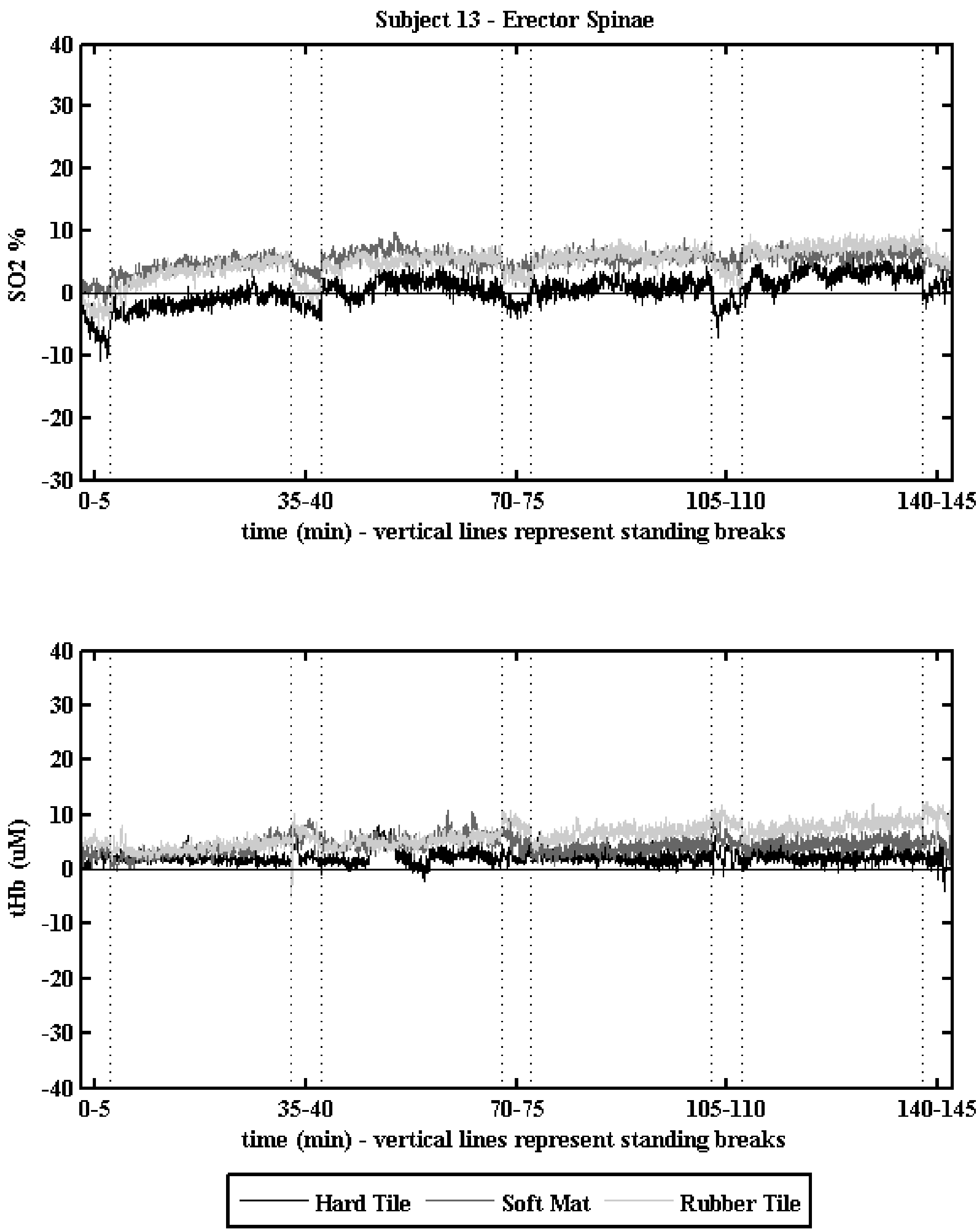


Figure 63: S13 erector spinae NIRS parameters while walking

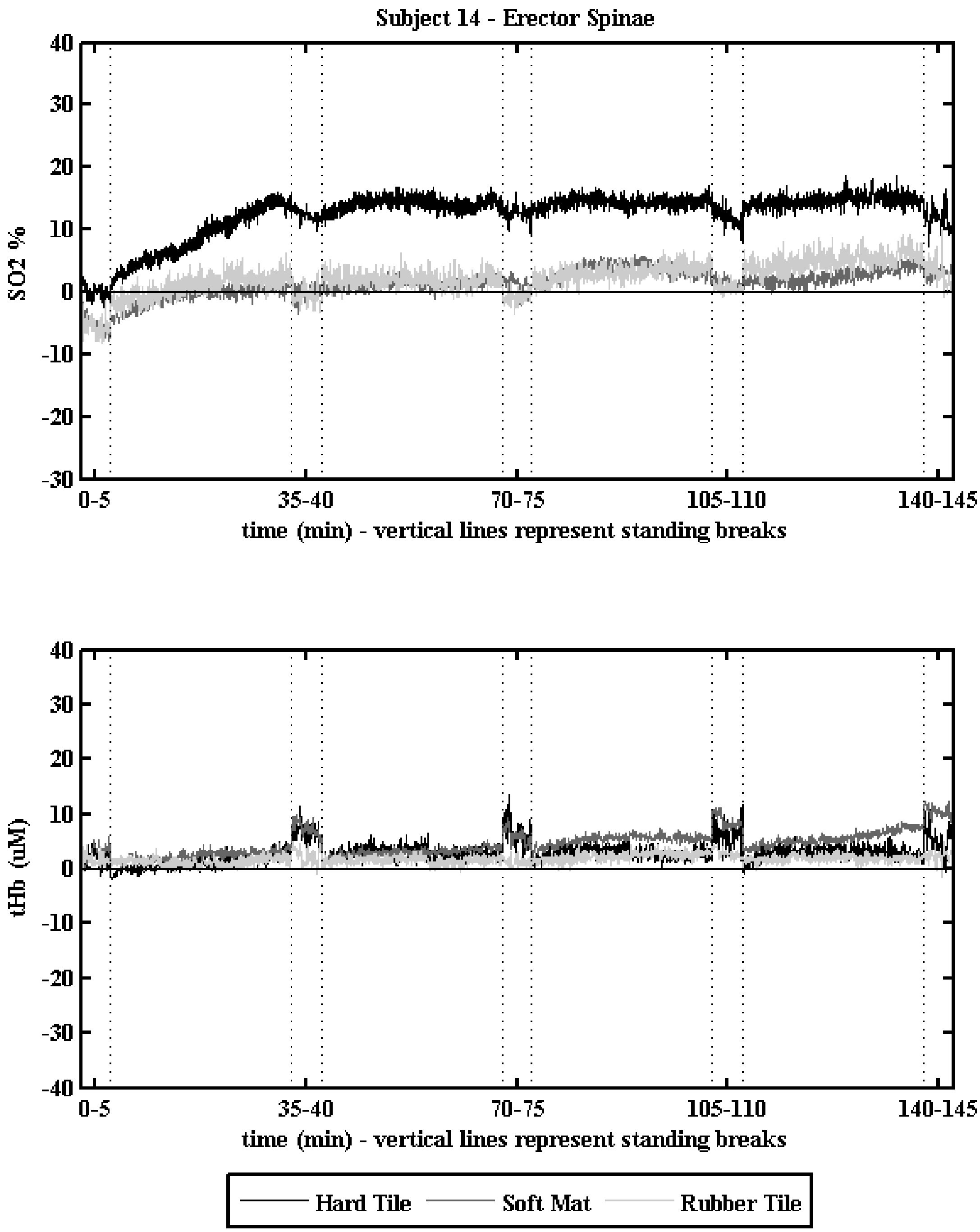


Figure 64: S14 erector spinae NIRS parameters while walking

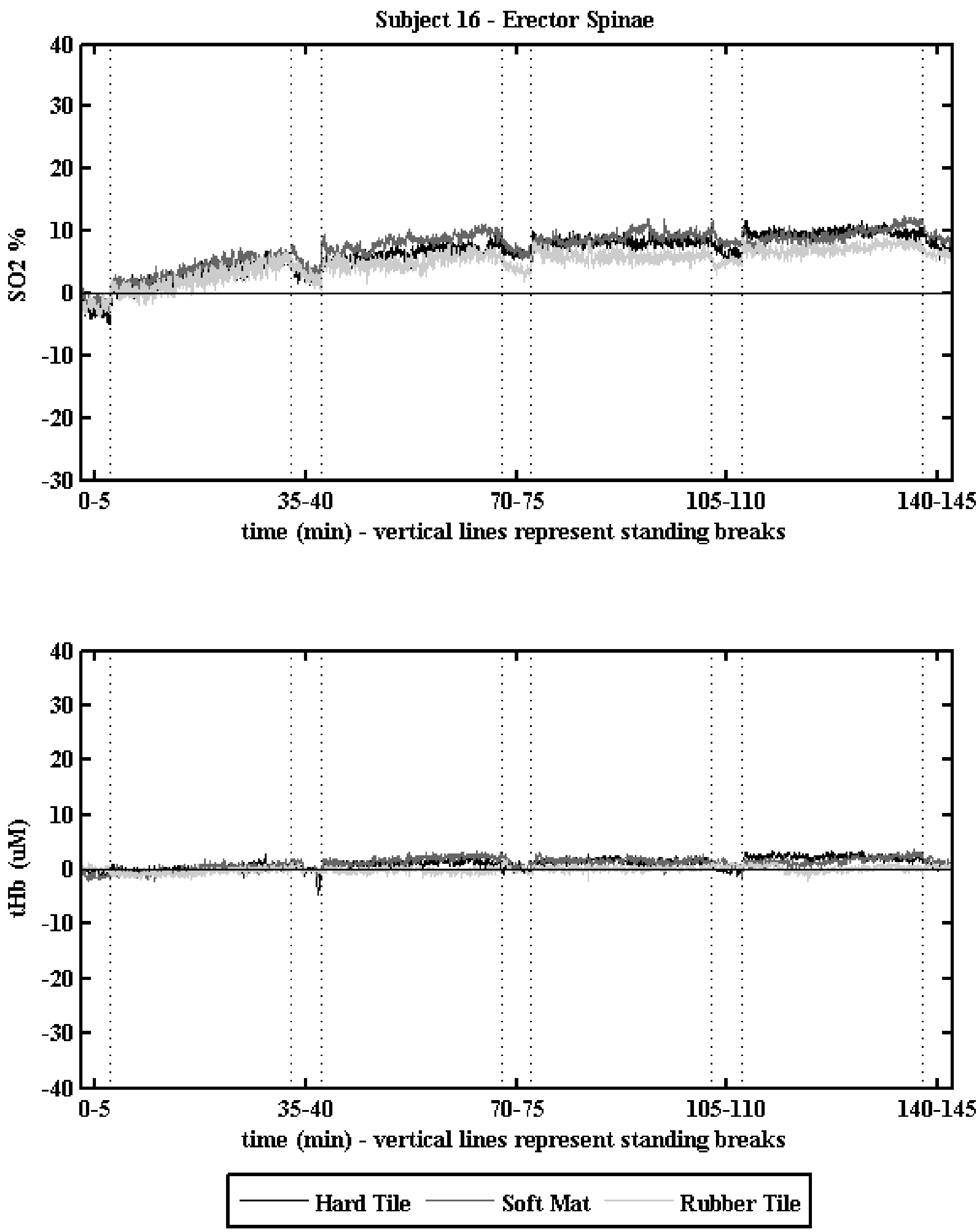


Figure 65: S16 erector spinae NIRS parameters while walking

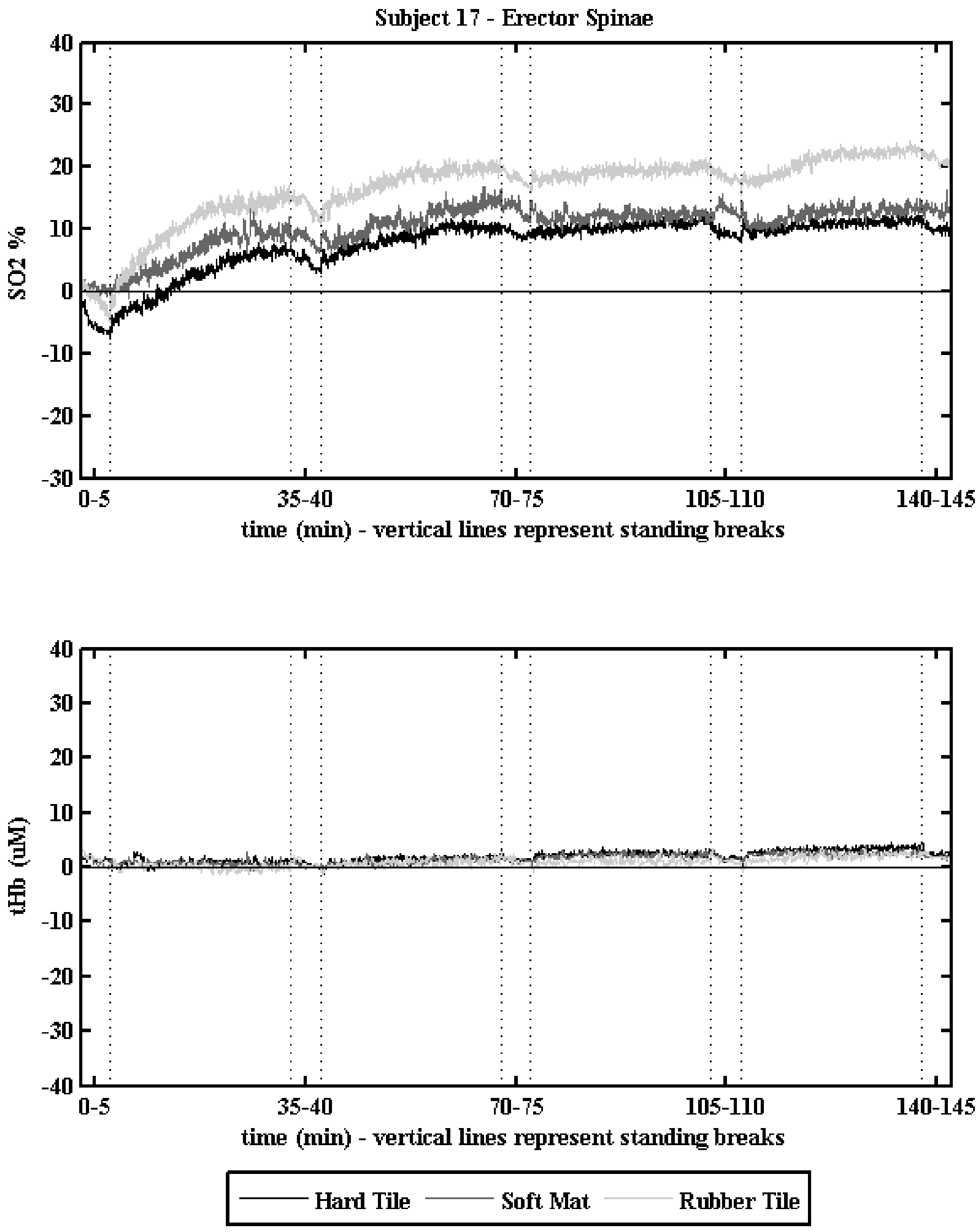


Figure 66: S17 erector spinae NIRS parameters while walking

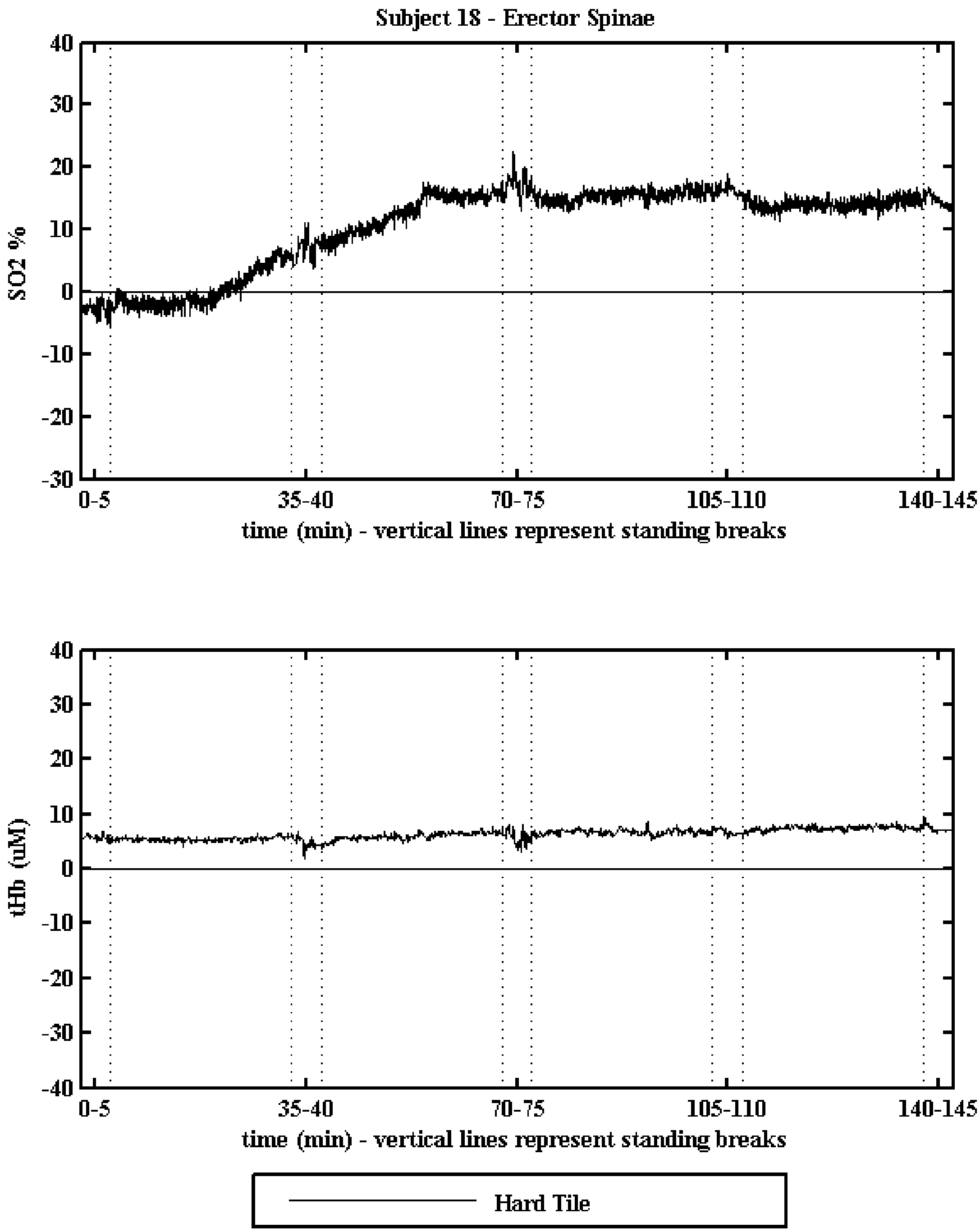


Figure 67: S18 erector spinae NIRS parameters while walking

B.3.2 Soleus

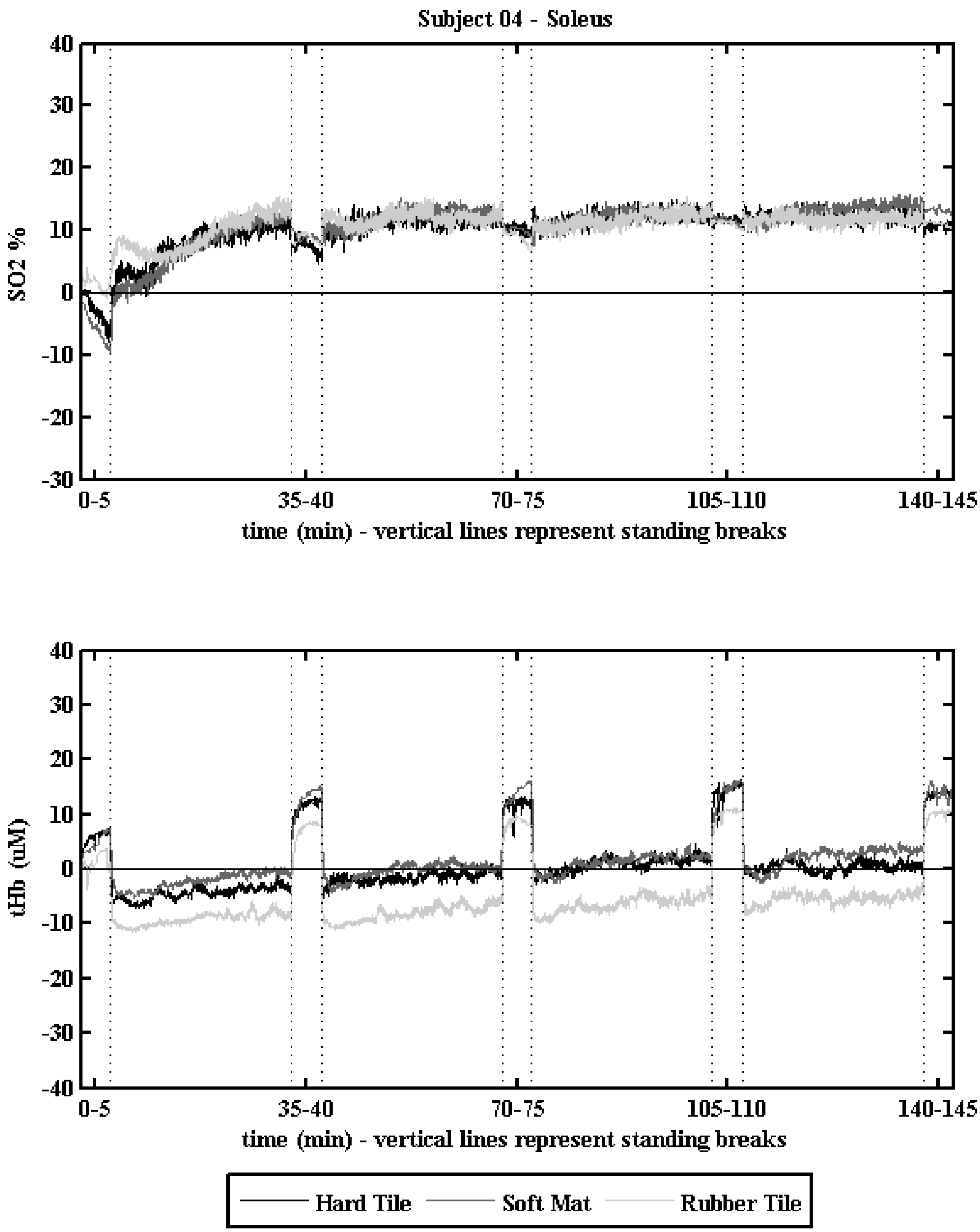


Figure 68: S04 soleus NIRS parameters while walking

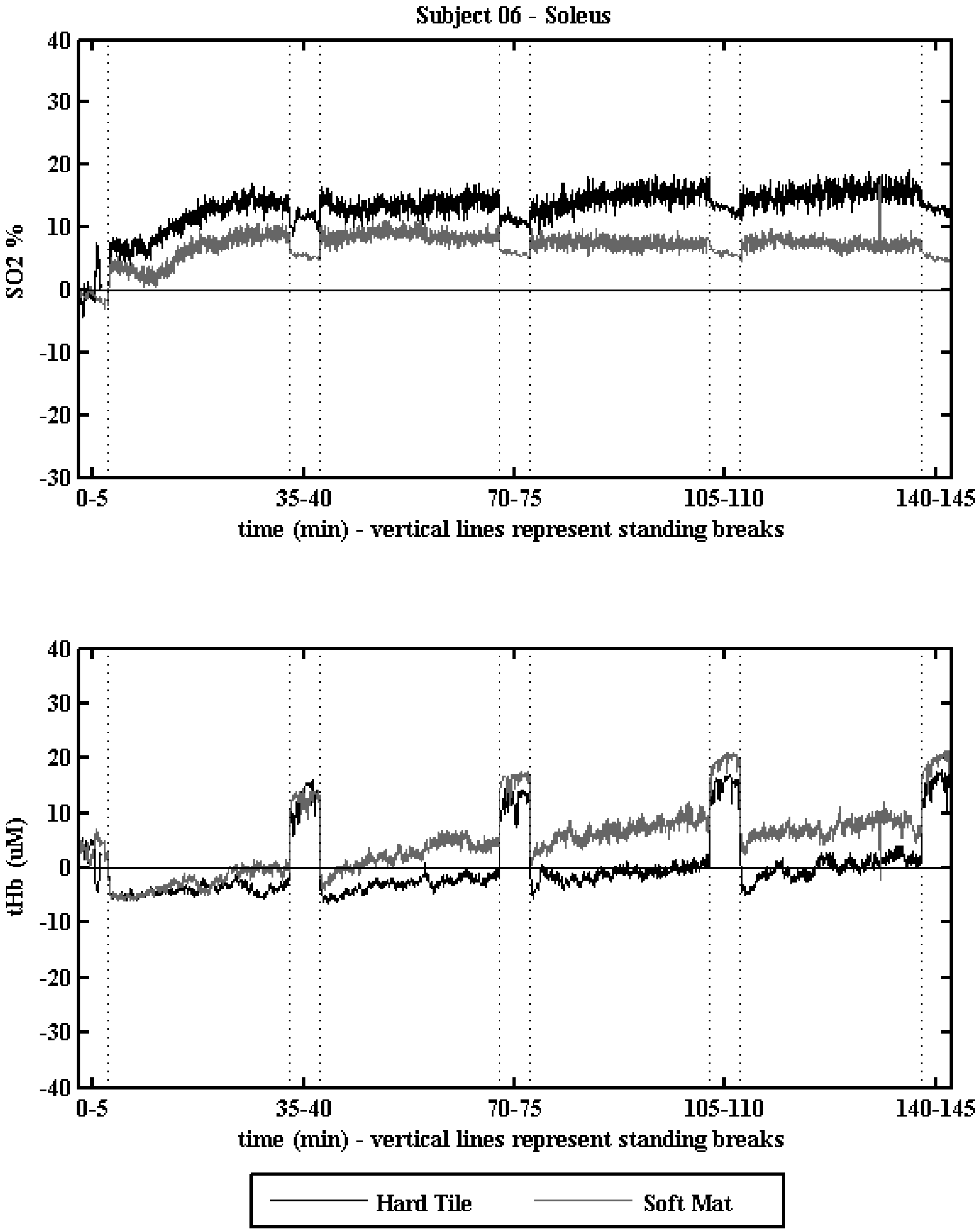


Figure 69: S06 soleus NIRS parameters while walking

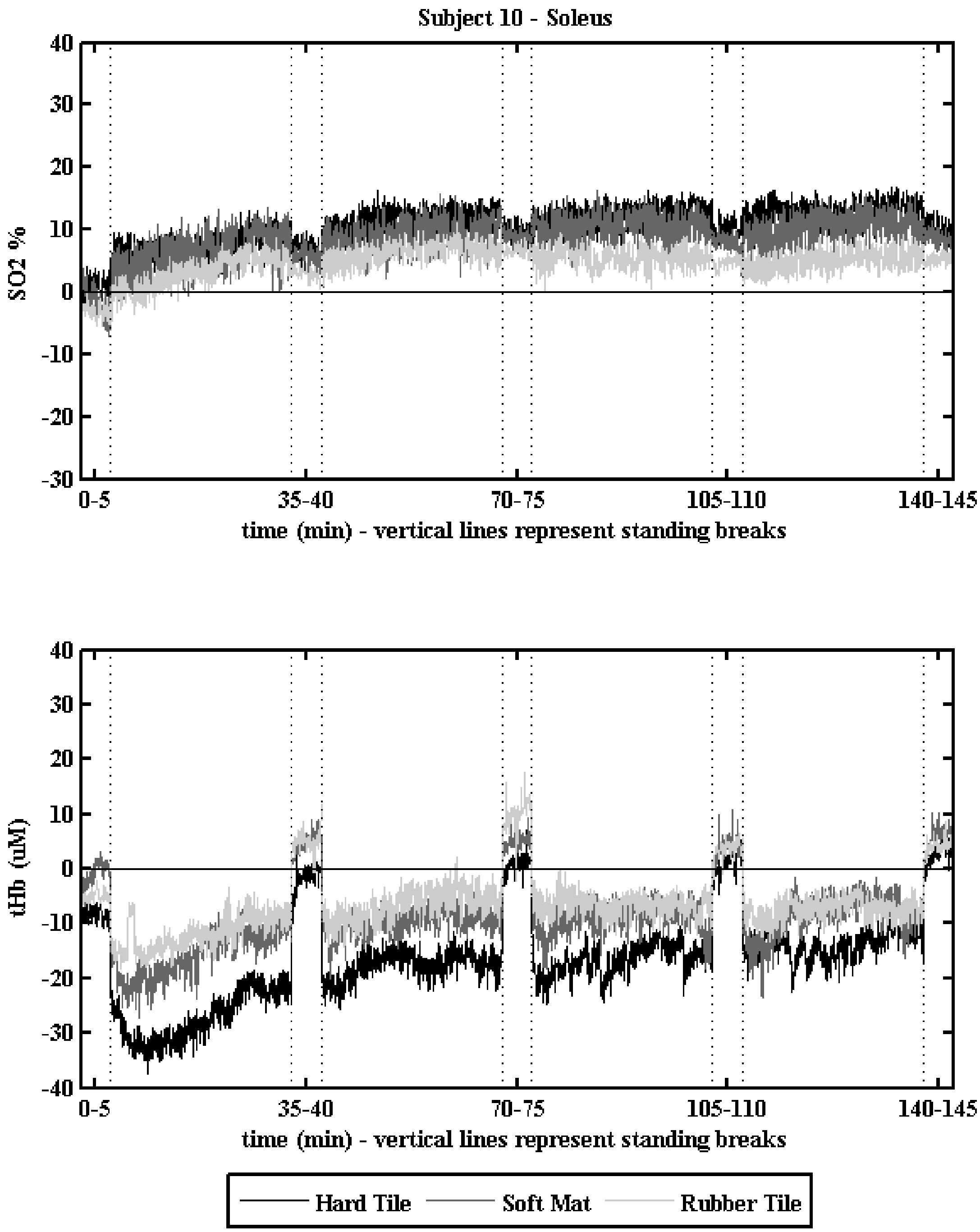


Figure 70: S10 soleus NIRS parameters while walking

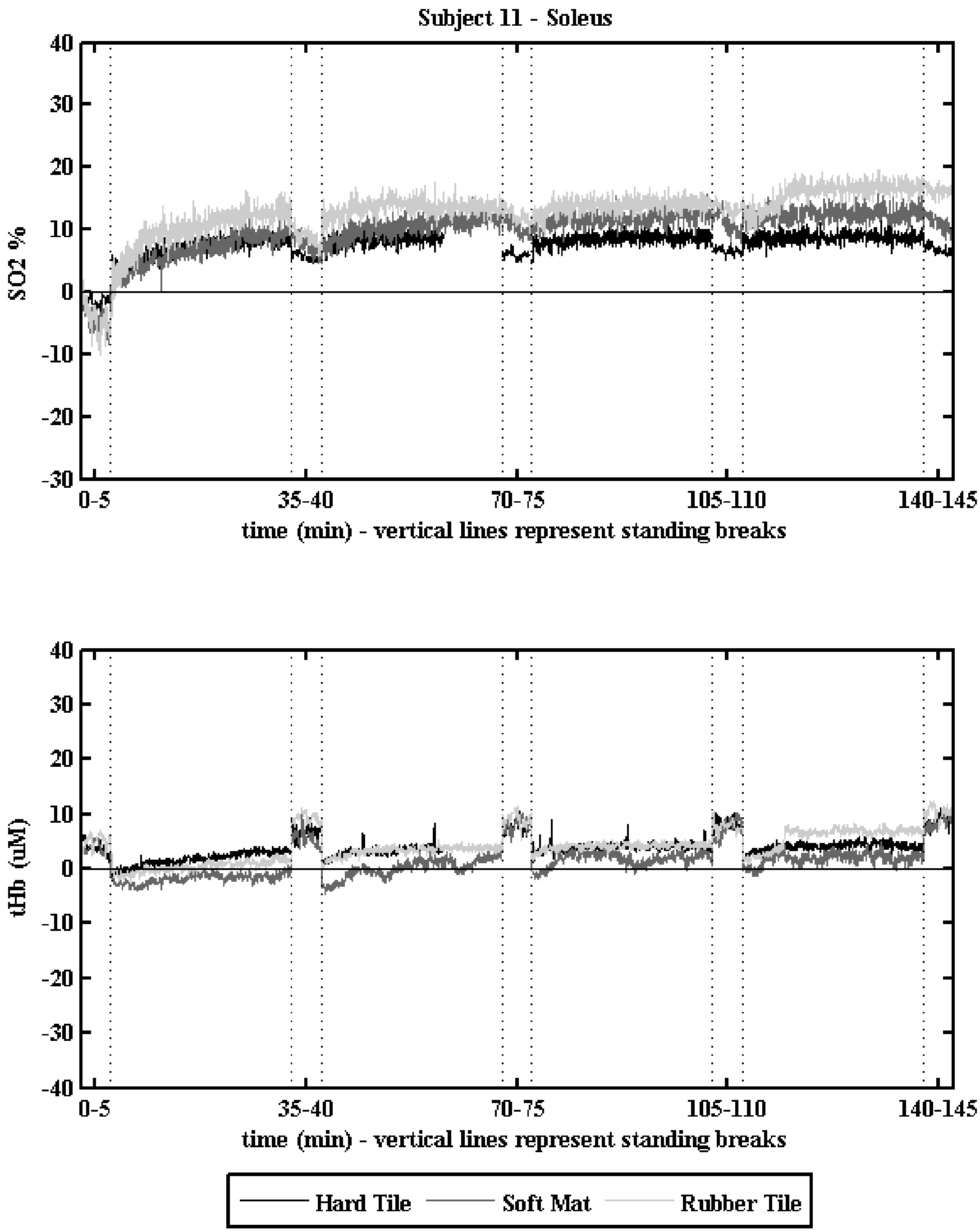


Figure 71: S11 soleus NIRS parameters while walking

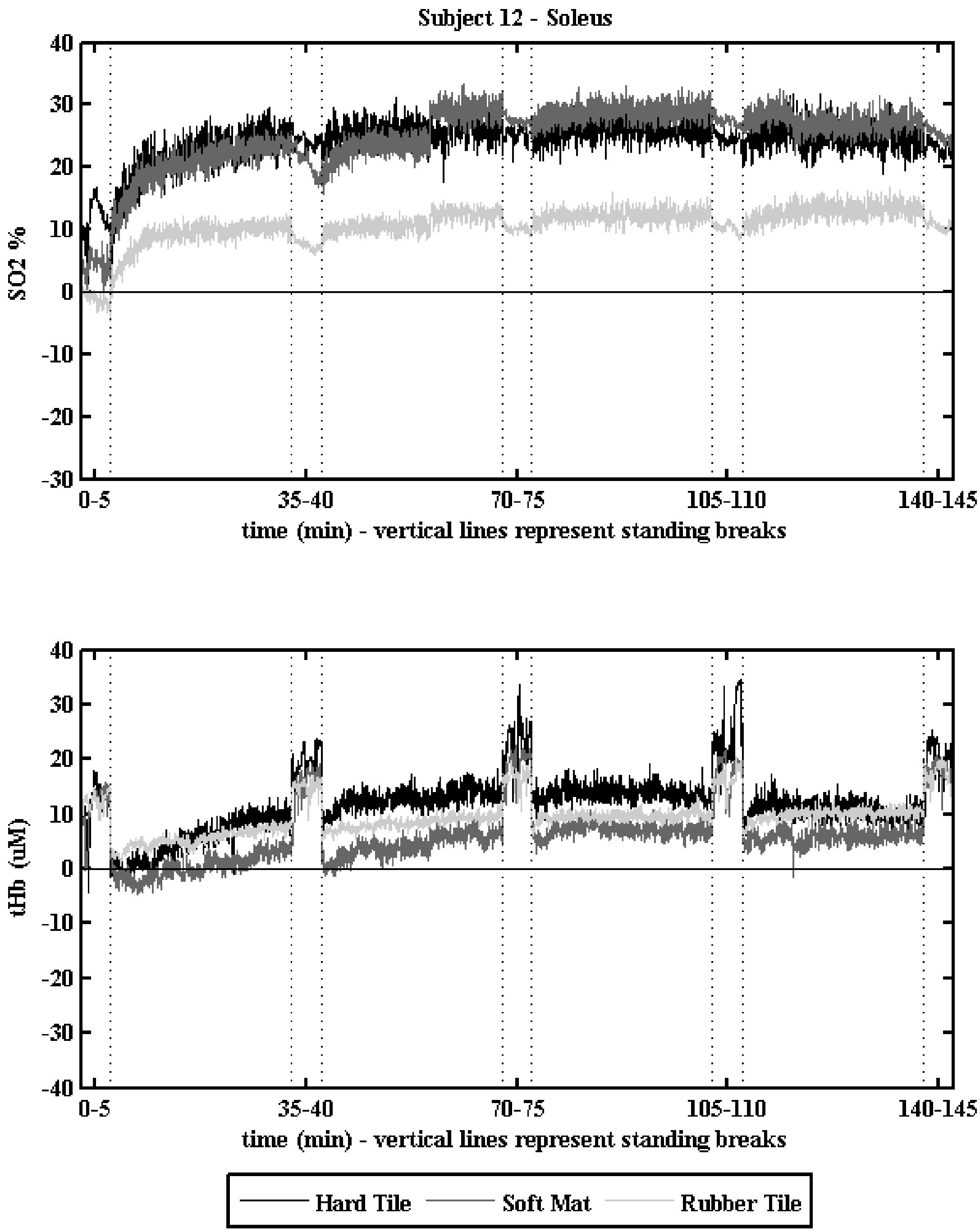


Figure 72: S12 soleus NIRS parameters while walking

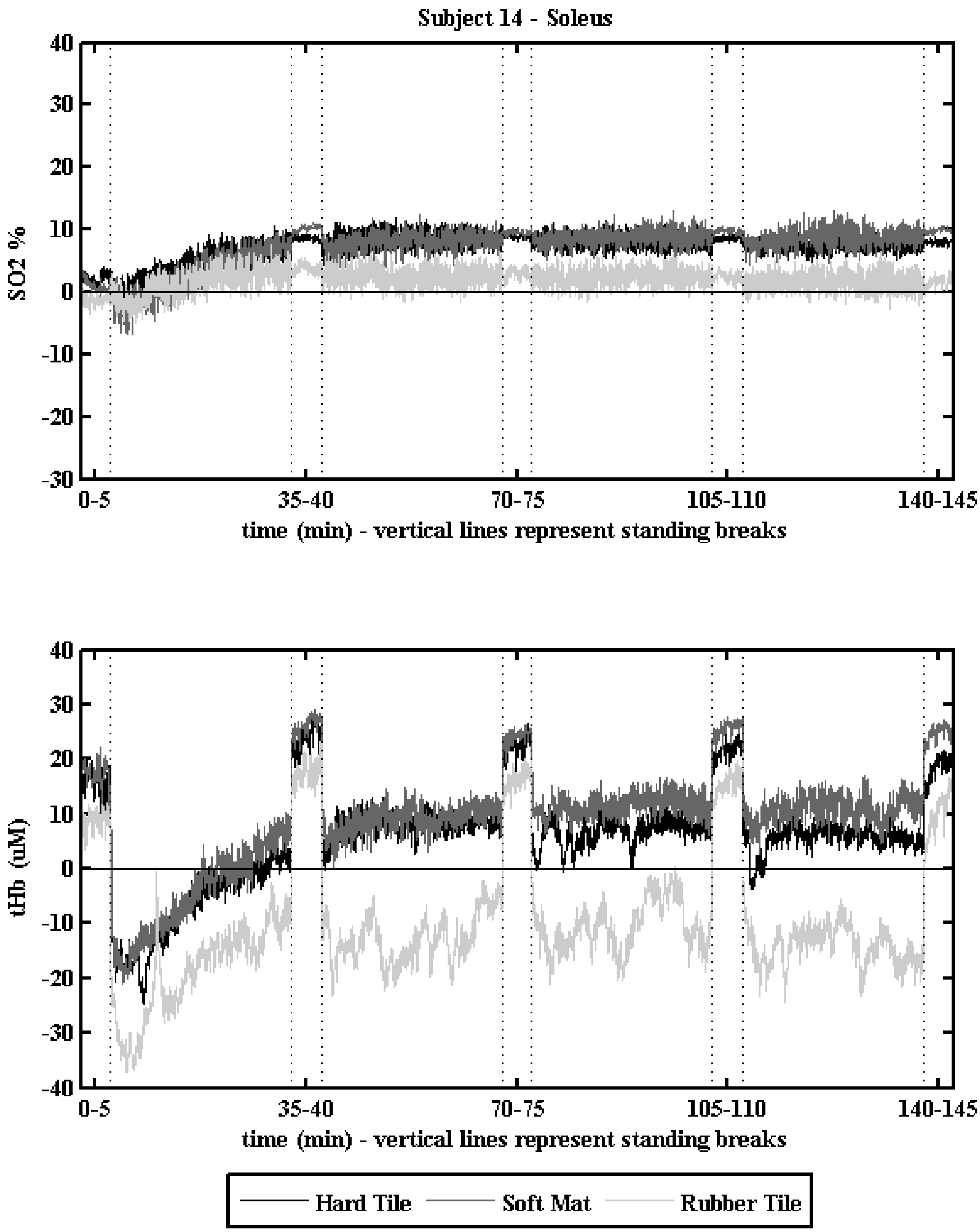


Figure 73: S14 soleus NIRS parameters while walking

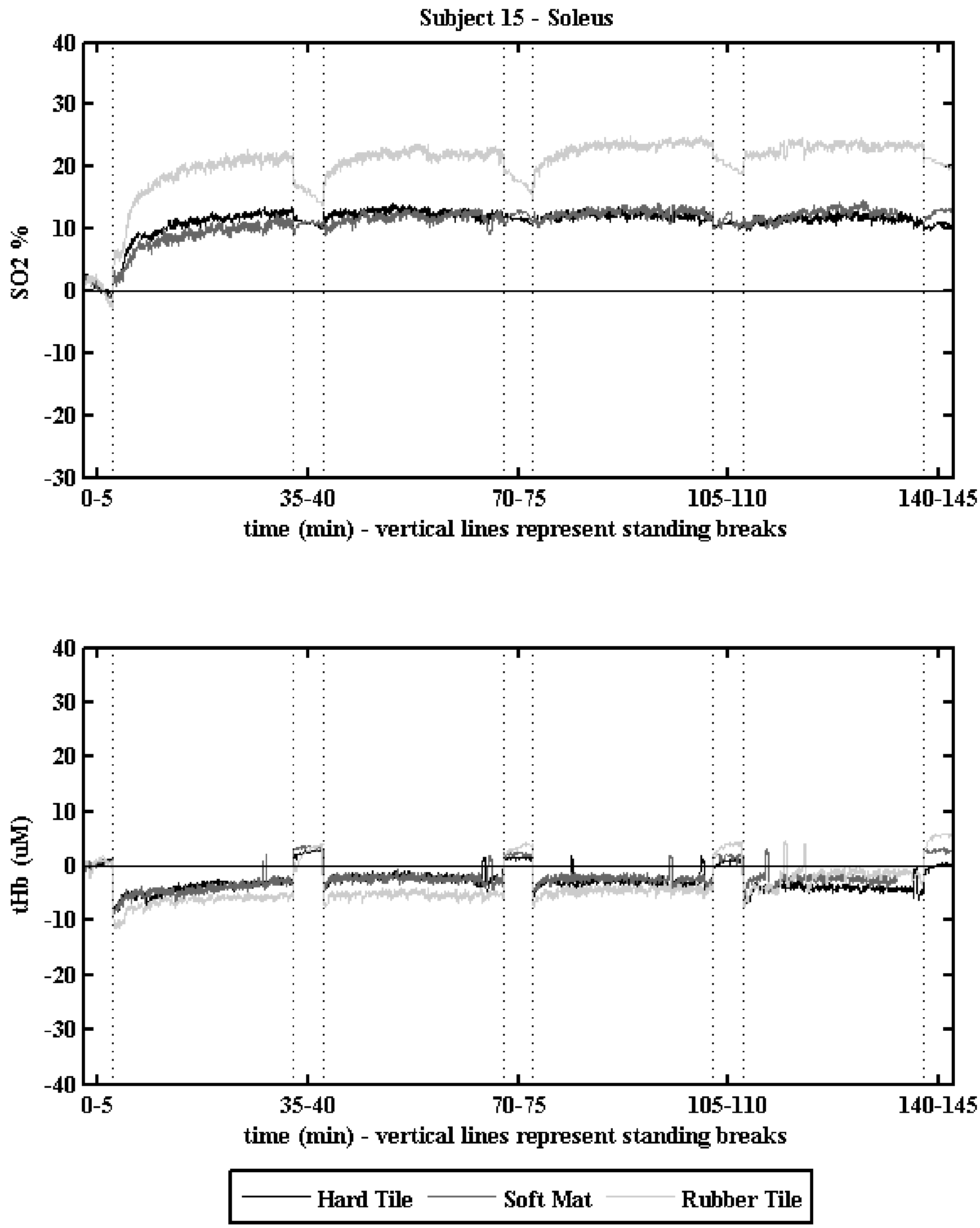


Figure 74: S15 soleus NIRS parameters while walking

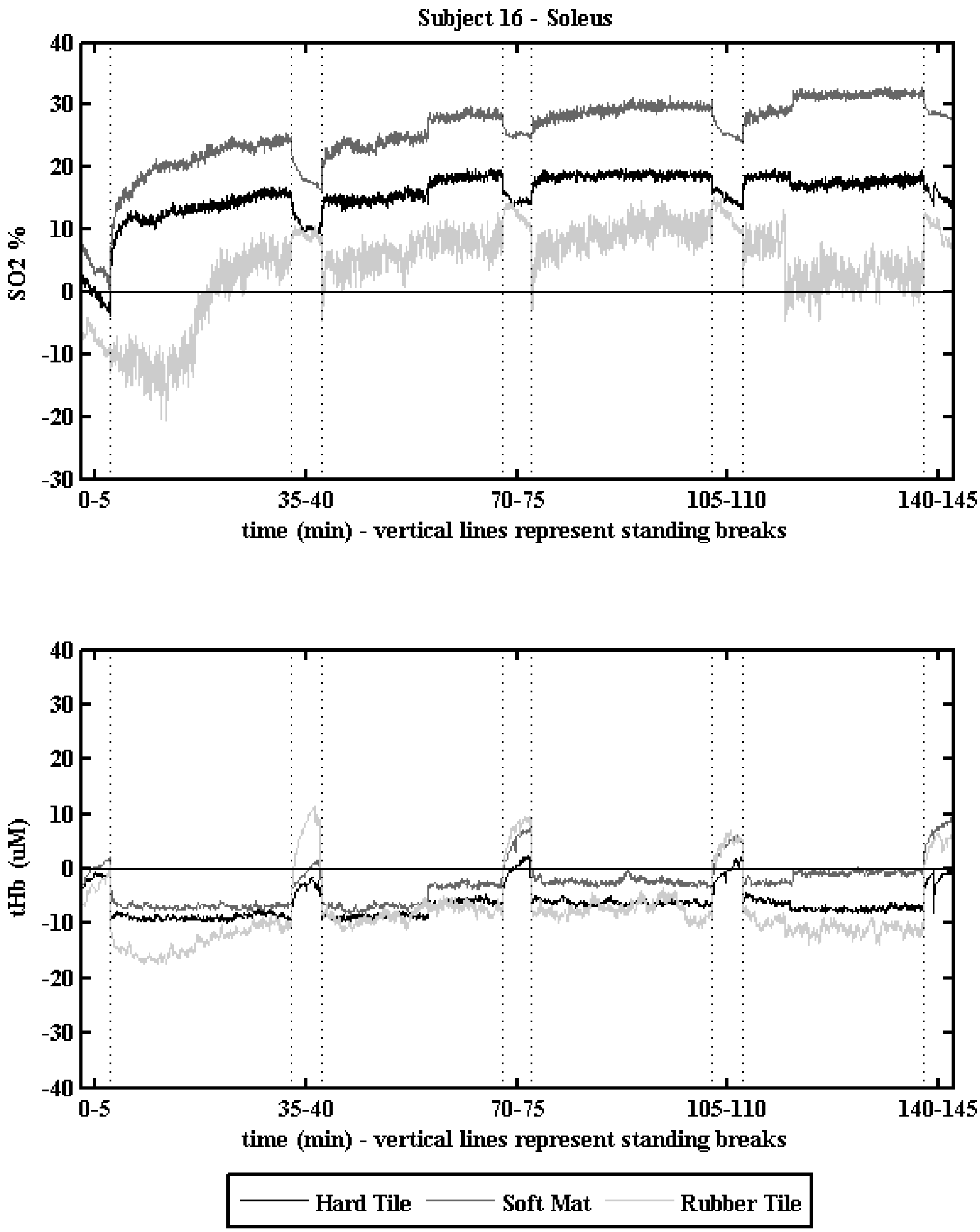


Figure 75: S16 soleus NIRS parameters while walking

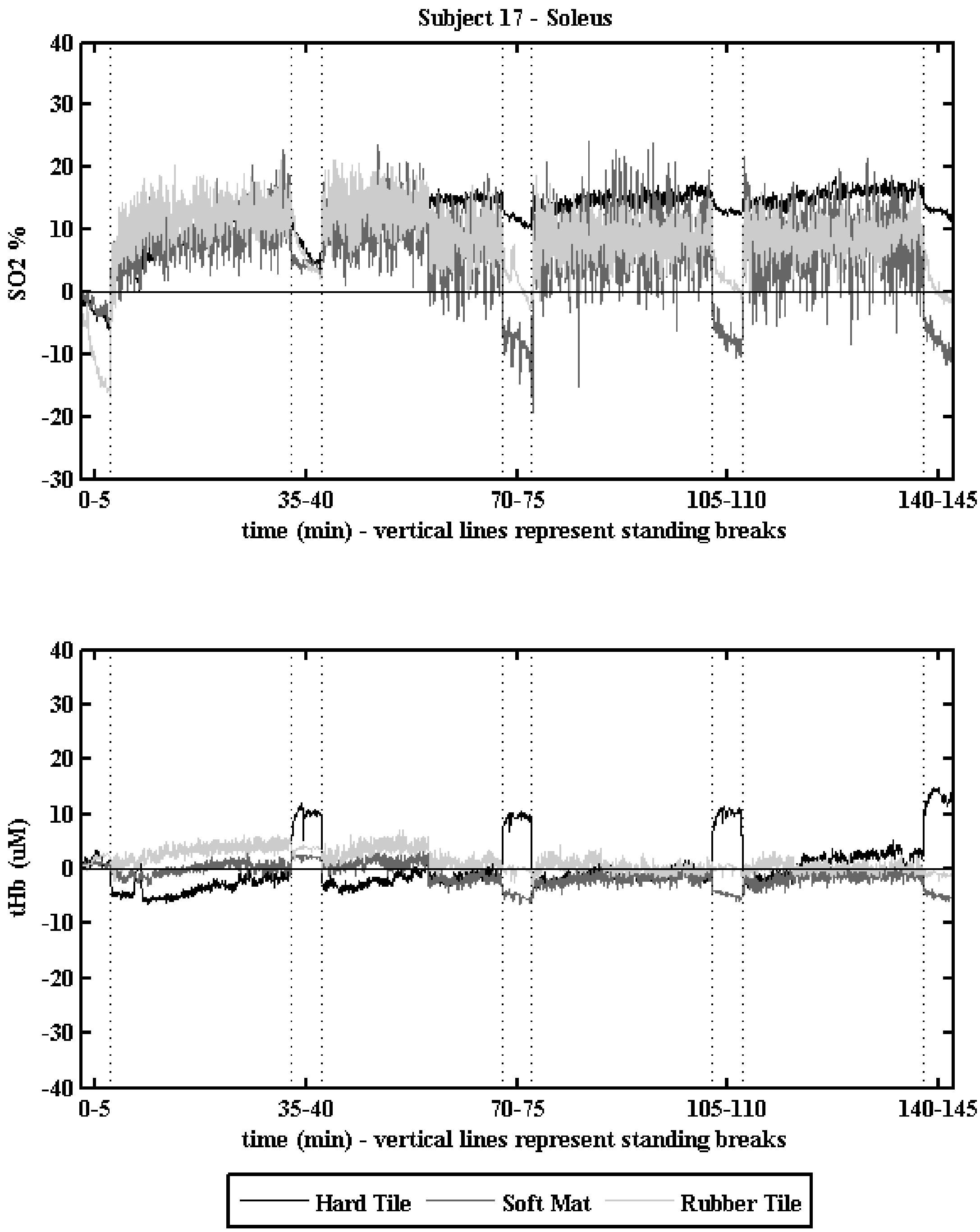


Figure 76: S17 soleus NIRS parameters while walking

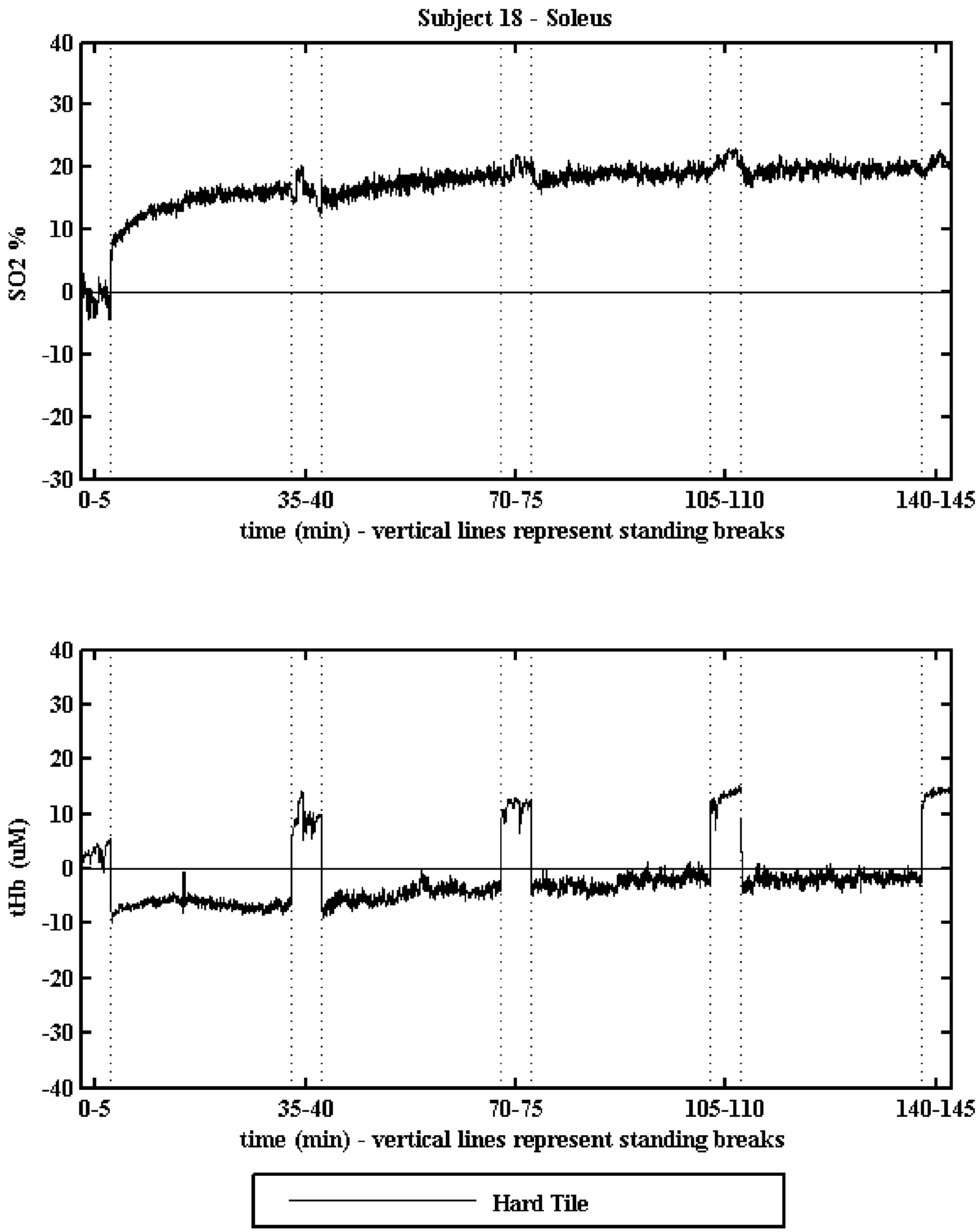


Figure 77: S18 soleus NIRS parameters while walking

B.4 INVESTIGATIONAL SHORT-TERM STANDING TRIAL

Two investigational short-term standing trials were conducted in order to further observe the response in soleus SO_2 during a period of quiet stance followed by a periods of postural movements. For the first trial, a volunteer was instructed to stand for 20 minutes while NIRS was used to measure soleus SO_2 on the right leg. The first 10 minute period consisted of standing quietly while maintaining an equal distribution of body-weight on both feet. The volunteer was then instructed to continually shift their body-weight in the medial/lateral direction at a constant rate for the final 10 minutes of the trial. The response of soleus SO_2 is shown in the following figure. A 4^{th} order low-pass filter was applied to the signal with a cutoff frequency of 0.15 Hz.

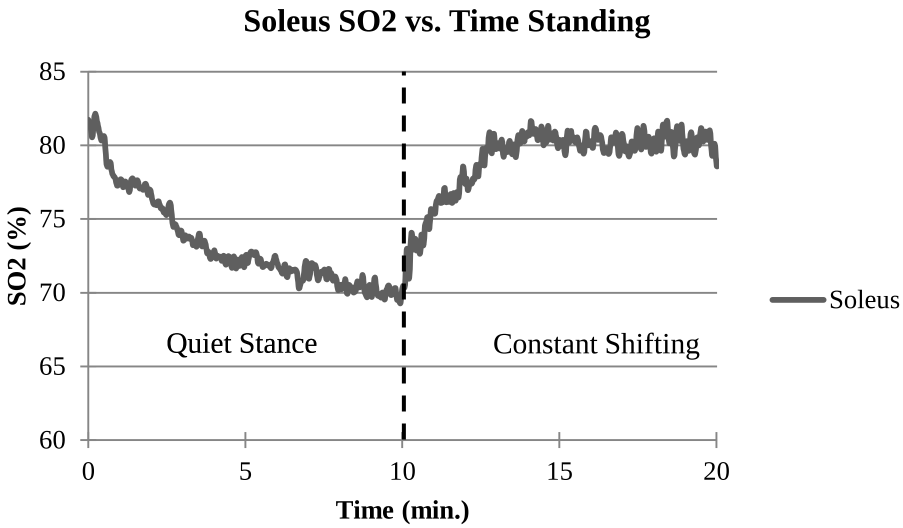


Figure 78: Soleus SO_2 during a 10 minute period of quiet stance followed by a 10 minute period of continual shifting. Soleus SO_2 declined until postural movements increased in which a gradual increase in soleus SO_2 was observed.

For the second trial a volunteer was instructed to stand for 30 minutes while NIRS was used to measure soleus SO_2 on the left leg. The first 10 minute period consisted of standing quietly while maintaining an equal distribution of body-weight on both feet. The volunteer was then instructed to distribute their body-weight to their right foot for 5 minutes, to the middle for 5 minutes, to the left foot for 5 minutes, and then back to the middle for 5 minutes. The response of soleus SO_2 is shown in the following figure. A 4^{th} order low-pass filter was applied to the signal with a cutoff frequency of 0.15 Hz.

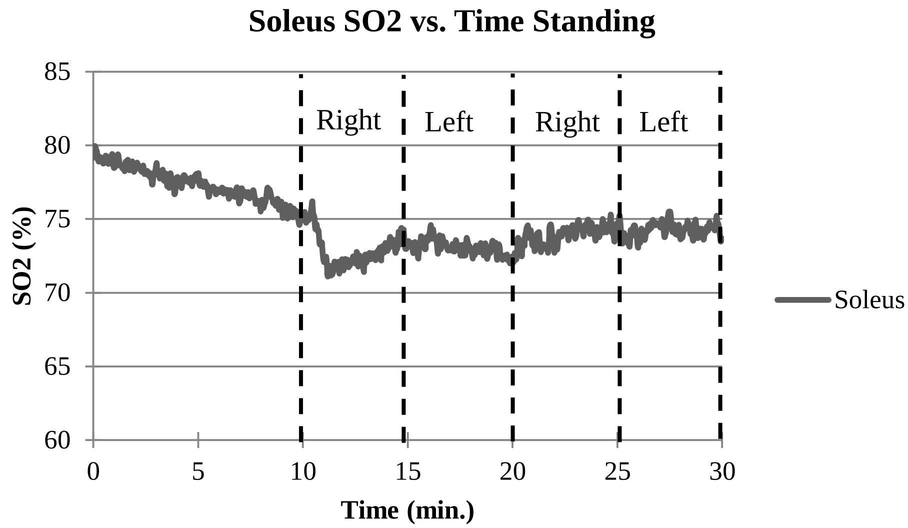


Figure 79: Left soleus SO_2 during a 10 minute period of quiet stance followed by 5 minute periods of body-weight distributed to either the left or right foot. Soleus SO_2 declined until the there was a redistribution in body-weight.

APPENDIX C

POSTURAL MEASURES

The following data are postural measure outcomes for subjects who completed the testing protocol. The total force output from each balance plate was used to calculate the distribution of total body-weight on the left and right feet during standing. Three conditions describing weight distribution during standing were previously defined by Wiggermann [50]: (1) At least 20% of total body-weight being supported by both the left and right foot, (2) >80% total body-weight being supported by the left foot, (3) >80% total body-weight being supported by the right foot. A weight shift was counted when there was a change in weight distribution between any of the three conditions. Body-weight shifts that occurred less than 7.5 seconds apart were considered to be a continuation of 1 shift. The total number of shifts was estimated in 30 minute intervals throughout standing.

The following table describes which subjects completed the standing protocol for each flooring condition and whom balance plate data was collected from and whether or not it was included in the analysis.

Table 80: Balance plate data collection: Standing on each flooring condition

	Balance plate data collection			Included in Analysis
Subject	**Hard Tile**	**Soft Mat**	**Rubber Tile**	
S04	✓	✓	✓	✓
S05	✓	✗	✓	✗
S06	✓	✓	✓	✓
S08	✓	✗	✗	✗
S10	✓	✓	✓	✓
S11	✓	✓	✓	✓
S12	✓	✓	✓	✓
S13	✓	✓	✓	✗
S14	✓	✓	✓	✗
S15	✓	✓	✓	✗

C.1 STANDING: ALL FLOORING CONDITIONS

Table 81: S04 Number of body-weight shifts during standing

S04	**Body-Weight Shifts**		
Time Interval (Hour)	**Hard Tile**	**Soft Mat**	**Rubber Tile**
0-0.5	2	13	15
0.5-1	7	15	14
1-1.5	11	16	24
1.5-2	11	20	27
2-2.5	21	17	19
2.5-3	36	30	26
3-3.5	29	19	28
3.5-4	42	26	25
4-4.5	30	22	25
4.5-5	34	26	25
5-5.5	24	27	27
5.5-6	35	22	28

Table 82: S06 Number of body-weight shifts during standing

S06	**Body-Weight Shifts**		
Time Interval (Hour)	**Hard Tile**	**Soft Mat**	**Rubber Tile**
0-0.5	45	53	11
0.5-1	44	79	19
1-1.5	68	65	50
1.5-2	75	83	103
2-2.5	100	90	79
2.5-3	119	101	57
3-3.5	84	131	68
3.5-4	82	140	144
4-4.5	92	107	87
4.5-5	118	82	108
5-5.5	85	127	66
5.5-6	97	125	122

Table 83: S10 Number of body-weight shifts during standing

S10	Body-Weight Shifts		
Time Interval (Hour)	**Hard Tile**	**Soft Mat**	**Rubber Tile**
0-0.5	1	0	2
0.5-1	1	1	12
1-1.5	6	1	0
1.5-2	11	10	5
2-2.5	9	6	4
2.5-3	16	4	3
3-3.5	16	8	2
3.5-4	20	21	2
4-4.5	6	11	10
4.5-5	1	10	16
5-5.5	2	4	14
5.5-6	6	0	14

Table 84: S11 Number of body-weight shifts during standing

S11	Body-Weight Shifts		
Time Interval (Hour)	**Hard Tile**	**Soft Mat**	**Rubber Tile**
0-0.5	37	50	56
0.5-1	77	84	73
1-1.5	61	64	78
1.5-2	62	83	85
2-2.5	47	95	73
2.5-3	63	89	99
3-3.5	43	59	45
3.5-4	98	63	96
4-4.5	93	54	64
4.5-5	99	50	52
5-5.5	83	52	67
5.5-6	69	102	64

Table 85: S12 Number of body-weight shifts during standing

S12	Body-Weight Shifts		
Time Interval (Hour)	**Hard Tile**	**Soft Mat**	**Rubber Tile**
0-0.5	2	8	6
0.5-1	4	7	5
1-1.5	3	8	9
1.5-2	8	7	18
2-2.5	13	14	23
2.5-3	16	6	35
3-3.5	8	12	38
3.5-4	21	14	51
4-4.5	12	5	41
4.5-5	20	12	49
5-5.5	31	16	41
5.5-6	33	21	43

Table 86: S13 Number of body-weight shifts during standing

S13	Body-Weight Shifts		
Time Interval (Hour)	**Hard Tile**	**Soft Mat**	**Rubber Tile**
0-0.5	7	18	7
0.5-1	32	21	25
1-1.5	20	19	31
1.5-2	21	27	40
2-2.5	22	58	32
2.5-3	18	46	12
3-3.5	29	40	17
3.5-4	51	45	38
4-4.5	54	39	23
4.5-5	51	50	34
5-5.5	55	34	24
5.5-6	32	50	25

Table 87: S14 Number of body-weight shifts during standing

S14	Body-Weight Shifts		
Time Interval (Hour)	**Hard Tile**	**Soft Mat**	**Rubber Tile**
0-0.5	6	6	5
0.5-1	0	17	0
1-1.5	7	10	6
1.5-2	6	13	3
2-2.5	8	19	10
2.5-3	5	27	2
3-3.5	12	39	14
3.5-4	7	65	10
4-4.5	5	34	17
4.5-5	14	29	4
5-5.5	11	16	12
5.5-6	8	30	8

Table 88: S15 Number of body-weight shifts during standing

S15	Body-Weight Shifts		
Time Interval (Hour)	**Hard Tile**	**Soft Mat**	**Rubber Tile**
0-0.5	1	2	1
0.5-1	4	3	0
1-1.5	3	6	2
1.5-2	12	13	0
2-2.5	8	9	4
2.5-3	22	10	5
3-3.5	24	5	3
3.5-4	13	15	9
4-4.5	22	63	2
4.5-5	21	39	17
5-5.5	15	17	5
5.5-6	8	6	22

APPENDIX D

EMG FATIGUE MEASURES

The following data are EMG fatigue measures during the standing sessions. The EMGs recorded muscle activity at a sampling rate of 1000 Hz. The raw EMG signals were downsampled to 840 Hz. For estimating the MPF, a notch filter was applied at 60 Hz. and its harmonics in order to remove power line noise. The soleus EMG signal was high-pass filtered at 20 Hz while the erector spinae EMG signal was high-pass filtered at 30 Hz. The MPF was then estimated between 0-275 Hz in 1 minute periods for each hour of standing.
For estimating the RMS, after downsampling the raw signals to 840 Hz, a 4^{th} order low-pass filter was applied with a cutoff frequency at 10 Hz. The RMS was then estimated in 1 minute periods for each hour of standing.

The following table is a list of subjects who completed the standing sessions for each flooring surface. Periods that contained errors in EMG data collection were removed from the figures and analysis. The vertical dotted lines in each figure represent the 2 minute seated breaks in the standing protocol. Subjects were included in the analysis if the EMG signal was maintained throughout standing sessions for all flooring conditions.

Table 89: Electromyography data collection: Standing on each flooring condition

	Balance plate data collection			**Included in Analysis**	
Subject	**Hard Tile**	**Soft Mat**	**Rubber Tile**	**Erector Spinae**	**Soleus**
S04	✓	✓	✓	✗	✗
S05	✓	✗	✓	✗	✗
S06	✓	✓	✓	✓	✗
S08	✓	✗	✗	✗	✗
S10	✓	✓	✓	✗	✓
S11	✓	✓	✓	✗	✗
S12	✓	✓	✓	✓	✓
S13	✓	✓	✓	✗	✓
S14	✓	✓	✓	✗	✓
S15	✓	✓	✓	✗	✗

D.1 STANDING: ALL FLOORING CONDITIONS

D.1.1 Erector Spinae

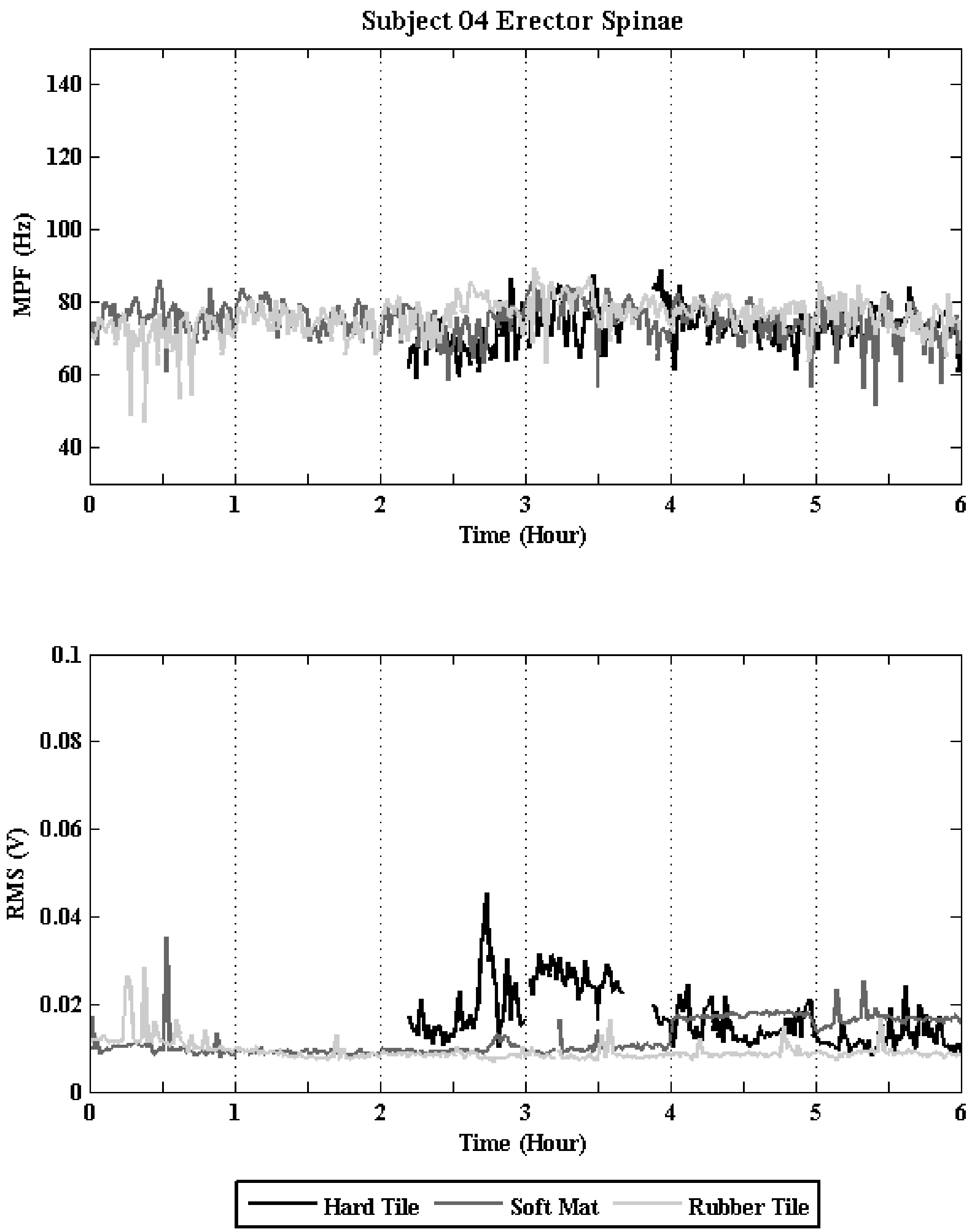


Figure 80: S04 erector spinae EMG fatigue measures

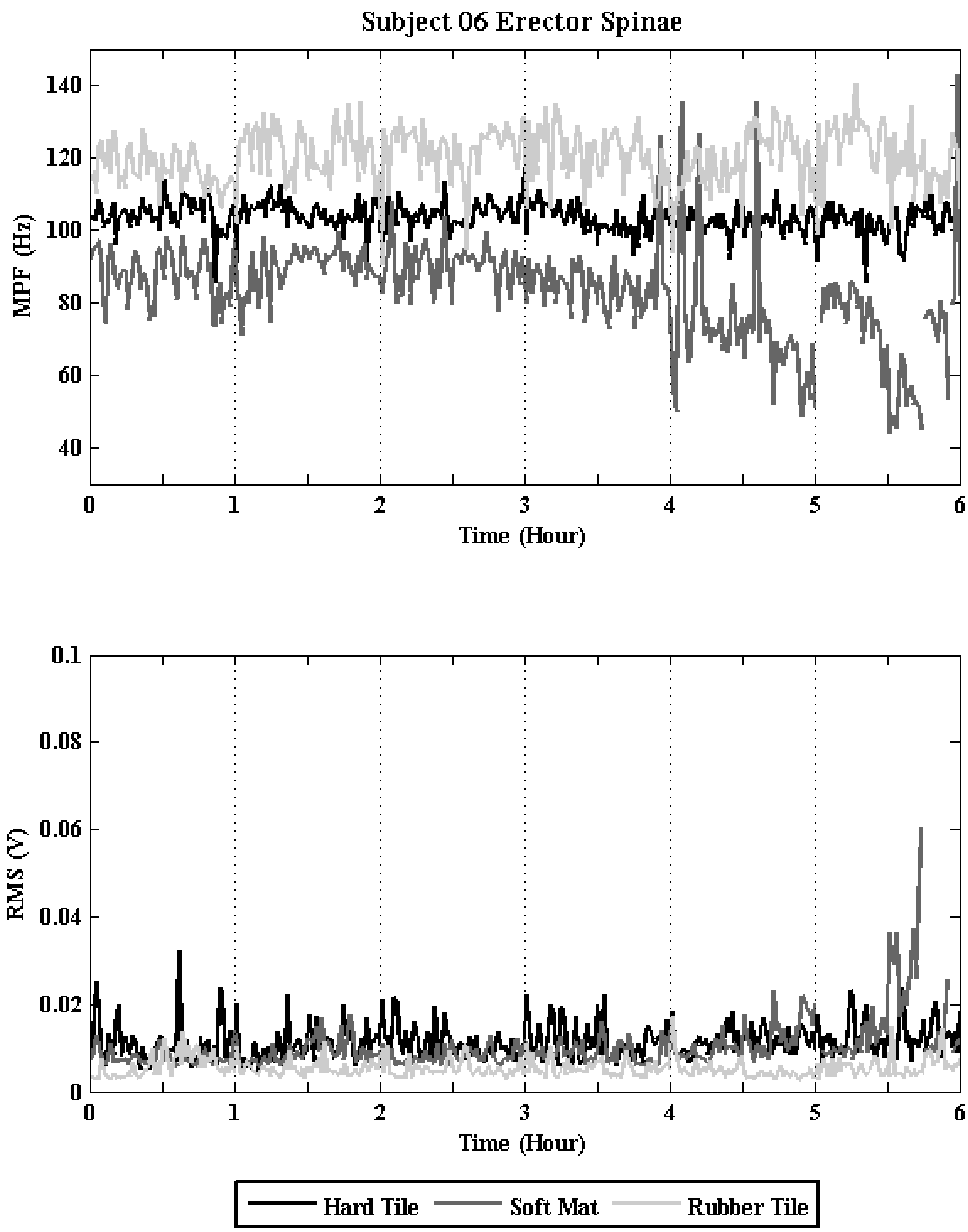


Figure 81: S06 erector spinae EMG fatigue measures

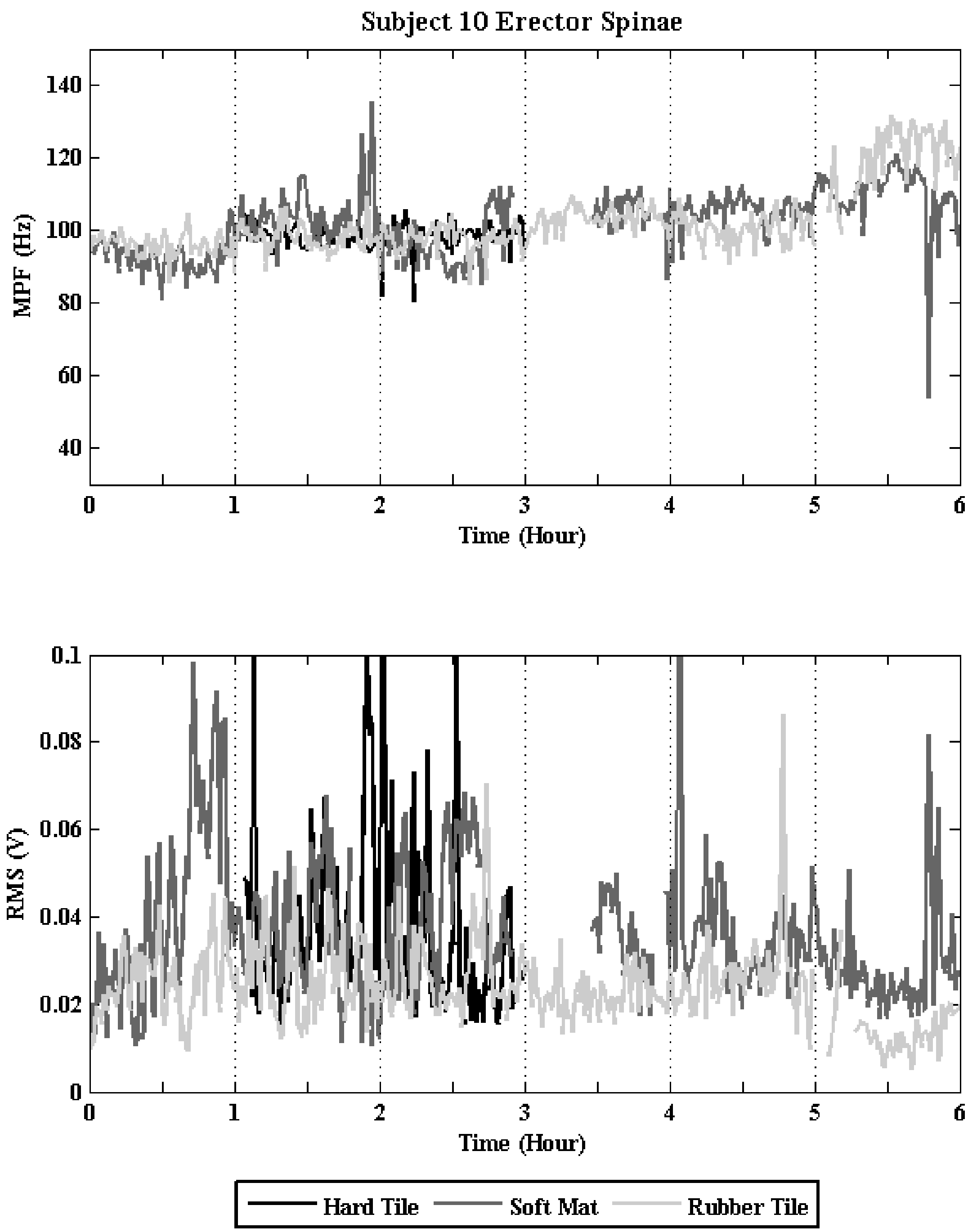


Figure 82: S10 erector spinae EMG fatigue measures

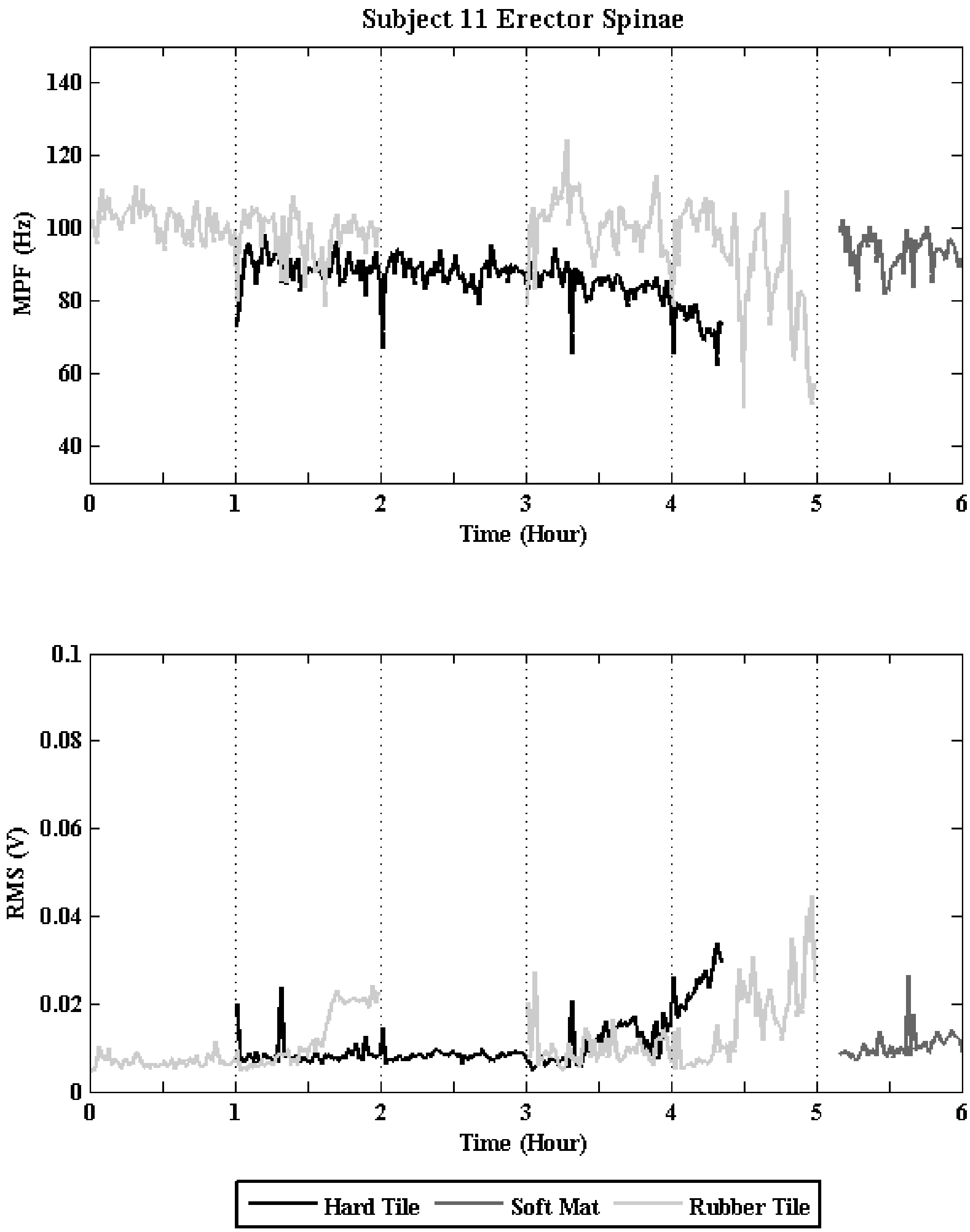


Figure 83: S11 erector spinae EMG fatigue measures

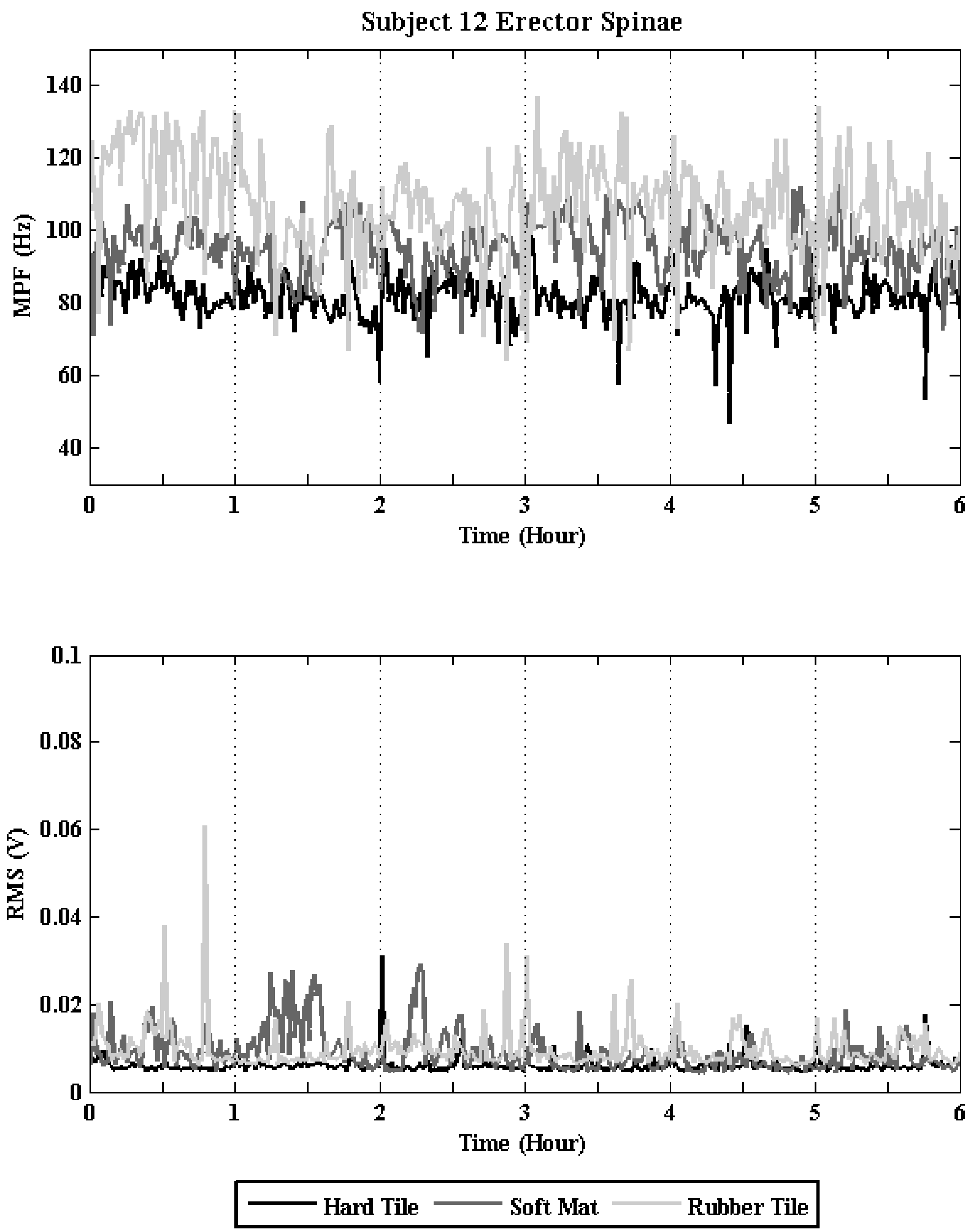


Figure 84: S12 erector spinae EMG fatigue measures

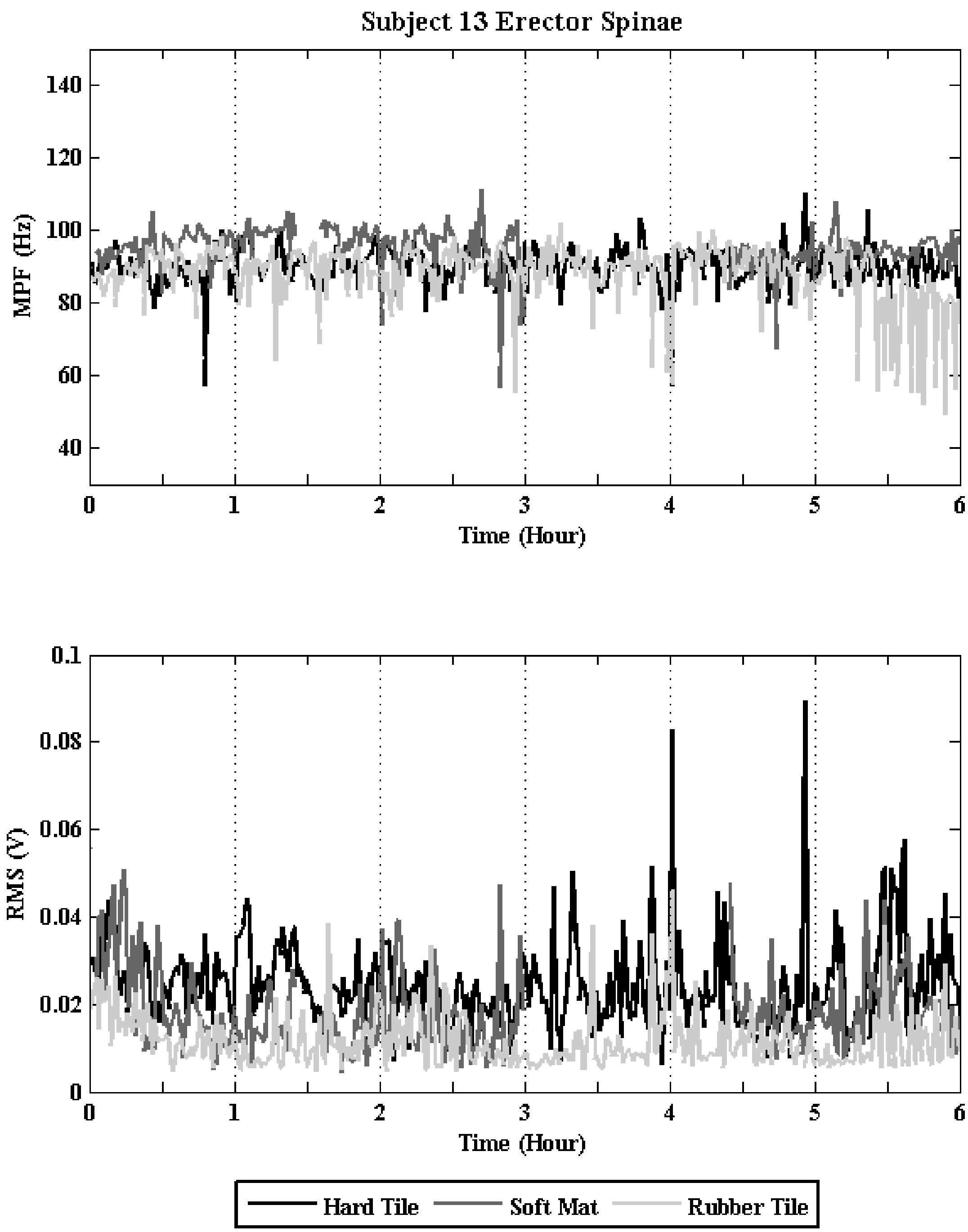


Figure 85: S13 erector spinae EMG fatigue measures

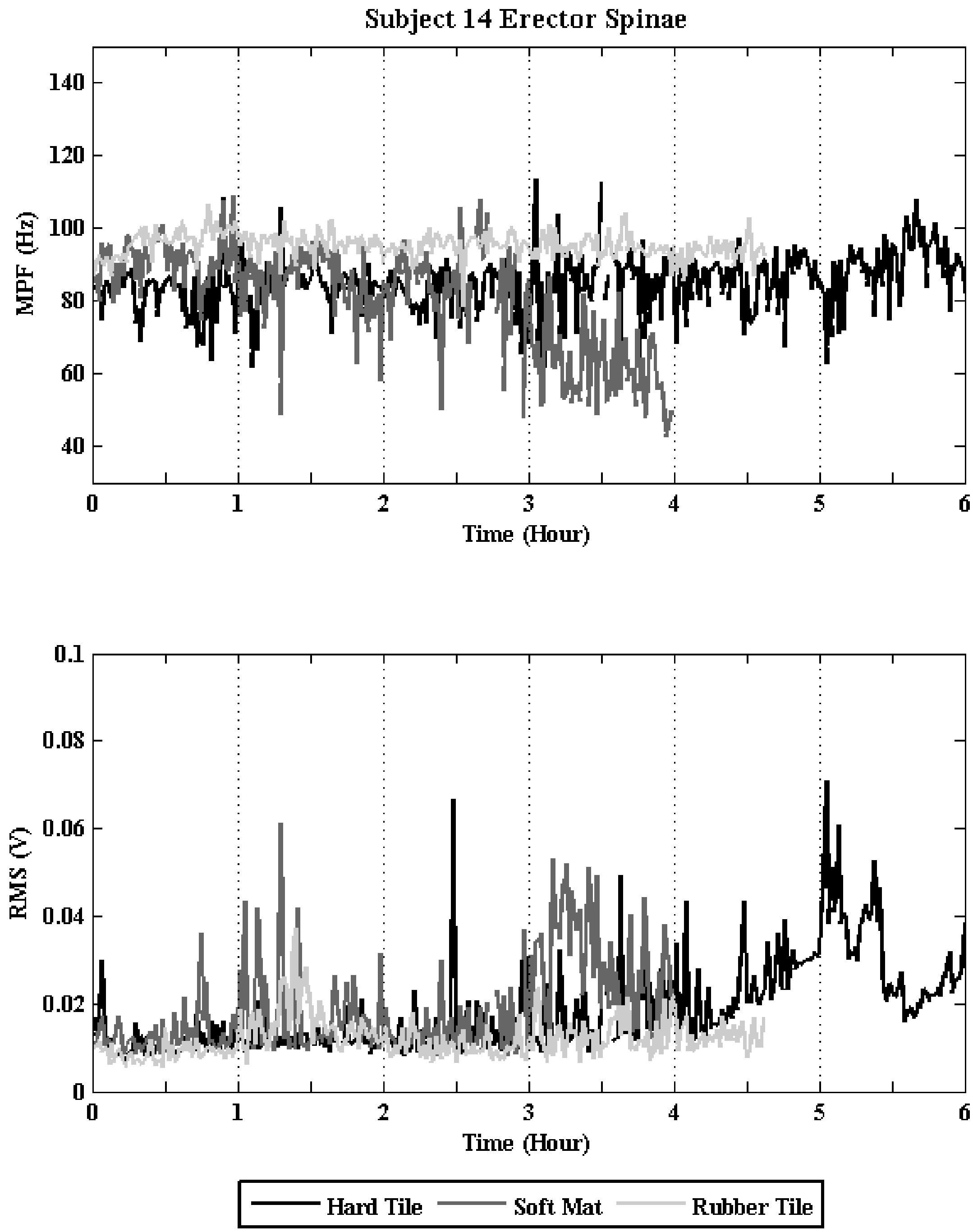


Figure 86: S14 erector spinae EMG fatigue measures

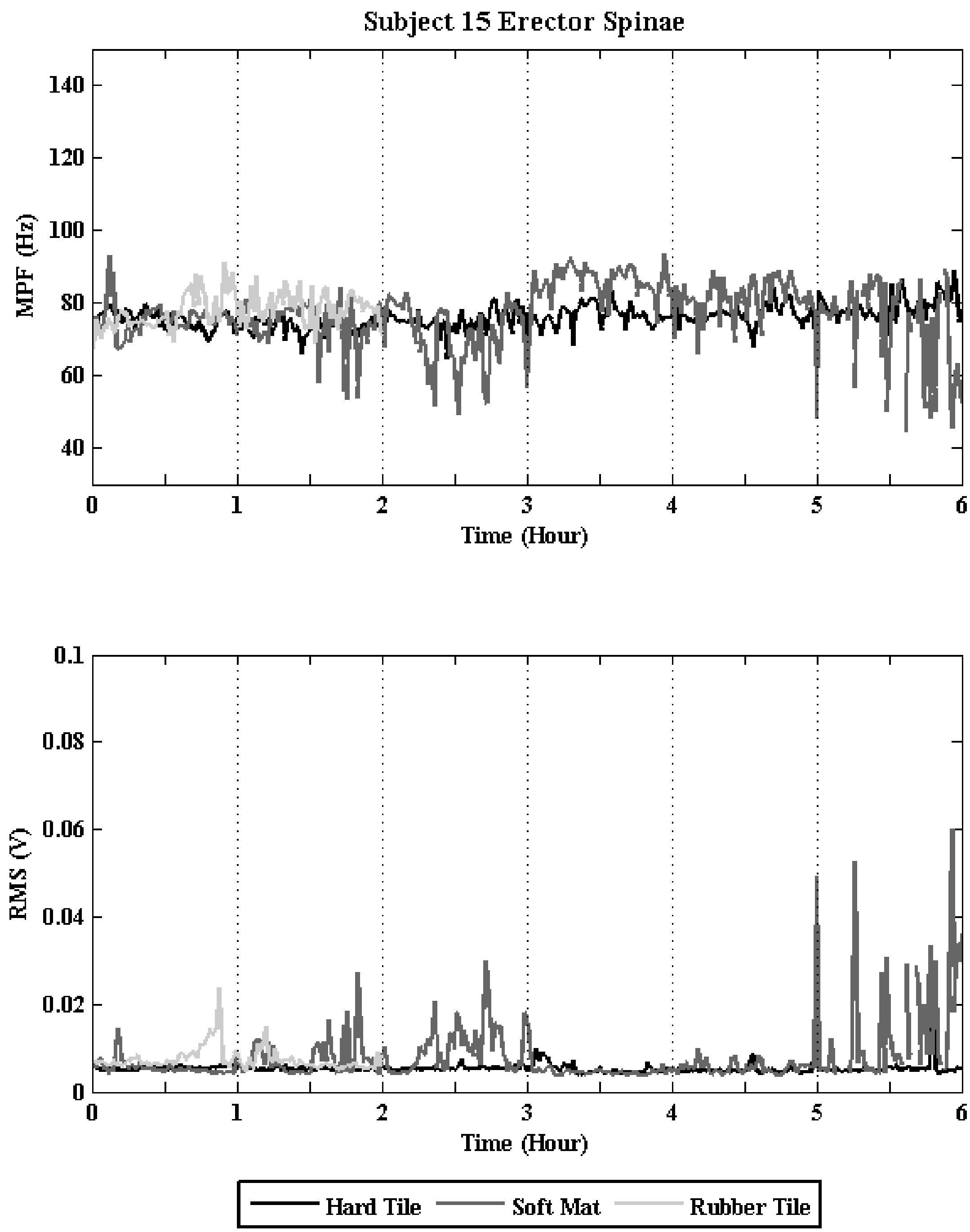


Figure 87: S15 erector spinae EMG fatigue measures

D.1.2 Soleus

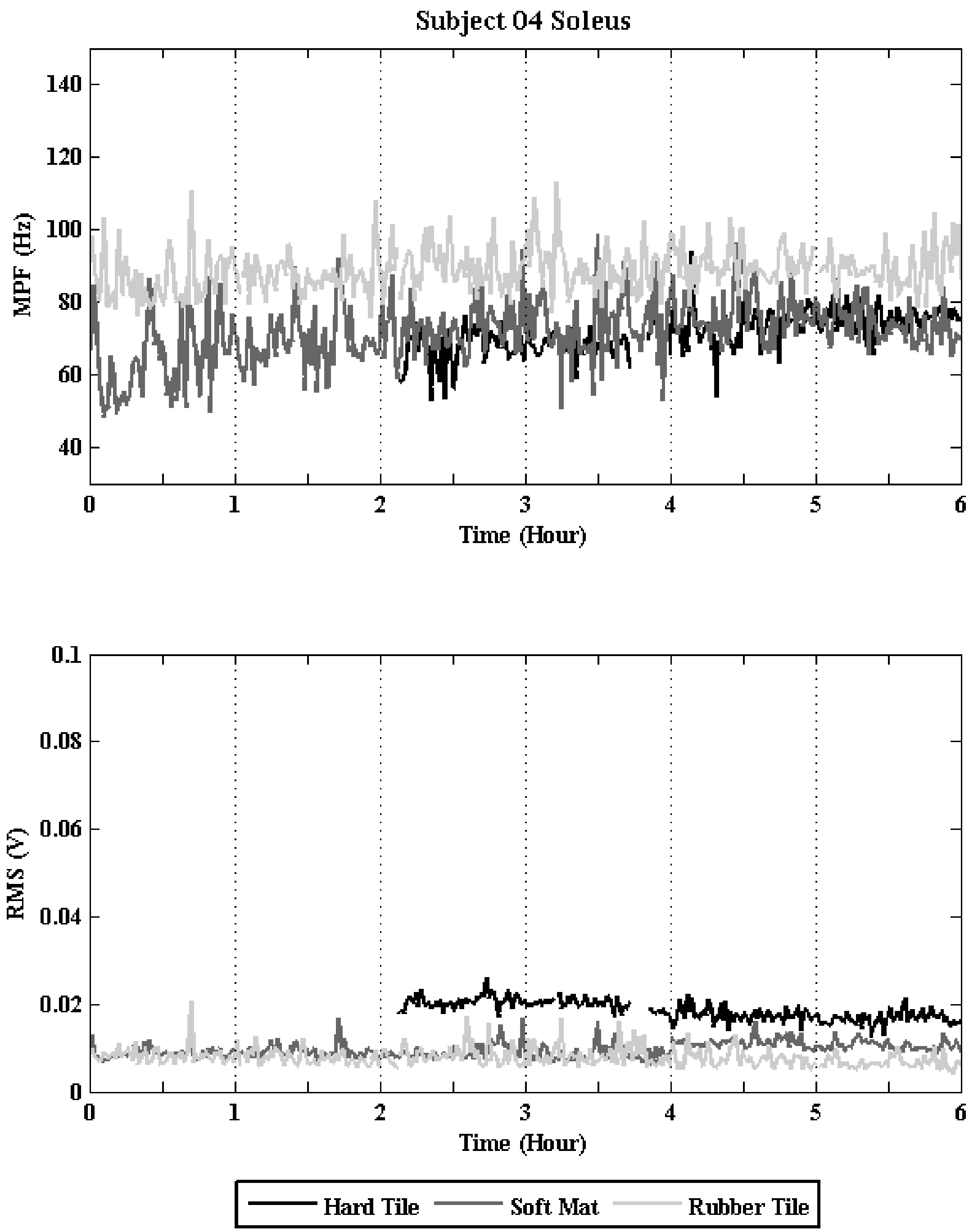


Figure 88: S04 soleus EMG fatigue measures

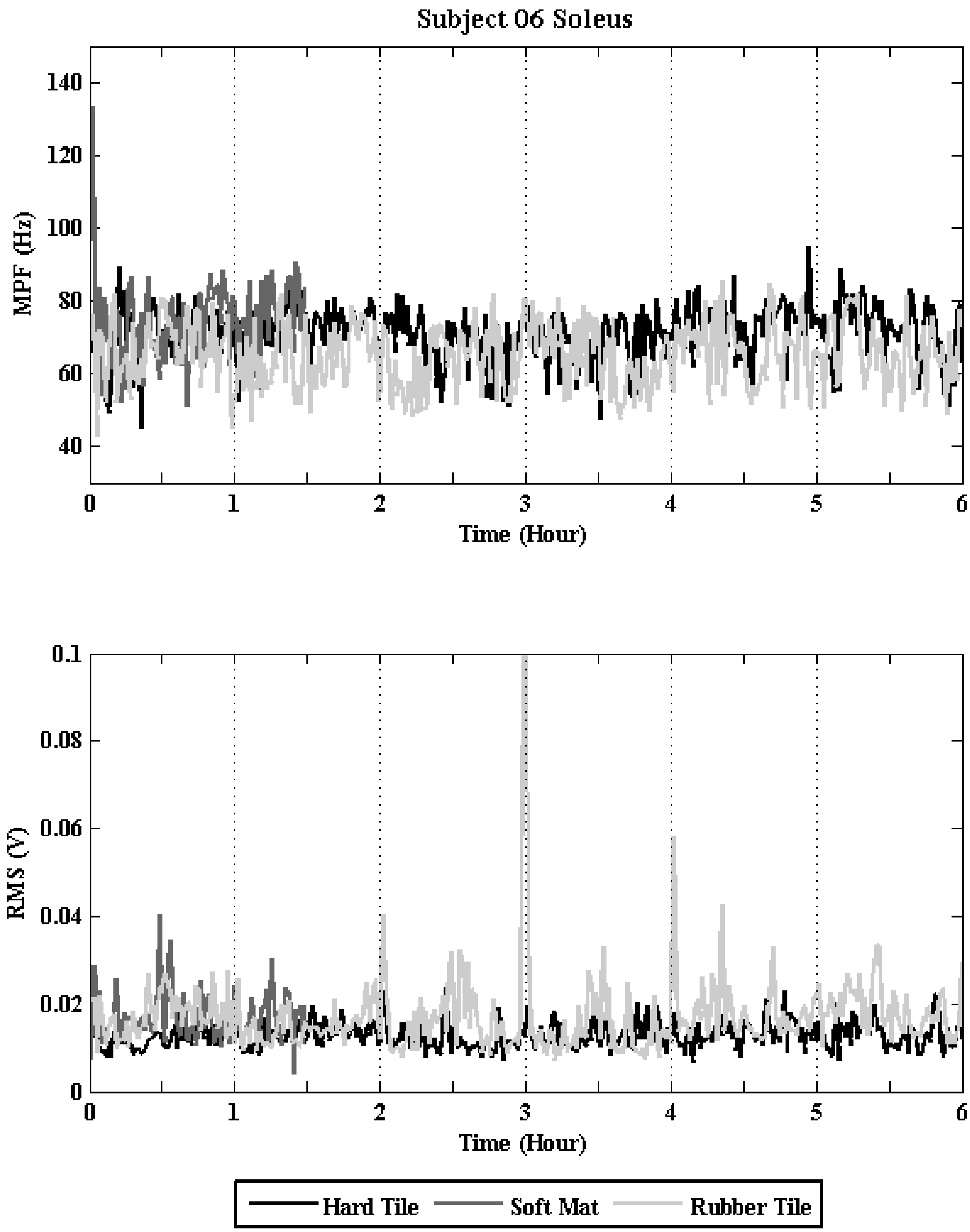


Figure 89: S06 soleus EMG fatigue measures

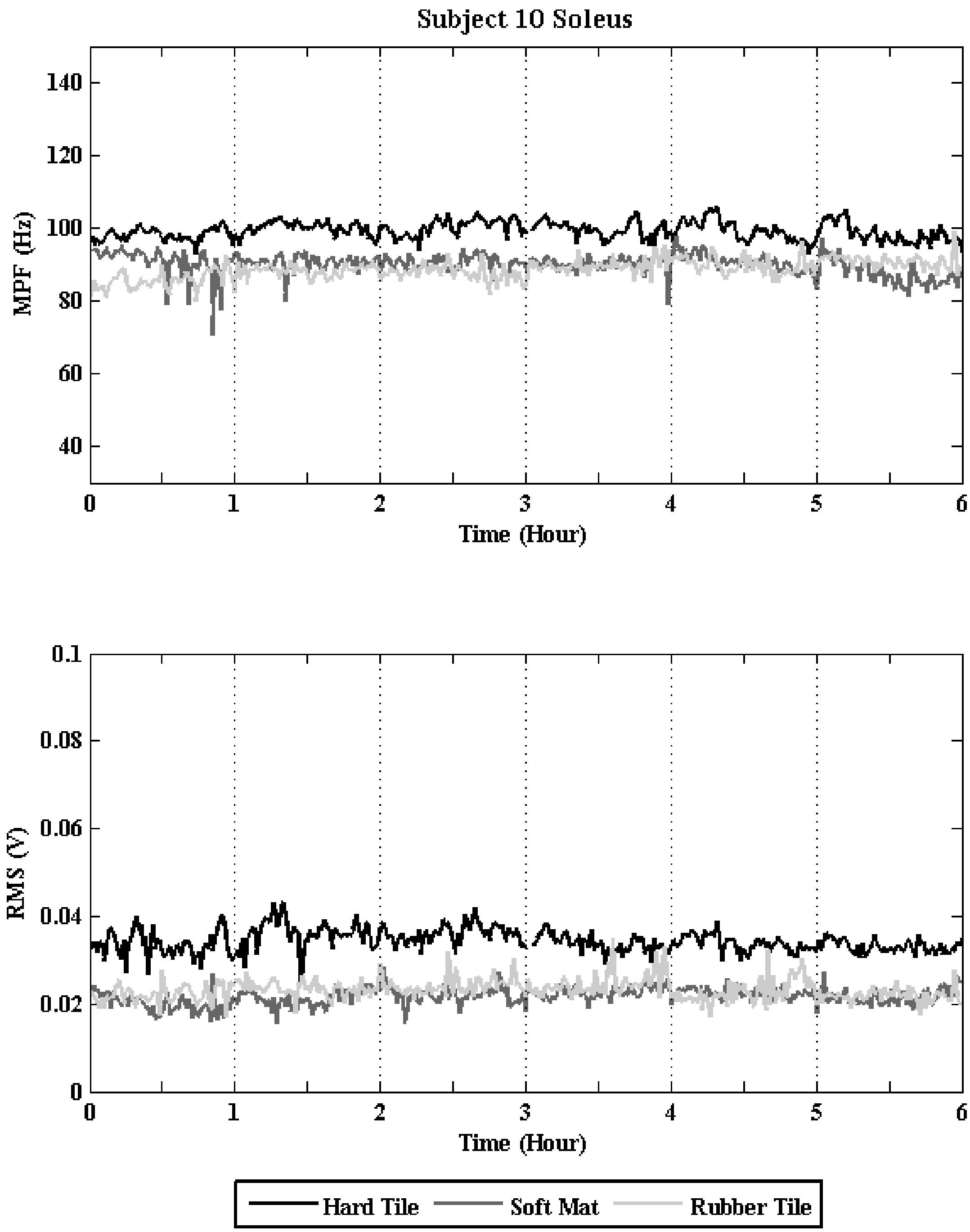


Figure 90: S10 soleus EMG fatigue measures

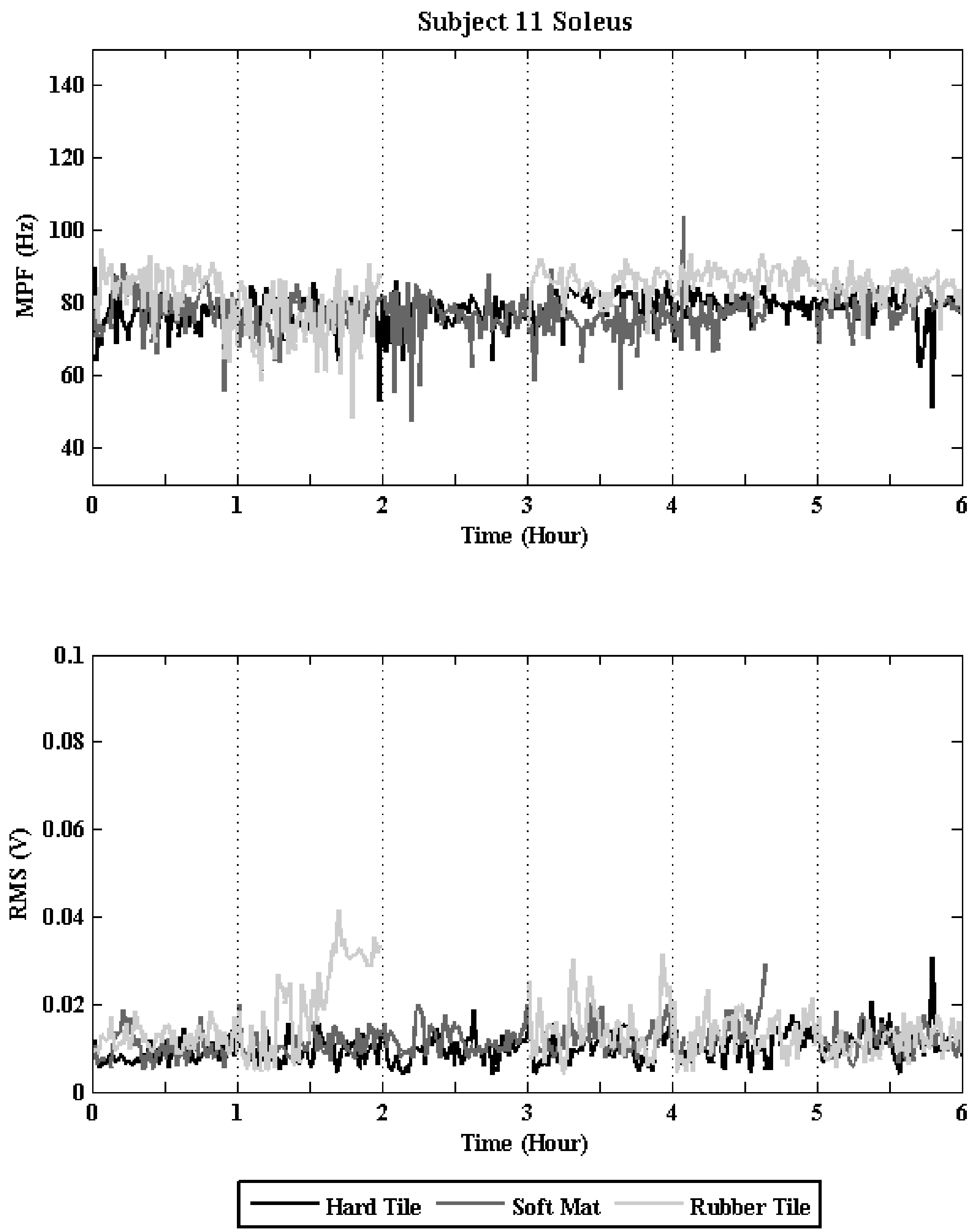


Figure 91: S11 soleus EMG fatigue measures

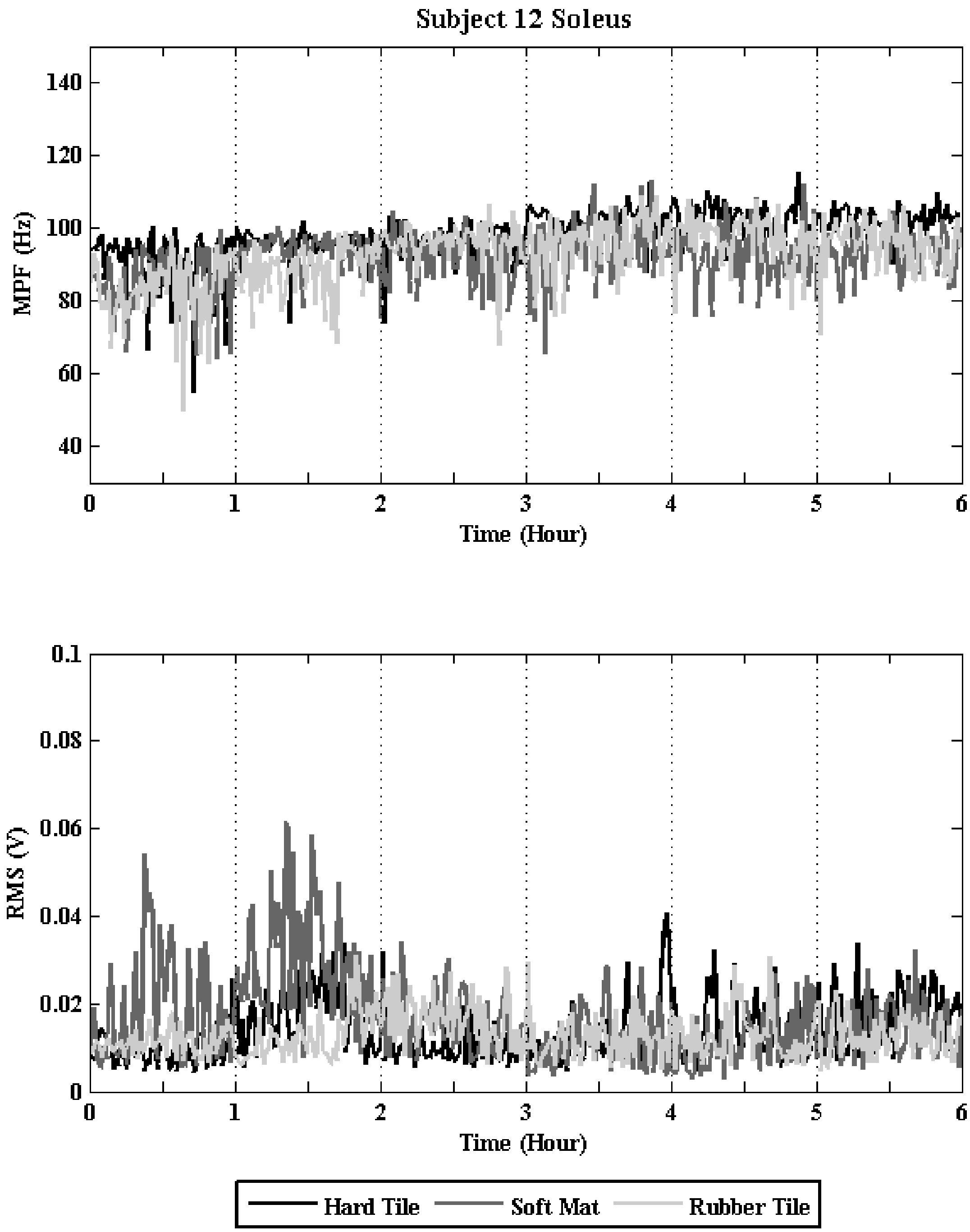


Figure 92: S12 soleus EMG fatigue measures

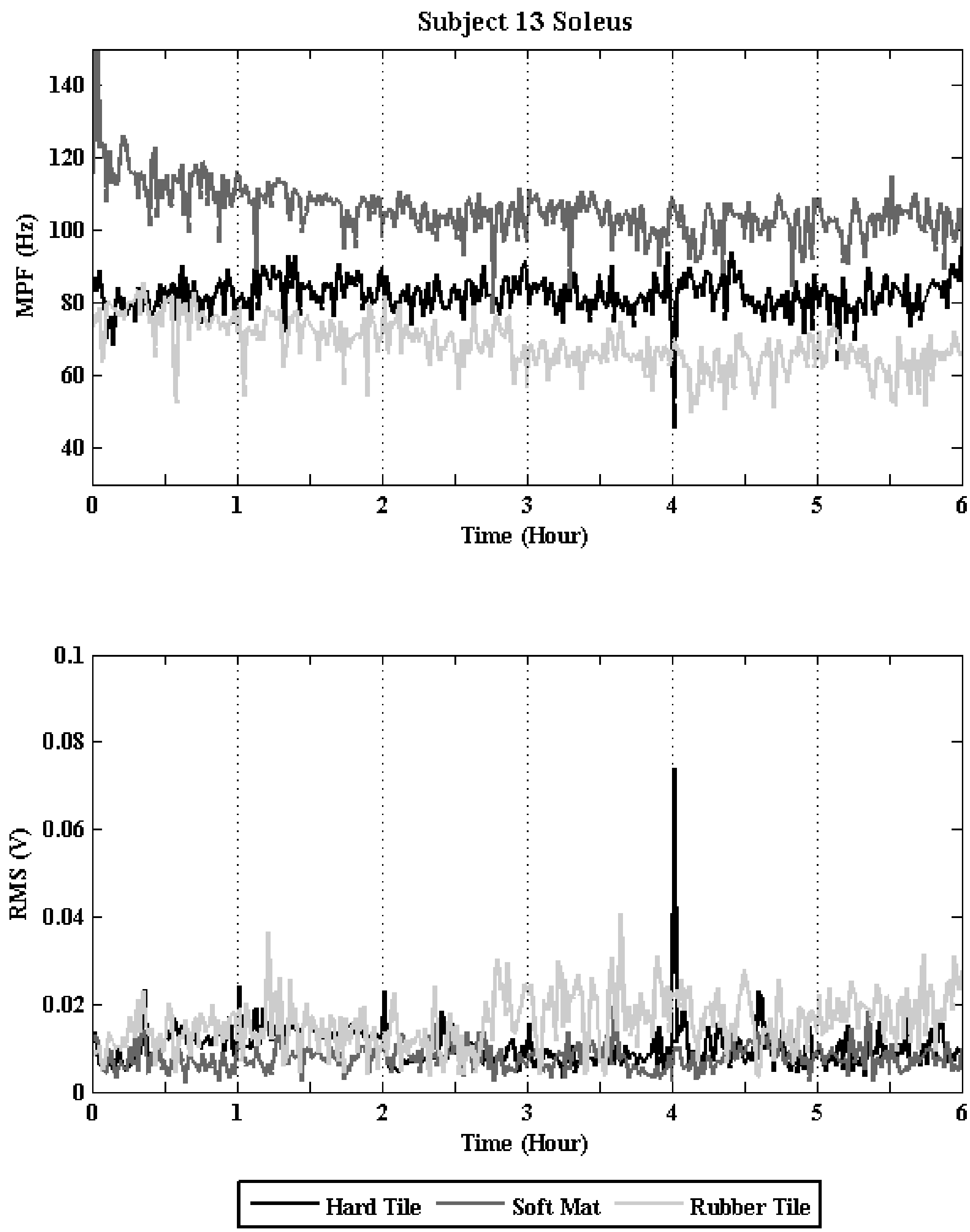


Figure 93: S13 soleus EMG fatigue measures

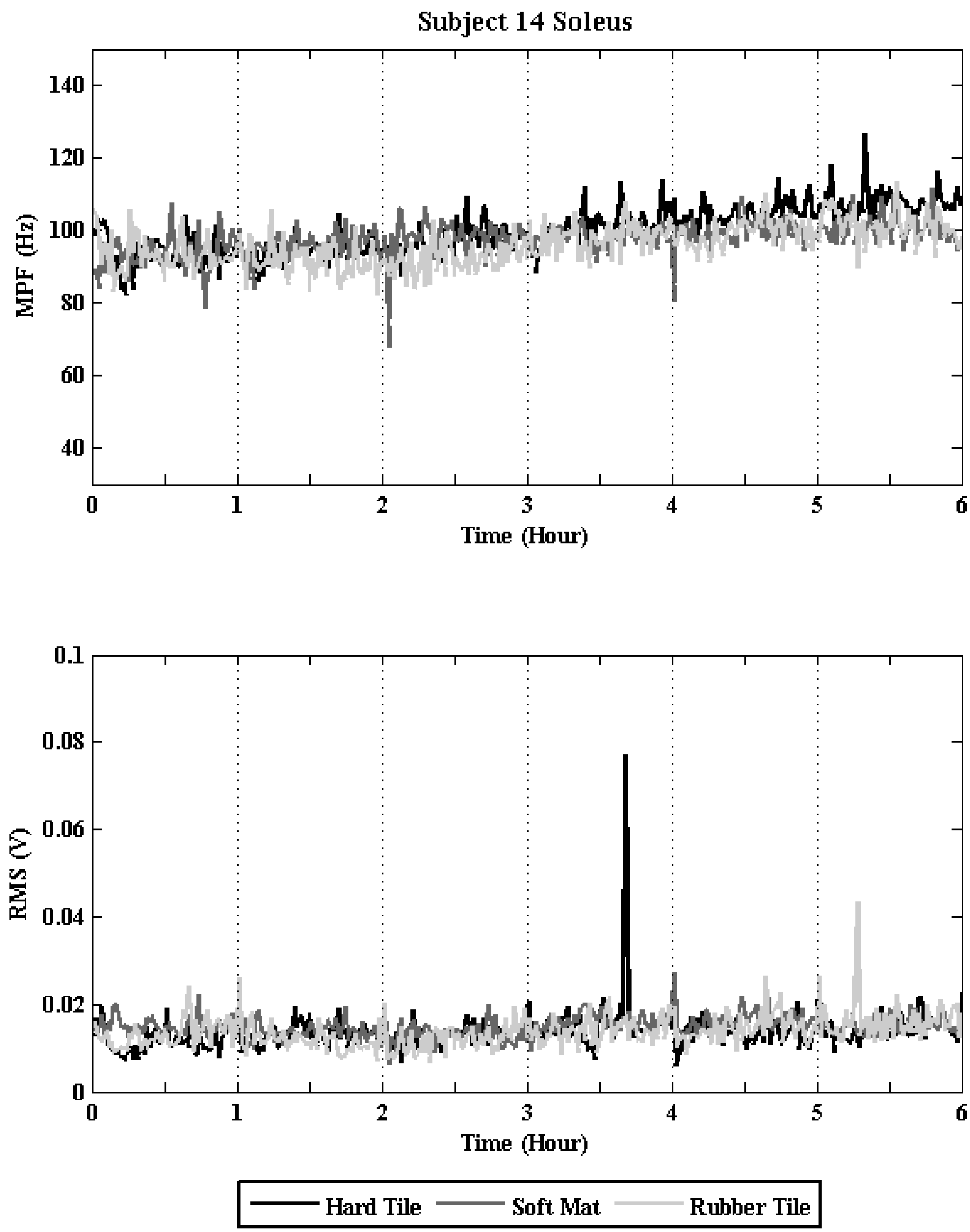


Figure 94: S14 soleus EMG fatigue measures

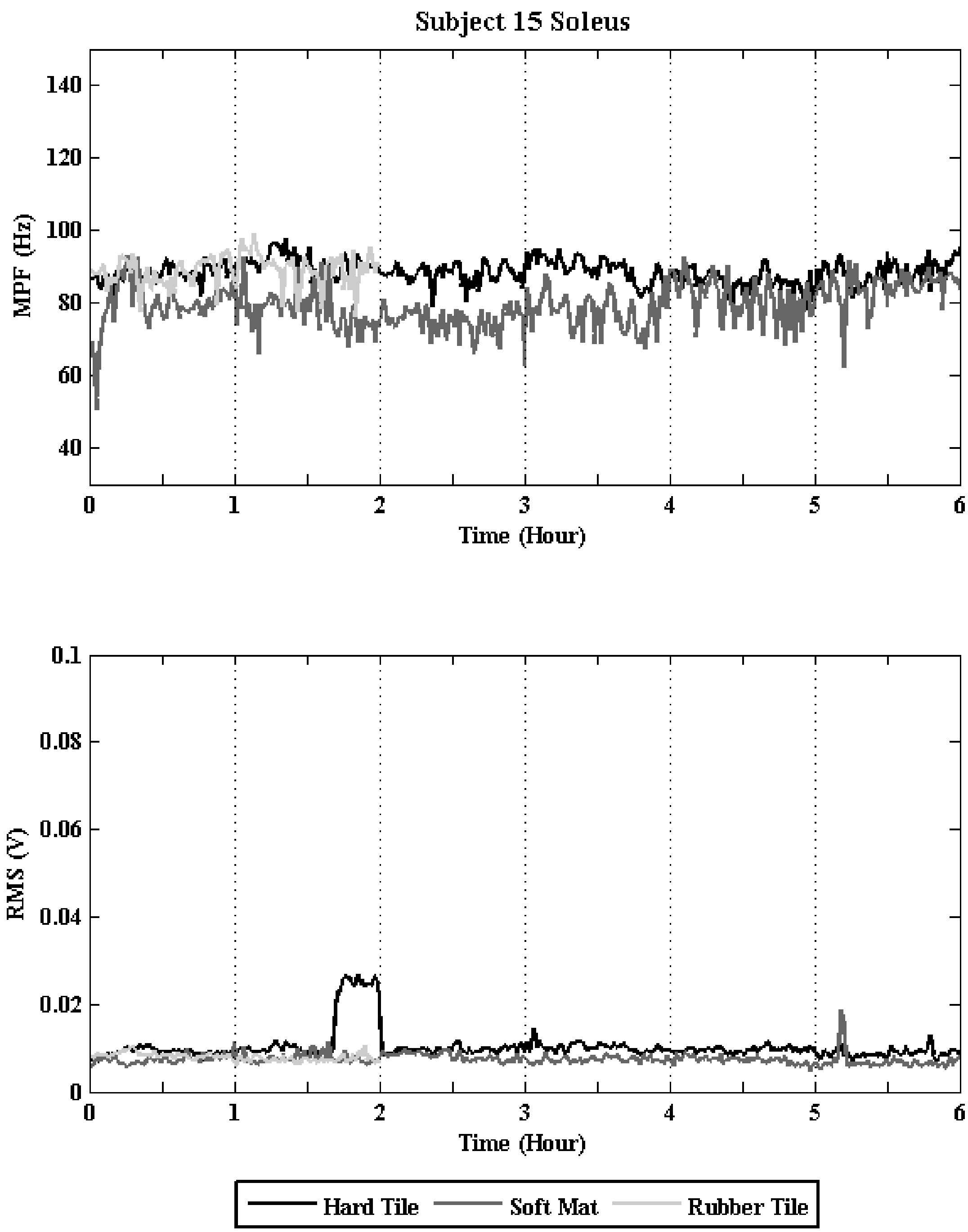


Figure 95: S15 soleus EMG fatigue measures

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