Issue Rehabil. Orthop. Neurophysiol. Sport Promot. 2022; 40: 47–56. ISSN 2300-0767
DOI: 10.19271/IRONS-000174-2022-40

ORIGNAL ARTICLE

THE USEFULNESS OF SURFACE EMG RECORDINGS FOR EVALUATION OF THE SYNERGISTIC MUSCLE FUNCTIONS OF LOWER EXTREMITIES IN NORMAL CONDITIONS FOR PHYSIOTHERAPY

PRZYDATNOŚĆ REJESTRACJI EMG POWIERZCHNIOWEGO DLA OCENY FUNKCJI MIĘŚNI SYNERGISTYCZNYCH KOŃCZYNY DOLNEJ W WARUNKACH PRAWIDŁOWYCH DLA CELÓW FIZJOTERAPII

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ABSTRACT

Introduction

A sedentary lifestyle causes severe changes in the functioning of the trunk muscles, pelvic girdle and lower extremities in the population of healthy people. Understanding the synergies of muscles active while maintaining a standing position may, in this aspect, provide clinically helpful information for kinesiotherapy. There is little data on the assessment of synergistic muscles activity of the lower extremities using non-invasive polyelectromyography recorded with surface electrodes (sEMG) in a relaxed standing position, and due to the tendency of decreasing activation the proximal muscles, it can be expected that the previously developed movement patterns may have changed.

Aim

This pilot study aims to verify the activity of the lower extremities' most crucial synergistic muscle groups engaged in posture maintenance in a population of healthy people using sEMG.

Material and methods

In a group of 14 healthy volunteers (7 women and 7 men), sEMG examination of the gluteus maximus (GM), rectus femoris (RF), tibialis anterior (TA), and dorsal foot extensors (EXT) was performed in 6 positions; resting in standing and lying, GM and RF maximal contraction in standing and lying and TA and EXT maximal contraction in standing and lying. A survey on daily activity was carried out among healthy volunteers. The output parameter of the sEMG tests was the mean value of the amplitude measured in microvolts.

Results

The subjects spent an average of 8 hours a day in a sitting position and 5.5 hours a day in a standing position. In the resting during standing position, the study of the electromyogram amplitude parameter showed a significant change in the involvement of the distal muscles of the lower extremity over proximal muscles (TA mean 67.5 μV; EXT mean 33.22 μV vs. GM mean 21.4 μV; RF mean 26.95 μV). The greatest tendency in changes of the lower extremities' synergistic muscle function can be observed in the disproportion of proximal and distal muscle activity by about 60% in maintaining a relaxed standing position.

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Authors reported no source of funding
Authors declared no conflict of interest

Date received: 31th August 2022
Date accepted: 7rd September 2022

Conclusions
The gluteal muscles show dysfunctional changes resulting from the sedentary lifestyle; they are no longer synergistic with the rectus femoris muscles in relaxed standing. Pilot studies showed no significant disturbance of the synergy of proximal and distal muscles during the attempt of their maximal contraction in the supine position. A significant disproportion in activation of the synergistic distal muscles of the lower extremities in the standing position was demonstrated.

Keywords: electromyography, standing, muscle synergy, healthy population

STRESZCZENIE
Wstęp
Sedentarny tryb życia powoduje w populacji zdrowych ludzi poważne zmiany w funkcjonowaniu mięśni tułowia, obręczy biodrowej i kończyn dolnych. Poznanie synergii mięśniowych aktywnych podczas utrzymania pozycji stojącej, może w tym aspekcie dostarczyć informacji przydatnych klinicznie dla celów kinezyterapii. Mało jest danych na temat oceny czynności mięśni kończyn dolnych z wykorzystaniem nieinwazyjnej polielektromiografii rejestrowanej elektrodami powierzchniowymi (sEMG) w pozycji stojącej, a z uwagi na tendencję malejącej ilości godzin aktywacji mięśni proksymalnych kończyny dolnej spodziewać się można, że dotychczas przyjęte wzorce ruchowe mogły ulec zmianie.

Cel
Celem pracy jest pilotażowa weryfikacja aktywności najważniejszych synergistycznych grup mięśniowych kończyny dolnej zaangażowanych w proces postawy w populacji zdrowych ludzi za pomocą sEMG.

Materiał i metody
W grupie 14 zdrowych ochotników (7 kobiet i 7 mężczyzn) wykonano badanie sEMG mięśni pośladkowych (GM), prostych uda (RF), piszczelowych przednich (TA) i prostowników grzbietu stopy (EXT) w 6 pozycjach: relaksacja w pozycji stojącej oraz leżeniu, maksymalny skurcz GM i RF w staniu oraz leżeniu, maksymalny skurcz TA i EXT w staniu oraz leżeniu. Wśród badanych przeprowadzono ankietę na temat codziennej aktywności ruchowej. Parametrem wyjściowym testów sEMG była średnia wartość amplitudy mierzona w mikrowoltach.

Wyniki
Badani spędzali w pozycji siedzącej średnio 8 godzin dziennie, a w pozycji stojącej średnio 5,5 godziny dziennie. W pozycji stojącej rozluźnionej, badanie parametru amplitudy elektromiogramów wskazało na znaczącą przewagę zaangażowania synergistycznych mięśni dystalnych kończyny dolnej w stosunku do mięśni proksymalnych (TA 67,5 μV, EXT 33,2 μV vs. GM 21,4 μV, RF 26,9 μV). Największą tendencję zmian czynności mięśni synergistycznych kończyn dolnych zaobserwować można w dysproporcji aktywności mięśni proksymalnych w stosunku do dystalnych o około 60% w utrzymaniu pozycji stojącej rozluźnionej.

Wnioski
Mięśnie pośladkowe wykazują zmiany dysfunkcyjne wynikającej z prowadzonego sedentarnego trybu życia, przestały pełnić funkcje synergistyczną do mięśni prostych uda w pozycji stojącej rozluźnionej. Badania pilotażowe wykazały brak znaczącego zaburzenia synergii mięśni proksymalnych oraz dystalnych w trakcie próby ich maksymalnej aktywizacji w pozycji

leżącej. Wykazano istotną dysproporcję w aktywizacji mięśni synergistycznych dystalnych kończyny dolnej w pozycji stojącej.

Słowa kluczowe: elektromiografia, pozycja stojąca, synergia mięśniowa, zdrowa populacja

Introduction

Individual muscle groups of the lower extremity work on the principle of synergy or antagonistic activity, controlled by the spinal circuits under the control of supraspinal centers, enabling the correct locomotion cycle and maintaining a proper standing posture (*Deniskina et al. 2001*). Understanding the changes in muscle synergy in the human population forced to sit is essential not only cognitively but also in the application, enabling the development of exercises in the field of kinesiotherapy that may reproduce the correct pattern of synergistic action (*Wytrążek et al. 2010*). A sedentary lifestyle is a significant factor giving the origin dysfunctions in synergistic and antagonistic muscles cooperating during the contractions and co-contractions, enabling optimal physical activity, including locomotion and maintaining the proper standing position (*Grottel et al. 1999*). A sitting position may expose muscles to fatigue and also to excessive relaxation, which can cause a change in function. The extremely excessive muscles overloading or diminishing the motor unit's activity lead to atrophic changes. Nowadays, the sedentary lifestyle trend has changed because of the growing awareness of physical activity necessity and taking care of motor units' functional state (*Huber et al. 2009*).

While standing, the gluteal muscles (GM) are synergists of the rectus femoris muscles (RF), while the anterior tibialis muscles (TA) are synergists of dorsal foot extensors (EXT) (*Rosse et al. 1997, Lisiński et al. 2014*). Muscle synergy defines a constant proportion of muscle activation necessary to coordinate the performance of a motor task. Each synergy is controlled by a series of nerve impulses sent from the motor neurons innervating the synergistic muscles. Muscle synergy enables the nervous system to perform permanent biomechanical functions that are shared between motor tasks; muscles and their degree of involvement in the performance of a given motor task are repetitive and schematic. Involving any muscle synergy necessary to maintain body control in a standing position is proportional to the vector force acting on the foot. Studying muscle synergy can provide important clinical information on how to perform the desired motor functions. Working on muscle synergy profiles can translate into more effective treatment of motor dysfunctions (*Ting 2007, Safavynia et al. 2011*). Muscle synergies are most often examined using electromyography, the bioelectric potentials recorded from the muscles, allowing for the objective evaluation of their function. The non-invasive sEMG, electromyography recorded with surface electrodes from several muscles, so-called polyelectromyography, is the most common method in the study of muscle synergy (*Safavynia et al. 2011*). Surface EMG, unfortunately, also has some limitations, such as the impact of subcutaneous fat tissue on the quality of the recording, the inability to examine deep muscles, and the possible influence of other active adjacent muscles affecting certain muscle recordings. The pelvic girdle muscles are often subjected to sEMG testing to determine the effectiveness of exercise for a given muscle or the degree to which it is involved in performing a specific movement (*Marshall et al. 2011*). Not many studies focused on performing poli-sEMG in a relaxed standing position in a healthy population of people or patients with different movement disorders (*Leinonen et al. 2000, Lafond et al. 2009, Lisiński et al. 2014*).

Aim

This pilot study aims to verify the activity of the lower extremities' most crucial synergistic muscle groups engaged in posture maintenance in a population of healthy people using sEMG.

Material and methods

Fourteen healthy volunteers (aged 22–45 years, average age 30.5 years) were recruited to perform the sEMG tests in muscles of lower extremities within the systematic research aiming to obtain the reference values of recording parameters (the average amplitude expressed in μV and the frequency of motor units firing in a recording during the muscles maximal contraction expressed in Hz). Such studies are routinely performed every three years in the clinical neurophysiology unit to compare them with the previously recorded, in order to find the differences indicating the trend of change. Examinations were performed in the Department of Pathophysiology of Locomotor Organs of the University of Medical Sciences in Poznań, Poland; the Bioethical Committee agreed to studies with the decision 670/16. The studies were performed in agreement with the Declaration of Helsinki. The inclusion criteria were the written consent from each of the volunteers to perform non-invasive sEMG tests and no neurologic and autoimmune diseases, spinal or nerve injuries or severe fractures in the lower extremities. The neurophysiological testing was performed with an 8-channel Keypoint System (Medtronic A/S, Skovlunde, Denmark), according to the Guidelines of the International Federation of Clinical Neurophysiology – European Chapter; every test was performed under the supervision of certified personnel for clinical neurophysiological testing.

Polyelectromyography recordings were performed from gluteus maximus (GM), rectus femoris (RF), tibialis anterior (TA) and dorsal foot extensors (EXT) muscles at rest and during the attempt of the maximal contraction in 6 positions. First the volunteers were standing on a 50 cm × 30 cm plastic platform (Figure 1), the sEMG was performed in resting during standing, contraction of GM and RF during standing and contraction of TA and EXT during standing. Then similar recordings were performed from the same muscles in a supine position (Figure 2), resting during lying, contraction of GM and RF during lying, contraction of TA and EXT during lying. In the final analysis, the output parameter of sEMG tests was the mean value of amplitude measured in microvolts. They were compared when recorded during the maximal contraction lasting 5 seconds as well as during the relaxation with normative parametres recorded 8 years ago from the same muscle groups in the Department of Pathophysiology of Locomotor Organs of the University of Medical Sciences in Poznań, Poland.

sEMG activity was recorded bilaterally with surface disposable Ag/AgCl electrodes, the active surface of each there was 5 mm^2. sEMG recordings were performed with an active electrode placed on the muscle's belly, while the reference electrode was placed on its distal tendon. The ground electrode was located in the distal part of the leg. Commonly, the Key Point recorder's upper 10kHz and lower 20Hz filters were set. Recordings were made at the time base of 80ms/D and amplified in a range 20–1000 μV/D. The average amplitude parameters (minimum-maximum, the peak-to-peak of recruiting motor unit action potential deflection regarding the isoelectric line, measured in μV) were analyzed. During performing sEMG studies, the neurophysiologist verbally instructed first to keep calm and relax muscles for 5 seconds, then encouraged the subjects to make three attempts at the muscle's maximal contraction. Participants were instructed to contract the tested muscle as hard and fast as possible until the neurophysiologist requested them to finish the attempt. The test was conducted three times, with a 1 minute resting period between each muscle contraction. Methodological guidelines and more principles of sEMG recordings analysis are described in studies by Lisiński *et al.* (*2014, 2017*) and Wincek *et al.* (*2021*).

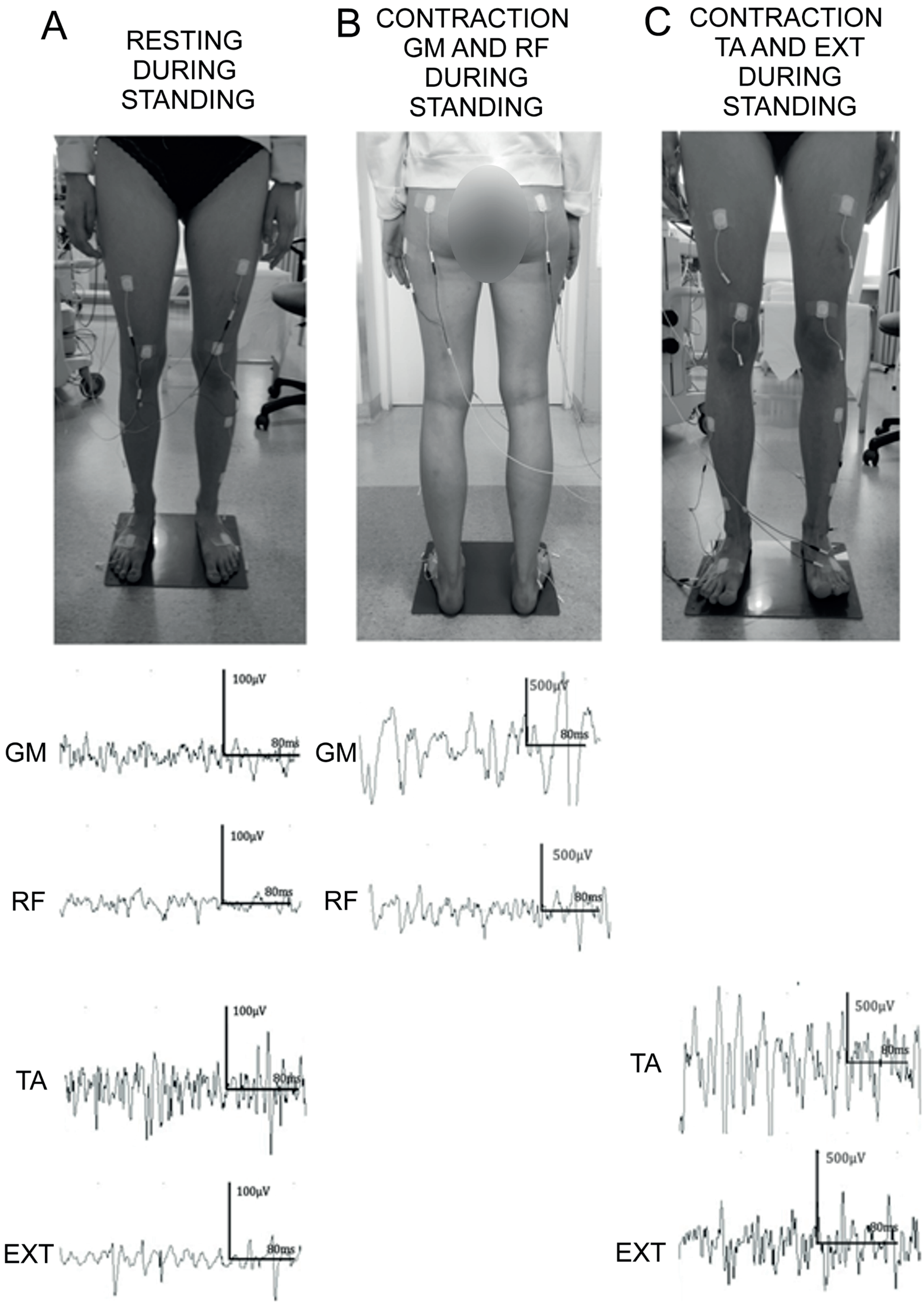

Figure 1. Examples of sEMG recordings from the right lower extremity muscles. A – resting during standing ("stand in a relaxed posture"), B – contraction of GM and RF during standing ("tight the buttocks, stand at attention for five seconds"), C – contraction of TA and EXT during standing ("toes up, stand on the heels for five seconds").

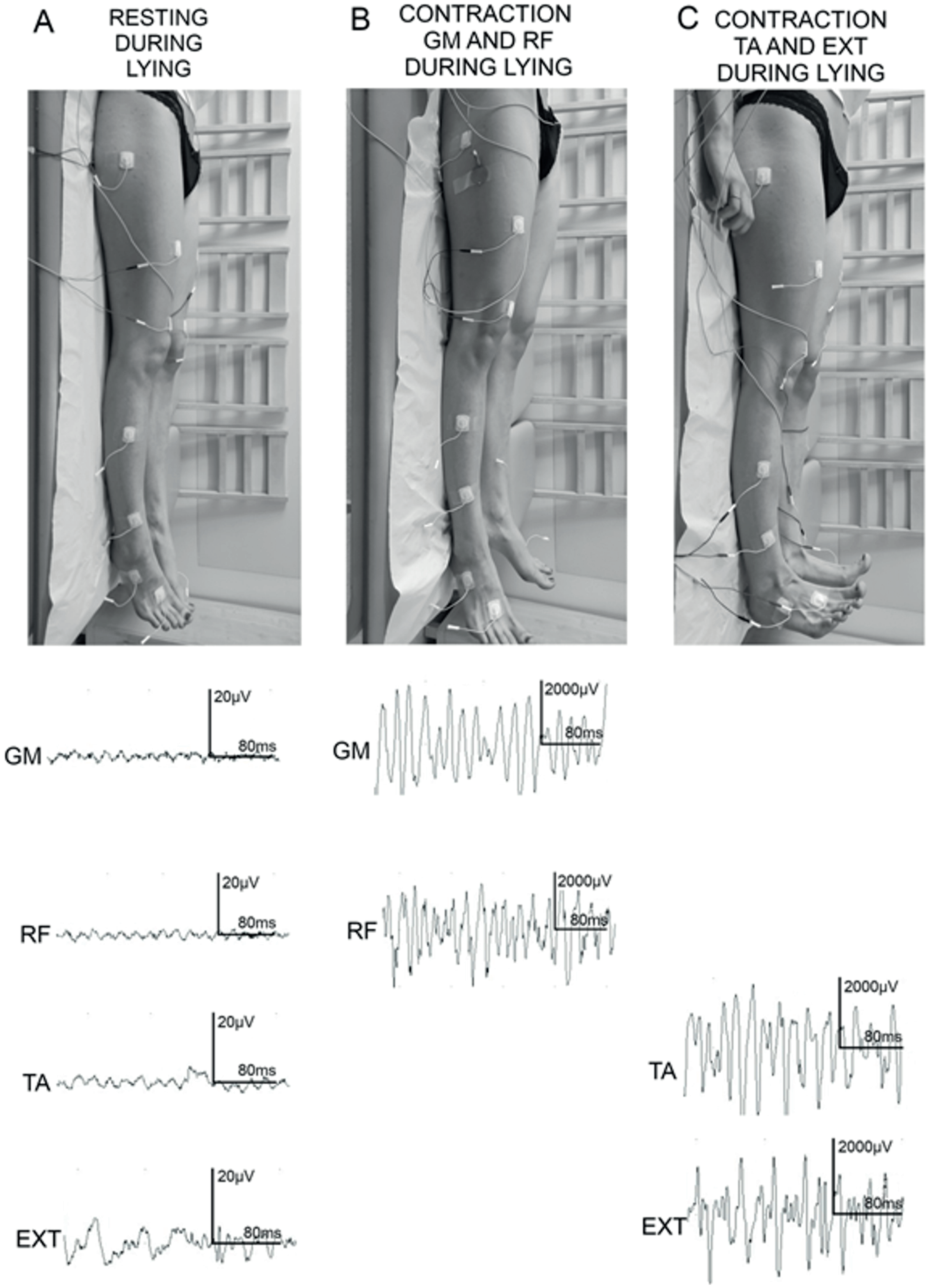

Figure 2. Examples of sEMG recordings in the right lower extremity. A – resting during lying ("relax muscles"), B – contraction of GM and RF during lying ("tight the buttocks, straight legs at the knees slightly up"), C – contraction of TA and EXT during lying ("toes to the face")

Statistical data were calculated with Statistica 13.3 software (StatSoft, Kraków, Poland). Descriptive statistics included minimal and maximal values (range), mean and standard deviations (SD) for measurable values. The results from all neurophysiological tests were compared to data recorded 8 years ago from the same muscle groups (reference values of sEMG recordings) in the Department of Pathophysiology of Locomotor Organs of the University of Medical Sciences in Poznań, Poland. Because of the pilot character of the study and the low number of participants, the parameters of sEMG were analysed between the right and left sides and simply compared as dependent groups with a dependent T-Student test, for data currently recorded and analogical 8 years ago (*Lisiński et al. 2014*). P-values of less than 0.05 were considered to be statistically significant.

Results

According to the current survey, the subjects spent an average of 8 hours a day in a sitting position and 5.5 hours a day in a standing position. A similar report performed 8 years ago revealed that the subjects spent an average of 6 hours a day in a sitting position and 7.5 hours a day in a standing position ($p = 0.03$).

Examples of original sEMG recordings during standing and during the attempt of maximal contraction in 6 studied positions are presented in Figures 1 and 2, respectively, while their parameters of mean amplitudes are summarized in histograms in Figure 3.

The lateralization of the activity of the homonymous muscle groups (significant difference in the mean amplitude parameters recorded on the right and left side) was not detected in any of the six studied positions.

At rest during standing position, there was found a significant change at about 60% of the involvement of the distal synergistic muscles of the lower extremity over proximal muscles (TA mean 67.5 μV; EXT mean 33.2 μV vs. GM mean 21.4 μV; RF mean 26.95 μV) (Figure 3A). Similar data recorded 8 years ago revealed almost the balance between the activity of distal vs. proximal activity of synergistic muscle groups (TA mean 45.3 μV; EXT mean 38.8 μV vs. GM mean 35.5 μV; RF mean 32.9 μV). This difference between results was revealed at p = 0.03–0.04.

The proportion of proximal versus distal synergistic muscle activity recorded in a lying position at rest did not show any significant changes in the amplitude parameters (20–24 μV), nor they differed from the previously accepted normative (Figure 3D).

The sEMG recordings performed during the 5 seconds attempts of maximal contraction of the proximal and distal synergistic muscle groups were characterized by similar fashions of activity both during standing (Figure 3 B, C) and the lying position (Figure 3 E and F). However, when comparing the parameters of mean amplitudes of sEMG recorded from GM and RF muscles as well as EXT bilaterally during the attempts of maximal contraction in this study and 8 years ago (*Lisiński et al. 2014*), the differences by 200 μV decrease have been observed. They were found even greater (by 300–400 μV) when compared to data presented by Grottel *et al.* in 1999.

Discussion

Studies concerning examinations of muscle motor unit activity in a relaxed standing position and the contribution of synergistic muscle groups to movement creation were described in pioneering Vaclav Janda studies (*Janda 1978*). Except few other descriptions mentioned in the Introduction section, there were not many attempts to complete such data (*Joseph et al. 1952, Deniskina et al. 2000; Masani et al. 2003; Saffer et al. 2008*). Polyelectromyography is gaining more and more recognition in physiotherapy due to its ability to precisely define the level of activation as well as allow the evaluation of muscle tension (*Gatev et al. 1999*). Moreover, comparative studies prove the efficiency of a certain type of therapy (*Wytrążek et al. 2010*). Previous studies rarely raise the issue of assessing hip joint synergists in a relaxed standing position; Janda, in his pioneering

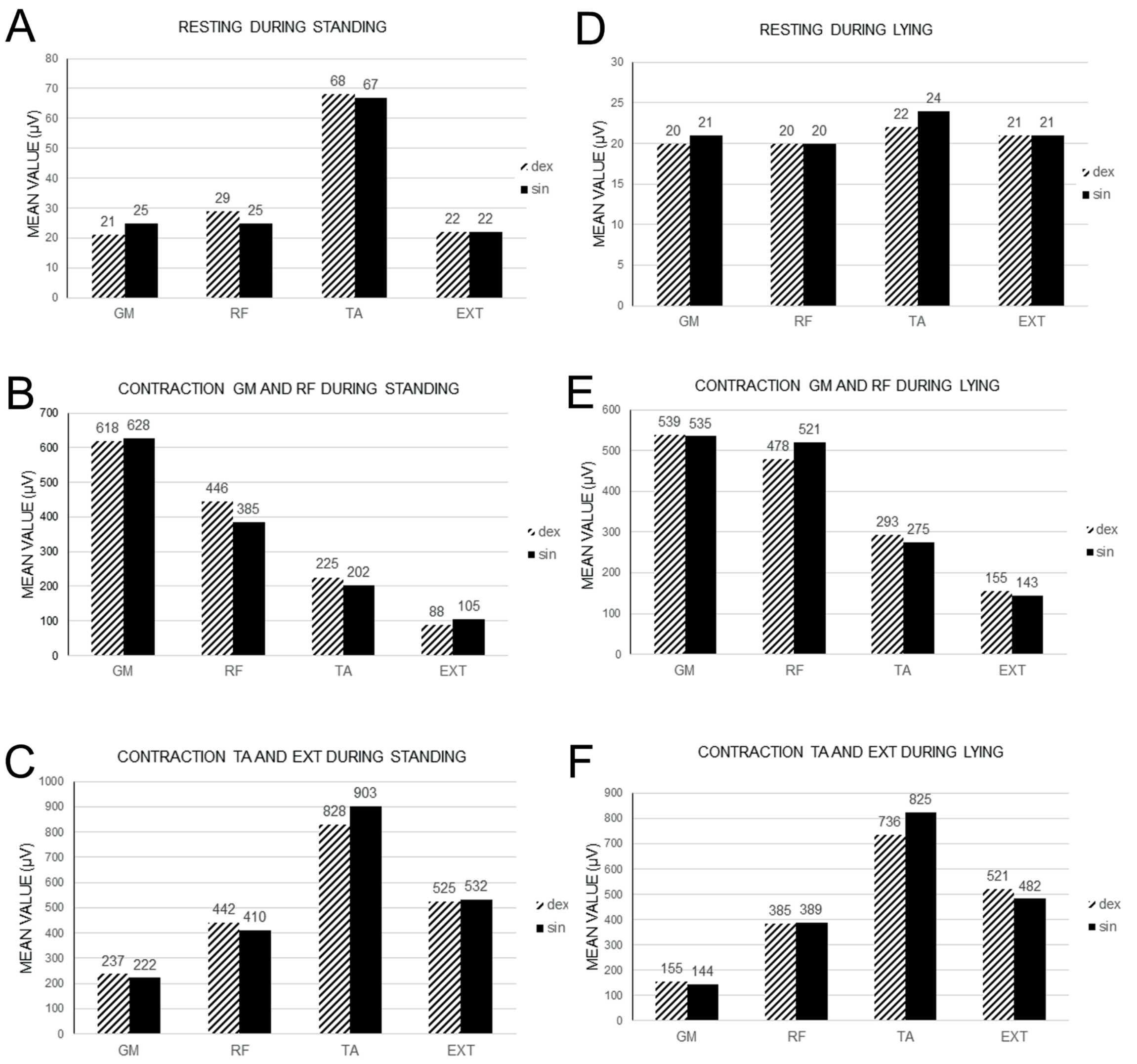

Figure 3. Mean values of sEMG amplitudes recorded from examined muscles in standing (A–C) and lying (D–F) positions at rest (A, D) and during the attempt of maximal contraction (B, C and E, F)

research, noticed that during lower extremity extension, the initiation of movement takes place with the participation of the gluteal muscles, then the biceps femoris muscles and the lumbar part of erector spinae (*Janda 1978*). This sequence of muscle activation limits the involvement of the lumbar spine, thanks to the activity of the gluteal muscles. Nowadays, this synergy has changed, and the extension movement in the hip joint is often initiated from the extensor of the erector spinae, not the gluteus. Lower back pain is currently the most common condition that hinders functioning in the world, mainly in middle and highly developed countries, where most people lead a sedentary lifestyle, which leads to changes in the functioning of hip synergists (*Leinonen et al. 2010, Nelson-Wong et al. 2012*).

Contrary to the results of this study, the predominance of activity in the gluteal and rectus femoris muscles was expected, whereas the current tendency is rather the synergy of tibialis anterior and dorsal foot extensors action in maintaining the standing position, what is sometimes called "the ankle strategy" in maintaining the proper postural position (*Gatev et al. 1999*). It may result from the sedentary lifestyle, which symptoms have been discovered in the surveys with participants of this study, changing the functions of the proximal lower extremity muscles associated with maintaining posture into a passive posture in relaxation. It was expected that the amplitudes of sEMG recordings from synergistic muscles of the proximal and distal groups should be of similar values (*Joseph et al. 1952; Grottel et al. 1999*). However, it was found in this study, that the amplitude of sEMG recordings from the tibialis anterior muscles is about 60% greater than in the proximal hip muscles. Some researchers confirm that due to a sedentary lifestyle, muscle synergies may change (*Ting et al. 2007, Safavynia et al. 2011, Nelson-Wong et al. 2012*); they also confirm a positive correlation between the activity of muscle groups and their weight (*Gatev et al. 1999*).

Knowledge about the contemporary tendencies of changes in lower extremity muscle synergies is necessary for the practical work of physiotherapists if they want to recover the pathological function to the normal state by targeting strengthening exercises. In 2014, the activity pattern of lower extremities muscle motor units during normal standing and in a tandem position was described in a healthy population (*Lisiński et al. 2014*). It was found that the sEMG amplitudes of the gluteal muscles during stance are roughly equal to the extensor muscle amplitude parameter at the level of activity 9–11% of the maximal voluntary contraction. According to the results of the present study, there is a significant change in the activity of the distal muscles of the lower extremities compared to the proximal muscles during standing. On average, the examined volunteers spent 8 hours a day in a sitting position, which is 1/3 of a day, of which the next 8 hours were spent lying while sleeping. It seems, that the activity of the motor units of the gluteal muscles has a decreasing tendency in a healthy population (*Grottel et al. 1999; Lisiński et al. 2014*).

Also noteworthy in this pilot study, on the limited number of individuals is its limitation, the considerable variability in the involvement of muscles during the activation positions, which may be associated with the involutional loss of muscle function in some volunteers, even though the research group consisted of young and active people. However, this hypothesis requires confirmation in the study on the greater number of healthy subjects.

Conclusions

The gluteal muscles show dysfunctional changes resulting from the sedentary lifestyle; they are no longer synergistic with the rectus femoris muscles in relaxed standing. Pilot studies showed no significant disturbance of the synergy of proximal and distal muscles during the attempt of their maximal contraction in the supine position. A significant disproportion in activation of the synergistic distal muscles of the lower extremities in the standing position was demonstrated.

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