Chapter

The Application of EMG-Based Methods in Evaluating the Impact of Prolonged Sitting on People's Health

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Abstract

This chapter demonstrates a practical application of electromyography (EMG) technology in assessing the potential negative impacts of new trends (i.e., prolonged sitting) in life and work on people's health. With the development of advanced technologies, prolonged sitting, have become more frequent at work and in everyday life. The potential risks associated with prolonged sitting can be assessed by evaluating localized muscle states using various EMG-based methods. However, due to the unique characteristics of prolonged sitting (i.e., sustained low-load condition), there are several challenges in applying traditional EMG methods to estimate the prolonged sitting related risks. Therefore, from the following aspects, this chapter discusses the potential applications and challenges of using surface EMG-based methods in identifying the effects of prolonged sitting: (1) what are the unique characteristics of the task conditions involved in prolonged sitting; (2) what are the available EMG-based methods; and (3) the advantage and disadvantage of each method in evaluating the impacts of prolonged sitting on people's health;

Keywords: muscle fatigue, prolonged sitting, low Back pain, EMG, muscle stimulation

1. Introduction

Electromyography (EMG) is an electrodiagnostic technique for assessing the contractile activity produced by skeletal muscles. Through electrodes placed on top of the skin's surface, surface EMG signals can detect neuromuscular states and abnormalities, muscle contraction levels, muscle recruitment order, and disorders of motor control and can estimate muscle forces and human movement.

By understanding the muscle state via EMG, the impacts of modern lifestyles and work conditions on the human musculoskeletal system that could lead to potential injuries and illnesses, such as low back pain (LBP), may be identified. LBP is one of the most common societal health problems, causing day away from works, high health services cost, and considerable disability. LBP is one of the leading factors that cause injuries and disability among those under 43 years old [1]. More than 38% of work-related musculoskeletal disorders can be linked to back disorders each year, with a total of 134,550 cases reported in the United States in 2016 [1].

As a new trend in both modern living and contemporary work, sedentary behaviors have become more and more prevalent. Prolonged sitting as a form of sedentary behavior presents emerging health risks in both occupational and non-occupational settings [2]. Sitting is commonly considered a critical ergonomic exposure related to LBP [3, 4]. Recent research has found that muscle activation levels around the lumbar area increase over time during sitting [5, 6] and cause higher levels of muscle co-contractions [7], which have been shown to positively correlate to the development of low back pain [6, 7].

During the sitting, postural muscles, such as trunk extensors, are required to stabilize the sitting posture via sustained contractions, which, however, usually require very low levels of muscle contractions (<10% of maximal muscle capacity) [8, 9]. However, after a long exposure duration, seated posture could block muscle oxygenation and blood flow [10], cause lumbar muscle fatigue, increase intradiscal loads, and further contribute to the development of LBP [11, 12]. Therefore, even though the muscle contraction level during sitting is low, the sustained contractions may cause above mentioned issues even after a continuous duration only greater than 20 minutes [13, 14]. After a long period of sitting (i.e., >90 min), EMG median power frequency has also been observed to shift to the lower frequencies [15, 16]. Even though there is evidence that EMG can measure muscle fatigue caused by sitting, it is generally believed that 15% of muscle contraction level (compared to maximum muscle contraction capacity) is required to detect and distinguish fatigue-induced EMG changes from noises [21]. Both lowered EMG median frequency and increased EMG amplitudes under consistent workloads are generally considered a sign of muscle fatigue [15]. However, such methods may lead to conflicting results when detecting muscle fatigue under low-level contractions.

Therefore, EMG-related measurements provide potential paths to reveal the underneath mechanisms that link prolonged sitting with LBP. At the same time, some potential challenges may affect measurement performance. Therefore, in this chapter, using a prolonged sitting experiment as an example, a series of EMG-based muscle fatigue measurement methods are discussed with respect to their capabilities and limitations in quantifying the negative impacts of prolonged sitting.

2. Determining the effects of prolonged sitting using EMG-based muscle fatigue measurement methods

2.1 Study design

Six participants [gender balanced, mean age (SD) = 25.1 (3.3) yrs] were recruited from the local community to complete a one-hour prolonged seated task. As shown in **Figure 1**, participants were required to sit in a relaxed posture without significant in-chair body movements, such as trunk rotation or bending that could cause significant off-sagittal plane movement. No use of backrest was allowed to minimize potential confounding effects caused by the backrest support on muscle activation pattern during the experiment.

During the experiments, participants were asked to conduct a relaxed internet browsing task to minimize the potential impacts of high mental workloads on muscle activities. The browsing tasks were self-selected with a similar level of mental/physical workloads, e.g., participants can choose to browse websites or stream videos but cannot play intense games or other high demanding tasks. All participants read and signed an informed consent with IRB approval prior to participation.

Figure 1.
Illustration of seating device and seated tasks.

2.2 EMG data collection and analysis

To understand how muscles support the trunk against the continuous sitting, the major muscles around the lumbar spine should be studied. In detail, sixteen muscles around the lower lumbar region were studied, which can usually be categorized into the trunk flexors group and the trunk extensors group based on the different function of each muscle. Trunk flexors are those dominant muscles that drive trunk flexion movement, while trunk extensors are those dominant muscles that lead the trunk extension movement. Trunk sideways bending and rotation usually are the results of the combined muscle activities from trunk flexors and extensors.

The tested trunk flexors group includes internal oblique (IO), external oblique (EO), and rectus abdominis (RA). The tested trunk extensors group includes iliocostalis lumborum pars lumborum (ILL), iliocostalis lumborum pars thoracis (ILT), multifidus (MF), longissimus thoracis pars lumborum (LTL), and longissimus thoracis pars thoracis (LTT). Both trunk flexors and extensors can be further divided bilaterally into the left side (L) and the right side (R). The deeper trunk muscles (e.g., psoas, quadratus lumborum, and transverse abdominis) are not included in the analysis due to the fact that such deeper muscles cannot be measured through surface EMG and do not significantly contribute to lumbar kinetics [17]. Each muscle is composed of a group of functional fascicles, each of which has distinct insertion, via, and origin points attached to the bone, which represent the diverse anatomy within each muscle. The initial insertion, via, and origin points are defined as the attach or wrap points where the muscles connect to the bone [18]. For these sixteen trunk muscles, there are a total of ninety-two fascicles (EO = 4, IO = 12, RA = 4, MF = 24, ILL = 8, ILT = 16, LTL = 10, LTT = 14). Equal contraction level is usually assumed among all the fascicles from the same muscle [19]. During trunk movement, each fascicle moves differently due to the different insertion, via, and origin points positions on the bone. Measured trunk kinematics can be used to estimate the line of action and length of each fascicle at each sample instant. So, the EMG activity measured from surface EMG devices can be used to describe the muscle contraction levels.

To monitor and collect muscle EMG data over a long period, a high-fidelity multimodal EMG system is required to collect reliable data continuously with flexible measurement options. A wireless EMG system (Trigno™, Delsys, MA) is included in this chapter. The Trigno wireless EMG system supports up to 16 wireless sensors, which can be used to monitor all 16 muscles simultaneously. To maximize the quality of the collected data, skin near the central position over the muscle belly (but not directly over motor points) of each target muscle was shaved, abrased, and cleaned with a mild alcohol solution to ensure that the impedance was lower than 10 KΩ. Electrodes were placed bilaterally over the surface of each muscle, as suggested in [20]. Raw EMG single amplitude usually ranges from −5000 to 5000 microvolts with frequency ranges between 10 and 500 Hz, in which most frequency power lies between 20 and 400 Hz. Using the Trigno system, raw EMG signals were collected at 2000 Hz, pre-amplified at 500 gain, and band-pass filtered between 20 and 400 Hz. To further smooth the signal, the root-mean-square (RMS) of EMG was calculated using a 200-milliseconds sliding window for the relatively static task, i.e., sitting. Then RMS EMG of the same muscle collected bilaterally were averaged since no significant off-sagittal plane in-chair movements were allowed during the experiment. Collected EMG data were furthered analyzed to answer the following questions for a better understanding of the impact of the prolonged sitting:

The first question is how much effort the related muscles have to contribute continuously to maintaining a seated posture for a prolonged duration. By answering this question, the neuromuscular demands required during prolonged seated tasks could be determined, and a corresponding ergonomics intervention can be developed to lower the stress and strain on workers.

To answer this question, the muscles' contraction levels relative to their maximum capacity need to be determined. Muscle EMG collected from a maximum voluntary contraction (MVC) test can be used as a reference of 100% muscle capacity, and muscle EMG measured during a task can be normalized to this reference to generate the percentage of effort needed to complete the task. The MVC values of all sixteen muscles were measured from suggested MVC tests [20, 21]. Once the MVC value for each muscle is determined, the muscle EMG during prolonged sitting can be converted into the percentage of the MVC value to estimate the level of neuromuscular effort needed for the prolonged sitting [22].

As shown in **Figure 2**, the average muscle activation levels over the entire one hour sitting are generally less than 10% MVC. However, unlike other physically demanding tasks, the exposure duration in such low load seated tasks is long, necessitating a significant amount of time for the muscles to recover from previous fatigue [11].

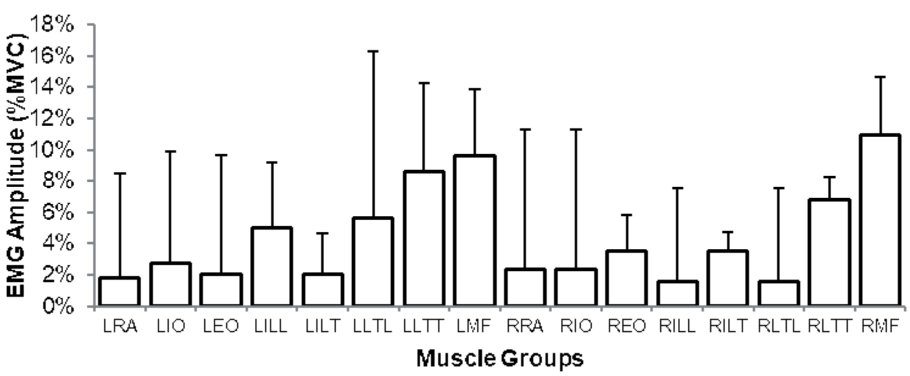

Figure 2.
Average muscle contraction level (%MVC) over the prolonged seated task.

The second question is whether there is any muscle fatigue developed during prolonged sitting. Muscle fatigue is one of the leading indicators that directly link to the development of LBP. Traditionally, both EMG amplitude and EMG median frequency show time-domain changes due to muscular fatigue. Therefore, monitoring EMG amplitude changes over time during prolonged sitting can estimate the level of muscle fatigue development. Using EMG amplitude, muscle fatigue is defined as an amplitude increase over time without an increase in the level of physical demands.

In this study, EMG amplitudes were continuously collected for one minute, and this procedure was repeated every ten minutes. The collected EMG over one minute was then averaged to present the general trend at each data collection period during prolonged sitting. As shown in **Figure 3**, EMG amplitude collected from both muscle groups, in general, increased toward the end of the sitting period. Both LMF and LLTT have a significant increase in measured EMG amplitude. Such an upward change trend, however, was not consistent and fluctuated up and down, which could further indicate that many moderating factors, such as body movement and external forces, could have affected the amplitudes of the collected muscle EMG.

The second indicator is the median power frequency (MPF) of raw EMG obtained from the prolonged sitting. Such MPF was calculated over 3-second windows. As described above, EMG data were continuously collected for one minute every ten minutes, and the mean EMG MPF from each one-minute period was calculated and compared. Changes between these mean values were used as a predictor of fatigue development in these muscles. Multivariate analysis of variance (MANOVA, using Wilks' Lambda) was used to determine the effects of prolonged sitting on all EMG MPFs as a whole. In the event of a significant MANOVA effect, univariate ANOVAs were performed to determine which muscle was mostly impacted by the prolonged seated task, which was considered significant when $p < 0.05$.

MANOVA results indicated that prolonged sitting ($p < 0.01$) had significant effects on the tested EMG MPFs. As shown in **Table 1**, subsequent univariate ANOVAs indicated that prolonged sitting significantly affected MPFs from some of the muscles, which manifested as a declining percentage of EMG MPF: left side LILL (16%) and LLTT (18%) muscles and right side RMF (14%) and RIO (8%) muscles.

As mentioned above, muscle contraction at 15% MVC or higher is usually considered to be the minimal muscle contraction level to detect fatigue-related

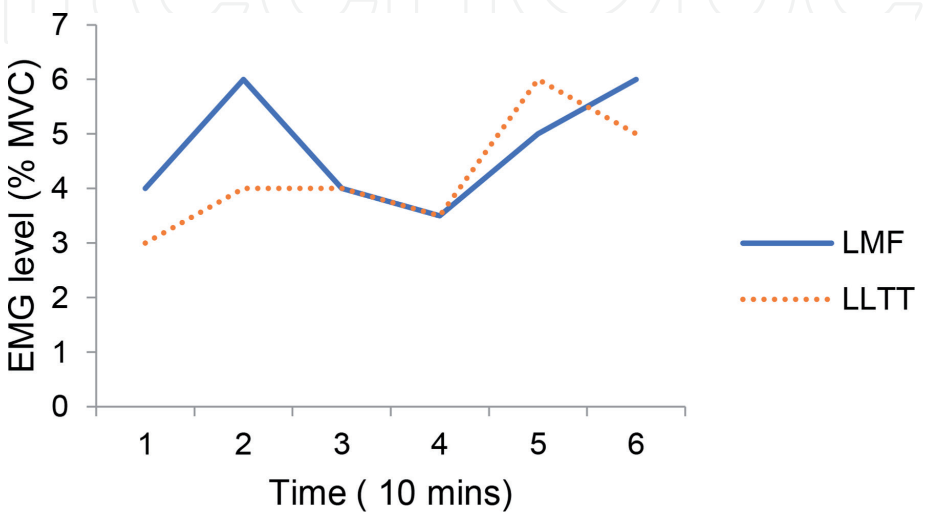

Figure 3.
An example of EMG amplitude (LMF and LLTT) changes over the one-hour prolonged seated task.

		Prolonged Sitting	
		$F_{(1,320)}$	p
EMG Median Frequency	LMF	2.16	0.15
	LILL	7.65	**<0.01**
	LILT	3.36	0.06
	LLTL	3.37	0.88
	LLTT	9.16	**<0.01**
	LEO	3.46	0.06
	LIO	4.51	0.05
	LRA	2.71	0.12
	RMF	5.58	**0.02**
	RILL	4.25	0.06
	RILT	4.34	0.06
	RLTL	3.17	0.08
	RLTT	4.02	0.06
	REO	0.03	0.86
	RIO	4.98	**0.04**
	RRA	4.10	0.06

Table 1.
Summary of ANOVA results for effects of prolonged sitting ($p<0.05$).

changes in the EMG signal during different working levels [23]. During low-level sustained muscle contractions, inconsistent evidence of fatigue development was observed between different muscle groups and across individuals [10]. Therefore, the analysis of EMG amplitude and median frequency as a measurement of muscle fatigue could lead to unreliable or conflicting results under low-level contractions. Existing evidence [11, 24], on the other hand, also illustrates the possibility of using traditional EMG methods to quantify muscle fatigue during low-level contractions as low as 2% MVC. However, these results were achieved from a relatively short duration with large inter-subject variations. Therefore, a sensitive method is needed to obtain reliable muscle fatigue measurements under these conditions of low-level sustained muscle contractions, i.e., prolonged sitting.

An alternative method to identify muscle fatigue is to combine muscle EMG with muscle stimulation technology. In this approach, an electrical stimulation pulse is sent to the target muscle to evoke an artificial muscle contraction, and the corresponding muscle stimulation response from these artificial contractions can be captured through surface EMG and other quantitative methods. In this method, muscle fatigue is defined as a significant change of observed muscle stimulation responses from the initial pre-fatigue status [25, 26]. Muscle fatigue has been identified using a single stimulation frequency [27, 28] or calculated as a decrement ratio of stimulation response results from high-frequency (50–100 Hz) and low-frequency (1–20 Hz) stimulation [26, 29]. While various stimulation frequencies have been used, low-frequency stimulation (LFS) usually creates stable stimulation responses and fatigue-induced changes [27]. Another benefit of using LFS is that it is less likely to cause muscle fatigue, and the level of discomfort is also low [28].

Therefore, in this chapter, a muscle stimulation method was further applied to determine the muscle fatigue results from prolonged sitting. All six participants completed a muscle stimulation trial after the initial MVC test and then repeated after the prolonged seated task, and the stimulation responses collected through both stimulation trials were compared to identify the potential muscle fatigue caused by the prolonged sitting.

Muscle stimulation responses were evoked using a dual-channel current-controlled muscle stimulator (Grass S88, AstroMed, RI) connected with a stimulus isolation unit (SIU5, AstroMed, RI) and a constant current unit (CCU1, AstroMed, RI). In this study, the MF muscle was selected to evaluate prolonged sitting induced muscle fatigue. The participant's skin around the MF muscle was appropriately prepared following the procedure described by [30]. After bilaterally placing the positive and negative stimulation electrodes (PALS, Axelgaard Manufacturing, CA) at the level of the rib cage bottom and the iliac crest, respectively, the most effective site for electrical stimulation was determined as suggested in [31] to determine appropriate stimulus intensity and electrode location for each participant. During the stimulation trial, participants were asked to sit in a customized fixture (**Figure 4**), with their upper body locked in a comfortable and relaxed upright sitting posture using a metal bar connected to their chest harness around the T8 level. A load cell (SM2000, Interface, AZ) was connected to the other end of the metal bar to collect the stimulation response (i.e., stimulation generated forces) generated by the artificial muscle contraction evoked by the stimulation. Muscle voluntary contractions were minimized by asking participants to relax their muscles and let the fixture hold their sitting postures. The muscle EMG were also monitored bilaterally to ensure minimal voluntary muscle contraction involved during the stimulation procedure. The stimulation train was repeated if the voluntary muscle contraction level monitored by surface EMG were greater than 5% of MVC. The fixture also has a height-adjustable seat pan to align the participant's trunk rotation center at the level of the L5/S1 joint in the sagittal plane. The participant's knee and ankle were also required to maintain a 90-degree using an adjustable footrest. While maintain such sitting posture, participants were also instructed to try to relax their muscles and eliminate potential movement during the data collection.

The overall experimental procedure was illustrated in **Figure 5**. Each participant completed one stimulation trial, starting with one conditioning train and three sampling trains, before and after the prolonged seat task. A conditioning

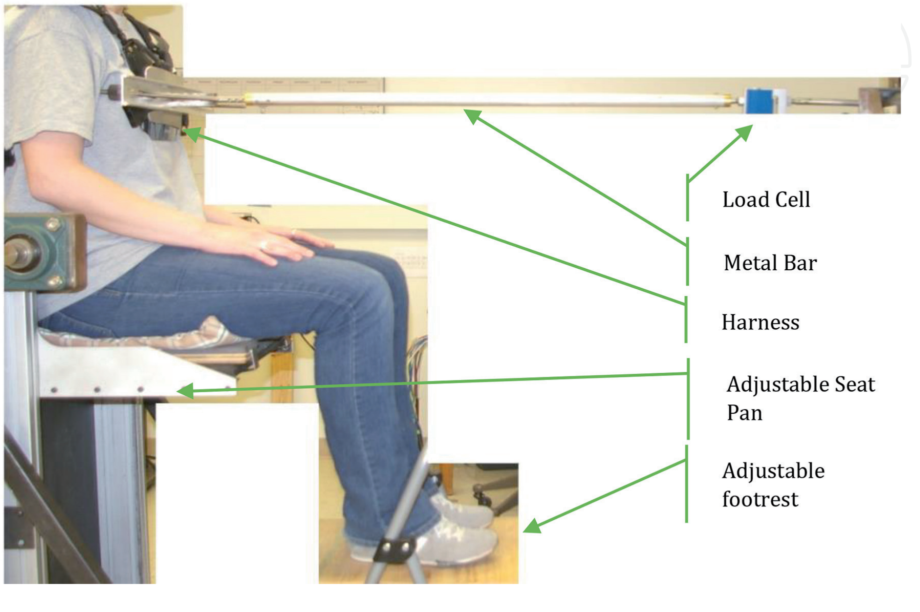

Figure 4.
Illustration of experimental fixture setup with a participant in an upright sitting posture.

train included stimulating muscles continuously at 2 Hz until a plateau and steady phases of measured muscle stimulation responses were observed. The duration of conditioning, i.e., the time-to-potentiation (t_p), is determined as the time at which the increasing rate of muscle stimulation response becomes zero. Immediately after the conditioning train, the same 2 Hz stimulation was applied again, and muscle stimulation responses were collected during three 9-second trains with a 10-second rest in between.

A repeated-measures analysis of variance (ANOVA) method was used to identify any significant changes in muscle stimulation response before and after the one hour of prolonged sitting.

Descriptive summaries of the stimulation response (i.e., stimulation generated forces) from two test trials are presented in **Figure 6**. Signs of muscle fatigue were clearly found in the measured stimulation response. Prolonged sitting resulted in a significant ($p = 0.03$) decrease in stimulation responses from the measured muscles.

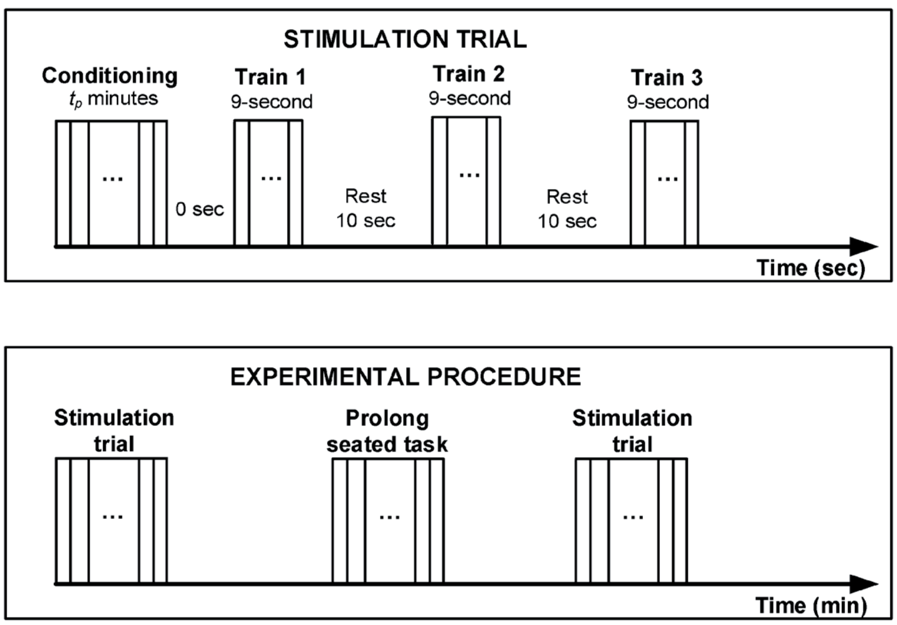

Figure 5.
Illustration of the overall experimental procedure. Conditioning: t_p minutes continuous stimulation at 2 Hz; train: 9-second stimulation at 2 Hz with a 10-second rest in between.

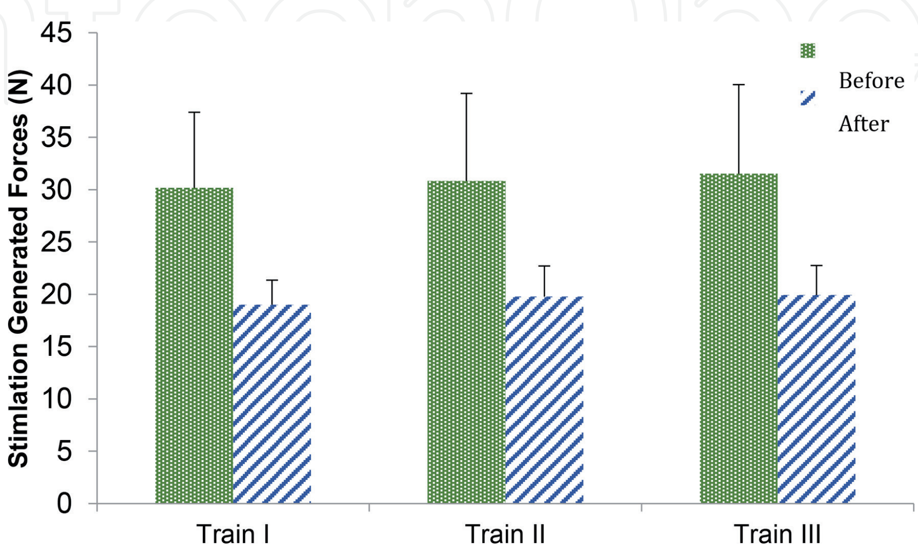

Figure 6.
Stimulation generated forces (mean and SD) collected among three trains before and after the prolonged seated task.

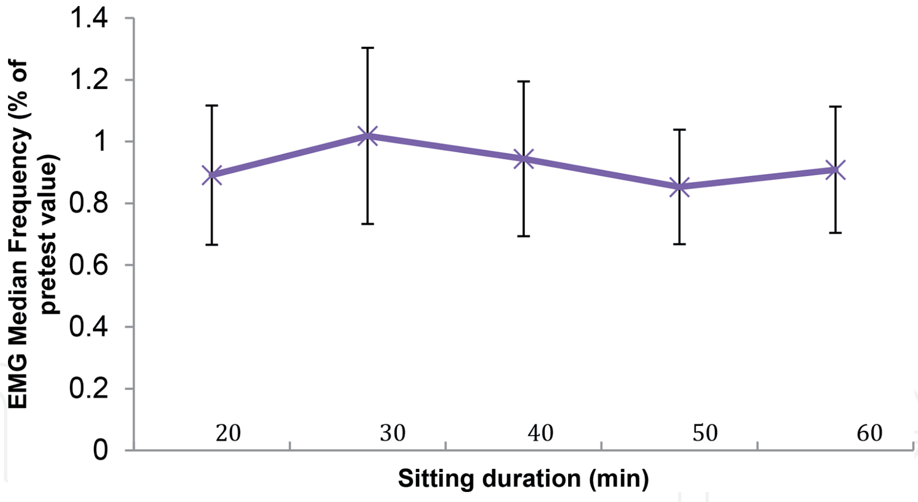

Figure 7.
Average EMG MPF of MF during the prolonged seated task.

As a comparison shown in **Figure 7**, the average EMG MPF of bilateral MF showed some signs of fatigue with a shifted MPF value, but the development of muscle fatigue was inconsistent over time, and the level of the observed shift was small.

3. Discussion and conclusions

Muscle fatigue was measured using EMG MPF, EMG amplitude, and muscle stimulation methods. In general, all three methods successfully captured the sign of muscle fatigue development through prolonged sitting. Consistency among these three measures supports that muscle fatigue indeed developed during the prolonged seated task.

EMG amplitude collected from 16 muscle groups showed a sign of increased amplitude toward the end of the sitting period. Two out of 16 muscles (i.e., LMF and LLTT) have significant increases in measured EMG amplitude, which in the absence of interference from external forces or movement may have been caused by muscle fatigue development over time. However, the EMG amplitude method did not detect any significant development of muscle fatigue over the rest of the 14 muscles, which may indicate the limited sensitivity of such methods in measuring muscle fatigue under prolonged sitting conditions. Furthermore, existing evidence also indicated that such EMG amplitude changes over a fatiguing task is also associated with the level of contraction, e.g., a task, which requires below 40% MVC, may show sign of EMG amplitude decrease [32], while other studies show increase of EMG amplitude during 40–50% MVC sustained contraction tasks [33, 34]. Therefore, using EMG amplitude alone may not be able to provide reliable estimation on muscle fatigue development.

EMG MPFs collected from four out of 16 muscles also showed signs of fatigue, but no general consistency was observed across all measured muscles. Some of the inconsistencies among various muscles in the measured MPFs may have been the result of the insensitivity of EMG in measuring low-load muscle fatigue. As shown in **Figure 2**, the average contraction level of most flexors and some extensors are between 2% and 5%. Since only a deficient level of muscle contractions are needed during the prolonged seated task, collected EMG signals may fall close to or even below the noise threshold, which may significantly affect the fatigue detection results derived from noisy EMG MPF. As a result, EMG amplitude and EMG MPF may only have limited capacity in measuring fatigue related muscle changes under such task conditions.

Another potential explanation could be linked to the functional differences between the trunk flexors and extensors. During the prolonged sitting, trunk extensors usually work as postural muscles that continuously contract to stabilize the sitting posture [5, 6]. Therefore, the observed decline of EMG MPF among three trunk extensors (ILL, LTT, and MF) was more substantial and could be used as a reasonable measurement of muscle fatigue caused by prolonged sitting. The decline of EMG MPF in the IO suggests that this muscle may also play an essential role in stabilizing the trunk posture during sitting, which is consistent with existing evidence [35]. All other muscles may have received only limited impacts from the prolonged seated task, or the actual fatigue could not be accurately measured using surface EMG during prolonged sitting.

Muscle fatigue measured by muscle stimulation, on the other hand, was more announced with a significant drop in measured stimulation responses across all three sampling trains. The same sign of fatigue was also observed in measured EMG amplitude and EMG MPF, but the magnitude of changes was small and inconsistent. Such results could indicate that muscle stimulation methods, compared to traditional EMG-based fatigue measurement methods, could provide more stable and visible results as a more sensitive method.

In summary, several EMG-based methods have been discussed in terms of their capabilities and limitations when used as ergonomic assessment methods to measure the effects of prolonged sitting. These outcomes were evident after one hour of continuous sitting. The effects of prolonged sitting have been successfully quantified by monitoring participants' muscle fatigue development. Current findings suggest that individuals who sit for prolonged periods can be at increased risk of cumulative disorder and injury, and various EMG-based methods can be used together to provide more reliable estimation and evaluation.

Conflict of interest

The author declares no sources of support or conflict of interest.

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