applied sciences

MDPI

Article

Physiotherapeutic Training Reduces Muscle Stiffness and Fatigue in Sedentary Administrative Workers: A Biomechanical Assessment Using Myotonometry and Electromyography

Slawomir Winiarski [1,*] and Dorota Molek-Winiarska [2]

[1] Department of Physiology and Biomechanics, Wroclaw University of Health and Sport Sciences, Paderewskiego 35, 51-612 Wroclaw, Poland
[2] Department of Human Resources Management, Wroclaw University of Economics and Business, Komandorska 118/120, 53-345 Wroclaw, Poland
* Correspondence: slawomir.winiarski@awf.wroc.pl

Featured Application

This work may be applied in workplace health and ergonomics programmes for sedentary employees, particularly administrative and office staff exposed to prolonged sitting. The proposed physiotherapeutic training model offers a practical, low-cost intervention for reducing postural muscle stiffness and fatigue, supporting musculoskeletal resilience, and informing evidence-based occupational well-being strategies.

Abstract

Prolonged sitting is a common occupational exposure among administrative and office workers and is associated with increased postural muscle stiffness, fatigue, and musculoskeletal discomfort. This study aimed to evaluate whether a dedicated physiotherapeutic training programme can reduce biomechanical indicators of muscle overload in sedentary administrative staff. Forty-five female administrative employees were allocated to an intervention group (n = 22) or a control group (n = 23). The intervention group completed a four-week supervised physiotherapeutic programme comprising three 45 min sessions per week, including stretching, strengthening, and sensorimotor exercises targeting postural muscles. Muscle stiffness was assessed using myotonometry, while muscle fatigue was evaluated with surface electromyography based on median frequency slope analysis. The intervention effect was assessed using ANCOVA, with post-intervention values adjusted for corresponding baseline values. The intervention group showed significant reductions in muscle stiffness and fatigue, particularly in the upper trapezius and thoracic erector spinae, with moderate-to-large effect sizes. These findings indicate that targeted physiotherapeutic training can improve neuromuscular function and fatigue resistance in sedentary workers. Incorporating structured physiotherapeutic exercise into workplace health programmes may support musculoskeletal resilience and reduce the biomechanical consequences of prolonged sitting.

Keywords: physiotherapeutic training; sedentary work; muscle stiffness; muscle fatigue; surface electromyography; myotonometry; workplace health; musculoskeletal disorders

Check for updates

Academic Editor: Nicola Magnavita

Received: 20 May 2026
Revised: 17 June 2026
Accepted: 19 June 2026
Published: 26 June 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license.

1. Introduction

Sedentary behaviour has become a defining characteristic of contemporary office work. Administrative and clerical employees commonly spend a substantial proportion of

the working day in a seated position, often performing repetitive computer-based tasks with limited postural variation. This occupational pattern is clinically relevant because prolonged sitting is not only a state of low energy expenditure but also a sustained biomechanical exposure affecting the musculoskeletal system, particularly muscles responsible for maintaining head, shoulder-girdle, and trunk posture. The resulting load may contribute to increased muscle stiffness, earlier onset of fatigue, discomfort, and work-related musculoskeletal symptoms.

The global importance of sedentary behaviour is reinforced by the high prevalence of insufficient physical activity among adults. The World Health Organization (WHO) indicates that a substantial proportion of the adult population does not meet minimum physical activity recommendations [1]. European data similarly indicate that a considerable proportion of workers spend most of their working time sitting, especially in desk-based occupations [2]. Prolonged sitting has been associated with adverse musculoskeletal outcomes, including low back pain, neck and shoulder discomfort, increased postural muscle activity, and thoracolumbar strain [3–5].

Prolonged sitting affects musculoskeletal health through mechanical, vascular, and neuromuscular mechanisms. Static sitting requires continuous low-level activation of postural muscles, including the upper and lower portions of the trapezius and the erector spinae, to stabilise the head, shoulder girdle, and spine [6,7]. Although this activity is usually submaximal, its persistence over time may impair local circulation, reduce oxygen delivery, and promote the accumulation of metabolic by-products. Over time, sustained postural loading may also alter neuromuscular recruitment patterns, reduce movement variability, and contribute to asymmetry between the left and right sides of the body. The trapezius and erector spinae are therefore particularly relevant muscles for evaluating the biomechanical consequences of sedentary office work [8].

The consequences of increased muscle stiffness and fatigue extend beyond local discomfort. Work-related musculoskeletal disorders are associated with pain, reduced work ability, impaired well-being, and decreased productivity [9]. In office workers, even moderate musculoskeletal symptoms may increase perceived effort during work, reduce concentration, and contribute to presenteeism, understood as being present at work despite health-related limitations. From an occupational health perspective, interventions that reduce muscle stiffness and fatigue may therefore have practical significance for both employee well-being and organisational productivity.

Physical activity and workplace exercise interventions have been widely proposed as strategies for counteracting the negative effects of sedentary work. Previous studies and reviews have reported beneficial effects of physical activity programmes on well-being, musculoskeletal health, and productivity [10–12]. Supervised exercise schedules have been used in sedentary populations and shown to produce measurable functional benefits [13–15]. For this reason, several authors have recommended incorporating physical activity into working hours through interventions designed to promote movement, reduce sedentary behaviour, and improve health-related behaviours [16,17]. Such interventions may take different forms, including strengthening exercises, stretching programmes, ergonomic education, movement breaks, and broader workplace wellness initiatives [18]. Regular physical activity may be particularly important for employees who spend a large proportion of their working day sitting ($\geq$25% of working time), as it can partly mitigate the health risks associated with sedentary occupational routines [19].

However, the available evidence remains heterogeneous. Workplace physical activity interventions differ substantially in duration, intensity, supervision, exercise content, target population, and outcome measures. Some studies rely mainly on subjective indicators such as self-reported pain, discomfort, or perceived health, whereas fewer studies include

objective biomechanical measures of muscle condition. Occupational health interventions can positively influence knowledge, beliefs, attitudes, and health-related behaviours [20,21], and may improve selected aspects of employee health [22,23]. Nevertheless, general physical activity programmes may not sufficiently address the specific neuromuscular demands imposed by prolonged sitting. In contrast, dedicated physiotherapeutic training can be designed to target the postural muscles most exposed to static load, improve mobility and strength balance, and support more efficient neuromuscular control.

Several studies have investigated physiotherapeutic or exercise-based interventions for reducing musculoskeletal symptoms in workers. Tailored exercise programmes, including strengthening and stretching components, have been shown to alleviate musculoskeletal pain associated with sedentary behaviour [9]. Workplace strength training has also been reported to improve muscle function and reduce fatigue in occupational groups exposed to repetitive or sustained loading [24]. Interventions that are specifically adapted to the neuromuscular demands of screen-based work may be more likely to improve adherence and musculoskeletal outcomes because they directly target muscles vulnerable to prolonged sitting, including the lumbar extensors, trapezius, deep cervical flexors, and other postural stabilisers.

Despite these promising findings, methodological limitations remain. Reviews of workplace interventions have emphasised variability in study design, intervention protocols, and outcome assessment, which limits comparability and translation into practice [25–27]. There is still limited evidence regarding physiotherapeutic interventions designed specifically for administrative employees and assessed using objective biomechanical tools. Surface electromyography and myotonometry provide complementary information on postural muscle function. Surface EMG reflects functional neuromuscular behaviour, including fatigue-related changes in muscle activation, whereas myotonometry characterises mechanical muscle properties such as stiffness and tone. Previous studies have reported good reliability of MyotonPRO measurements for assessing skeletal muscle stiffness [28–30]. Their combined use therefore allows simultaneous assessment of whether physiotherapeutic training modifies both fatigue resistance and passive or active mechanical muscle state. This integrated approach provides a more comprehensive evaluation of short-term training-related responses than either method alone. The present study was not designed to compare different exercise dosages or to determine the superiority of one workplace exercise approach over another. Instead, its contribution lies in assessing whether a structured physiotherapeutic programme delivered in real workplace conditions is associated with measurable changes in objective muscle-specific outcomes. Therefore, the focus of the study was on myotonometry-derived muscle stiffness and EMG-derived fatigue indices as indicators of biomechanical and neuromuscular responses in sedentary administrative workers.

There also remains a need for controlled studies evaluating dedicated physiotherapeutic programmes tailored to sedentary administrative staff. Such studies should assess not only subjective discomfort but also objective indicators of muscle stiffness, fatigue, and bilateral symmetry. This is important because asymmetrical loading and persistent differences between the left and right sides of postural muscles may contribute to dysfunctional movement patterns and chronic discomfort.

Therefore, the purpose of this study was to assess the effects of a dedicated physiotherapeutic training programme on muscle stiffness and fatigue in administrative staff exposed to prolonged sitting. The specific objectives were to evaluate changes in stiffness of the trapezius and erector spinae muscles, quantify changes in muscle fatigue using surface electromyography, and determine whether the intervention improved left–right symmetry of selected muscle parameters. The study addressed the following research questions: does

dedicated physiotherapeutic training reduce muscle stiffness in the postural muscles of administrative staff; does it decrease electromyographic indicators of muscle fatigue; and does it improve left–right symmetry of muscle stiffness and fatigue? We hypothesised that, compared with a control condition, the physiotherapeutic training programme would reduce muscle stiffness, attenuate fatigue-related electromyographic changes, and improve symmetry in the assessed postural muscles.

Although workplace exercise, stretching, and ergonomic interventions have been widely studied, previous research has often relied primarily on self-reported indicators such as pain, discomfort, well-being, or general physical activity. Less attention has been given to objective, muscle-specific biomechanical and neuromuscular responses to physiotherapeutic training in sedentary administrative workers. Therefore, the novelty of the present study lies in combining myotonometry-based assessment of muscle stiffness with EMG-derived fatigue indices to characterise both mechanical and neuromuscular adaptations to a structured workplace physiotherapy programme. By integrating objective biomechanical measurement with an applied workplace intervention, this study contributes to occupational biomechanics, clinical physiotherapy, physical activity science, and workplace health promotion. The findings may support the development of evidence-based physiotherapeutic programmes for office employees and provide practical guidance for reducing the neuromuscular consequences of prolonged sitting.

2. Materials and Methods

2.1. Study Design

This study used a non-randomised controlled, parallel-group, pre-test/post-test design to evaluate the effects of a dedicated physiotherapeutic training programme on muscle stiffness and fatigue in sedentary administrative staff. Participants were assessed twice: before the intervention period and immediately after completion of the four-week training programme. The intervention group participated in supervised physiotherapeutic training, whereas the comparison group maintained their usual daily routine and did not take part in structured physiotherapy during the study period.

The study was designed to determine whether targeted physiotherapeutic exercises could modify objective biomechanical indicators of postural muscle function. The primary outcomes were muscle stiffness measured using myotonometry and muscle fatigue assessed using surface electromyography. Measurements were performed bilaterally for selected postural muscles exposed to prolonged sitting.

2.2. Participants

A total of 45 professionally active female administrative employees were recruited through an internal call for participation. Eligible participants were adults aged 20–65 years who performed administrative or office-based work in a remote or hybrid mode and spent at least 50% of their working time in a seated position. This population was selected because desk-based administrative work is commonly associated with prolonged sitting, limited postural variability, and sustained low-level activation of postural muscles.

The mean age of the full sample was 41.8 ± 6.7 years, with a range of 30–58 years. The mean job tenure was 18.0 ± 6.2 years, ranging from 7 to 30 years, and the mean duration of working in a sitting position was 16.3 ± 6.1 years, ranging from 6 to 26 years. Participants were allocated to either the intervention group (n = 22) or the comparison (control) group (n = 23). In the intervention group, the mean age was 43.1 ± 6.7 years, job tenure was 19.4 ± 6.3 years, and years working in a sitting position were 17.7 ± 5.5 years. In the control group, the mean age was 40.5 ± 6.6 years, job tenure was 16.6 ± 6.0 years, and years working in a sitting position were 13.8 ± 6.7 years. Group allocation was not

randomised and was based on participants' availability, willingness, and ability to attend three supervised physiotherapeutic training sessions per week. Participants unable or unwilling to attend the required sessions were assigned to the control group. Participants were not blinded to group allocation because of the nature of the intervention. However, biomechanical measurements were performed by an independent assessment team, and all participants were pseudonymised during data processing and analysis.

The exclusion criteria were serious health problems, certified disability, musculoskeletal pain exceeding 7 points on the Visual Analogue Scale for Pain (VAS), structured physical activity exceeding 2 h per day, participation in another employer-organised training or physical activity programme, or any condition that could prevent safe participation in the physiotherapeutic intervention or interfere with biomechanical assessment. All participants were informed about the study aims, procedures, potential risks, and their right to withdraw at any stage. Written informed consent was obtained from all participants before data collection.

2.3. Ethical Approval

The study was conducted in accordance with the Declaration of Helsinki and approved by the Rector's Commission on Research Ethics at the Wroclaw University of Economics and Business, Poland (Decision no. 44/2024), issued on 12 December 2024. The trial was registered in the Australian New Zealand Clinical Trials Registry under number ACTRN12624001311549.

2.4. Physiotherapeutic Intervention

The intervention consisted of a dedicated physiotherapeutic training programme conducted over four weeks. This duration was selected because previous studies have shown that short-term, four-week exercise or physiotherapeutic interventions may be sufficient to produce measurable functional and musculoskeletal effects [31–34]. Participants in the intervention group attended three supervised sessions per week, with each session lasting 45 min. This frequency and session duration were chosen to provide regular therapeutic stimulus while remaining feasible in real workplace conditions. All sessions were conducted by a qualified physiotherapist to ensure correct exercise execution, participant safety, and adherence to the training protocol.

The programme was designed to reduce tension and fatigue in postural muscles commonly affected by prolonged sitting, particularly the trapezius and erector spinae muscles. Exercises were selected to improve mobility, sensorimotor control, postural stability, and muscular endurance. During each session, participants received verbal instructions regarding proper exercise technique and the purpose of each exercise in relation to specific postural muscles.

Each training session included four components: a general warm-up, stretching exercises, sensorimotor exercises, and strengthening exercises. The warm-up lasted approximately 10 min and included marching in place, arm raises, leg bends, and transitions into a front plank position. Stretching exercises lasted approximately 5 min and included thoracic spine mobilisation using a foam roller, upper back and shoulder-girdle stretching, and lower-limb flexibility exercises. Sensorimotor exercises lasted approximately 10 min and included controlled cervical movements, head repositioning tasks, lumbar spine mobilisation in quadruped and standing positions, and exercises performed from a neutral head, neck, and trunk position. Strengthening exercises lasted approximately 15 min and included postural reaching tasks, resisted shoulder external rotation and abduction using an elastic band, plank holds, and cervical flexor endurance exercises. Exercises were performed in controlled positions with attention to neutral alignment of the head, neck, and spine.

The comparison group continued their usual work and daily activities and did not participate in any structured physiotherapeutic or exercise programme during the study period.

2.5. Measurement Procedure

All participants underwent the same measurement protocol before and after the four-week intervention period. Measurements were performed under standardised laboratory conditions. The assessment included muscle stiffness testing using MyotonPRO and muscle fatigue testing using surface electromyography during a standardised endurance task.

The examined muscles were selected because of their role in maintaining posture during prolonged sitting and computer-based work. Measurements were performed bilaterally for the upper trapezius, lower trapezius, thoracic erector spinae, and lumbar erector spinae. The same measurement sites and procedures were used before and after the intervention.

During the endurance test, participants sat upright without back support and maintained a 30° forward trunk inclination while holding 2 kg weights with the hands positioned behind the head (Figure 1). Participants were instructed to maintain this position until voluntary exhaustion. Time to exhaustion was recorded as an indicator of muscular endurance. A researcher monitored posture throughout the test to ensure safety and consistency. Standardised verbal encouragement was provided to all participants.

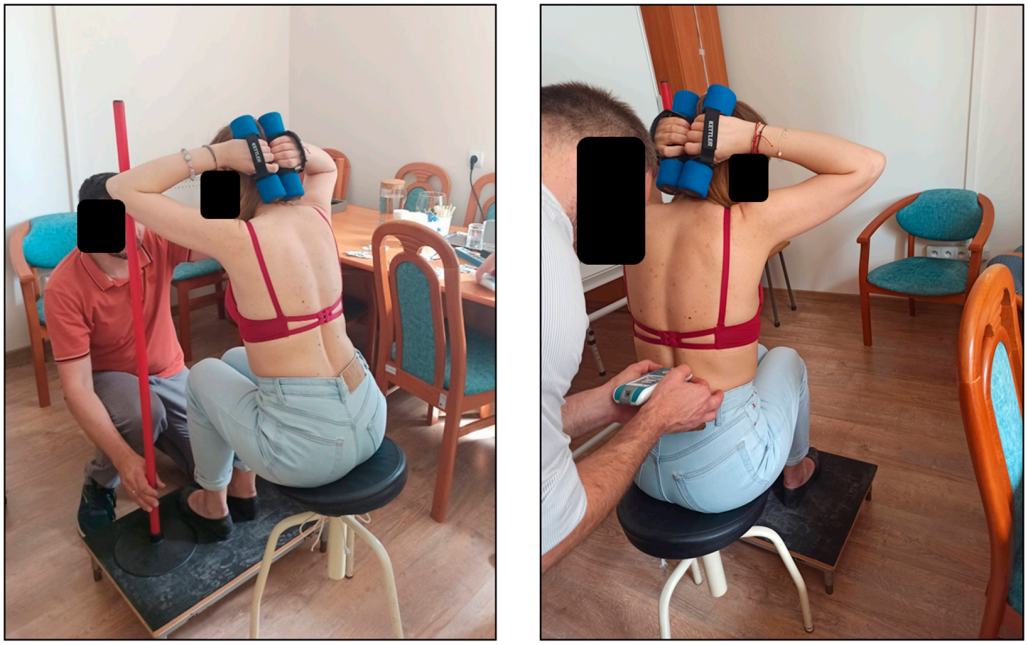


Figure 1. Endurance Test and Muscle Elastic Stiffness Evaluation. Participants performed the endurance test by maintaining a 30° trunk forward inclination while sitting upright without back support, holding 2 kg weights in their hands positioned behind the head. This posture was sustained until voluntary exhaustion (**left panel**). Concurrently, muscle elastic stiffness was measured using the MyotonPRO device applied to the targeted muscles, including the Upper and Lower Trapezius, and Erector Spinae in both the lumbar and thoracic regions, on both sides of the body (**right panel**).

All biomechanical measurements were performed in a laboratory operating under a PN-EN ISO 9001-certified quality management system, and the procedures followed the laboratory's certified standard operating procedures.

2.6. Surface Electromyography

Surface electromyography was used to assess neuromuscular fatigue of the selected postural muscles. EMG electrodes were placed bilaterally over the upper trapezius, lower

trapezius, thoracic erector spinae, and lumbar erector spinae muscles according to standard surface EMG procedures [35]. The skin was prepared before electrode placement to reduce impedance and improve signal quality.

These muscles were selected due to their central role in maintaining postural stability and spinal alignment during prolonged sitting, which is characteristic of administrative work. As primary stabilisers of the scapula and spine, dysfunction or fatigue in the Trapezius and Erector Spinae muscles contributes significantly to the development of musculoskeletal discomfort and postural deviations commonly observed in sedentary populations [36,37].

EMG signals were recorded during the endurance test. The raw EMG signal was processed using full-wave rectification and smoothing with a root mean square algorithm using a 100 ms moving window. Muscle fatigue was quantified using frequency-domain analysis. The median frequency was calculated from the fast Fourier transform spectrum over time, and the slope of the median frequency was used as the fatigue index. A more negative median frequency slope indicated a faster decline in muscle fibre conduction velocity and greater fatigue development during sustained contraction.

For each muscle and side, the median frequency slope was expressed in Hz/s. The median frequency is indicative of muscle fatigue, as it shifts towards lower frequencies with increased muscle fatigue. These values were used for pre–post comparison between the intervention and comparison groups.

The slope of the median frequency of the EMG signal (in Hz/s) reflects the rate of muscle fatigue and varies with the level of muscular activation—being more negative under higher intensity or electrically stimulated conditions [38,39]. During low to moderate voluntary contractions, slope values are relatively small (e.g., -0.1 to -0.4 Hz/s) [40,41] whereas during sustained or high-intensity efforts, especially near or at maximal voluntary contraction (MVC) or under electrical stimulation, slope values can reach -1.2 to -1.6 Hz/s, indicating a faster decline in muscle fibre conduction velocity due to fatigue.

2.7. Myotonometric Assessment of Muscle Stiffness

Muscle stiffness was assessed using the MyotonPRO device (Myoton AS, Tallinn, Estonia). The device applies a brief mechanical impulse to the skin over the examined muscle and records the resulting tissue oscillation using an integrated accelerometer. Muscle stiffness was expressed in N/m and interpreted as the muscle's resistance to external deformation.

Measurements were performed with the probe positioned perpendicular to the skin surface over the target muscle. The MyotonPRO device applied a short mechanical impulse, and repeated impulses were recorded at each measurement point. Stiffness was assessed bilaterally for the upper trapezius, lower trapezius, thoracic erector spinae, and lumbar erector spinae. The same anatomical locations were used during pre- and post-intervention testing.

The primary myotonometric outcome was muscle stiffness in N/m. Left–right differences were also calculated to evaluate bilateral symmetry of muscle mechanical properties.

The device's initial sampling rate is 3200 Hz, with stiffness average coefficients of variation CV < 1.72%, as reported by Muckelt et al. [42], and good measurement reliability of average interrater reliability ICC3,1 > 0.98, as reported by Agyapong-Badu et al. [43]. Other studies have also demonstrated the MyotonPRO's validity and reliability in assessing the biomechanical properties of various tissues. Intra- and inter-operator reliability assessments have shown high consistency, with intraclass correlation coefficients (ICCs) ranging from 0.74 to 0.99 for different muscles and parameters [44,45].

2.8. Outcome Measures

The primary outcomes were changes in muscle stiffness and muscle fatigue from pre- to post-intervention. Muscle stiffness was quantified using MyotonPRO measurements expressed in N/m. Muscle fatigue was quantified using the slope of the EMG median frequency expressed in Hz/s. Secondary outcomes included endurance time during the standardised trunk-inclination task and left–right symmetry for muscle stiffness and fatigue.

2.9. Statistical Analysis

Data were screened before statistical analysis. Missing or zero values were identified and checked. Only two repeated measurements were missing across the full dataset. Analyses were conducted using available complete pre- and post-intervention data for each outcome, and missing values were not imputed. Given the very small amount of missing data, its influence on statistical power and result interpretation was considered minimal. Extreme outliers were assessed using the interquartile range method, with values below $Q1 - 1.5 \times IQR$ or above $Q3 + 1.5 \times IQR$ considered potential outliers.

Sample size estimation was conducted a priori using the Statistica 14.0 (Tibco Software Inc., Santa Clara, CA, USA) Sample Size and Power Analysis module. The calculation was based on the originally planned pre–post controlled design, assuming a medium effect size (f = 0.25), statistical power of 0.80, and an alpha level of 0.05. The analysis indicated that a minimum of 40 participants would be required to detect a group $\times$ time effect. The final sample included 45 participants, exceeding this minimum requirement. The original sample size estimation was retained as the a priori justification for study recruitment.

Descriptive statistics were calculated separately for each group, muscle, side, and time point. Data are presented as mean $\pm$ standard deviation. The primary intervention effect was assessed using analysis of covariance (ANCOVA). This model was selected because it allows comparison of post-intervention outcomes between groups while adjusting for the corresponding pre-intervention value of the same outcome, treated as the baseline covariate. This is particularly important in non-randomised studies, where initial differences between groups may occur and may influence post-intervention results. In ANCOVA, for each outcome, the post-intervention value was entered as the dependent variable, group allocation as the fixed factor, and the corresponding baseline value as a covariate. Because group allocation was not randomised, available socio-demographic and occupational variables, including age, job tenure, and years working in a sitting position, were examined as potential confounding variables. These variables were considered as additional covariates when relevant between-group differences or theoretical justification suggested that they could influence the analysed outcome. Before fitting the final model, the homogeneity of regression slopes assumption was tested by including the group $\times$ baseline interaction term. When this interaction was not statistically significant, the final ANCOVA model was fitted without the interaction term. Adjusted group means, F values, p-values, and partial eta-squared effect sizes were reported. Separate analyses were conducted for muscle stiffness, EMG median frequency slope, endurance time, and left–right asymmetry indices.

Effect sizes were reported using partial eta squared. The level of statistical significance was set at $p < 0.05$. Statistical analyses were performed using Statistica software (Statistica 14.0, TIBCO Software Inc., Santa Clara, CA, USA).

3. Results

3.1. Muscle Stiffness

Table 1 presents pre- and post-intervention muscle stiffness values for the intervention and control groups. The intervention effect was assessed using ANCOVA, with

the post-intervention value as the dependent variable, group as the fixed factor, and the corresponding baseline value as a covariate.

Table 1. Muscle stiffness (N/m) of the trapezius and erector spinae muscles before and after the physiotherapeutic intervention in the intervention and control groups. Descriptive values are presented as mean ± standard deviation (SD). The intervention effect was analysed using ANCOVA, with the post-intervention value as the dependent variable, group as the fixed factor, and the corresponding baseline value as a covariate. ANCOVA results are presented as F-values, *p*-values, and partial eta-squared (ηp^2) for the adjusted between-group effect. Statistical significance was defined as $p < 0.05$.

	Intervention Group		Control Group		ANCOVA			
Muscle/Variable	**Pre Mean ± SD**	**Post Mean ± SD**	**Pre Mean ± SD**	**Post Mean ± SD**	**F**	***p*-Value**	**ηp^2**	**Group × Baseline *p***
Upper trapezius, L	417.6 ± 96.7	344.0 ± 73.0	370.1 ± 90.9	359.2 ± 117.8	7.485	0.009	0.158	0.002
Upper trapezius, R	390.4 ± 89.8	312.1 ± 71.7	343.5 ± 108.5	373.6 ± 132.6	36.579	<0.001	0.484	0.025
Lower trapezius, L	395.0 ± 173.0	399.3 ± 138.8	402.7 ± 167.7	467.2 ± 121.5	5.868	0.020	0.128	0.783
Lower trapezius, R	365.0 ± 161.8	369.0 ± 116.2	364.8 ± 167.4	506.6 ± 157.2	14.826	<0.001	0.275	0.539
Erector spinae, central, L	573.1 ± 209.5	494.9 ± 132.9	525.0 ± 249.9	537.4 ± 233.2	13.476	<0.001	0.252	0.003
Erector spinae, central, R	554.4 ± 212.2	477.5 ± 147.3	526.7 ± 256.2	543.4 ± 231.8	11.449	0.002	0.227	0.009
Erector spinae, inferior, L	284.7 ± 148.0	243.6 ± 119.0	242.8 ± 101.3	267.5 ± 111.2	3.803	0.058	0.087	0.821
Erector spinae, inferior, R	292.5 ± 174.2	287.4 ± 153.1	245.6 ± 99.4	285.5 ± 125.2	1.465	0.233	0.036	0.269

The homogeneity of regression slopes assumption was tested using the group × baseline interaction term before fitting the final ANCOVA model. Significant group × baseline interactions indicate that the adjusted group effect should be interpreted with caution.

For the upper trapezius, significant adjusted between-group effects were found bilaterally. On the left side, post-intervention stiffness differed significantly between groups after adjustment for baseline stiffness, F = 7.485, $p = 0.009$, $\eta p^2 = 0.158$. On the right side, the adjusted group effect was stronger, F = 36.579, $p < 0.001$, $\eta p^2 = 0.484$. Descriptively, stiffness decreased in the intervention group on both sides, from 417.6 ± 96.7 to 344.0 ± 73.0 N/m on the left and from 390.4 ± 89.8 to 312.1 ± 71.7 N/m on the right. In contrast, the control group showed only a small decrease on the left side and an increase on the right side. However, the group × baseline interaction was significant for both upper trapezius outcomes, indicating that the adjusted group effects should be interpreted with caution.

For the lower trapezius, significant adjusted between-group effects were also observed on both sides. For the left side, ANCOVA showed a significant group effect, F = 5.868, $p = 0.020$, $\eta p^2 = 0.128$. For the right side, the adjusted effect was larger, F = 14.826, $p < 0.001$, $\eta p^2 = 0.275$. The intervention group showed relatively stable stiffness values, whereas the control group demonstrated an increase in stiffness after the intervention period, particularly on the right side, where stiffness increased from 364.8 ± 167.4 to 506.6 ± 157.2 N/m. The group × baseline interaction was not significant for either lower trapezius variable, allowing standard interpretation of the ANCOVA results for these outcomes.

For the central portion of the erector spinae, significant adjusted between-group effects were found bilaterally. On the left side, ANCOVA showed a significant group effect, F = 13.476, $p < 0.001$, $\eta p^2 = 0.252$. On the right side, the adjusted group effect was also significant, F = 11.449, $p = 0.002$, $\eta p^2 = 0.227$. In the intervention group, stiffness decreased from 573.1 ± 209.5 to 494.9 ± 132.9 N/m on the left and from 554.4 ± 212.2 to 477.5 ± 147.3 N/m on the right. In the control group, post-intervention stiffness was higher than baseline on both sides. As with the upper trapezius, the group × baseline interaction was significant for both central erector spinae outcomes; therefore, these adjusted effects should be interpreted cautiously.

For the inferior portion of the erector spinae, the effects were weaker and not statistically significant. On the left side, the adjusted group effect approached statistical significance, F = 3.803, $p = 0.058$, $\eta p^2 = 0.087$, but did not reach the predefined significance threshold. On the right side, no significant adjusted group effect was observed, F = 1.465, $p = 0.233$, $\eta p^2 = 0.036$. Descriptively, the intervention group showed a reduction in stiffness

on the left side and only a small change on the right side, whereas the control group showed increased stiffness after the intervention period. The group × baseline interaction was not significant for either inferior erector spinae outcome.

Overall, the ANCOVA results indicate significant baseline-adjusted between-group differences in muscle stiffness for the upper trapezius, lower trapezius, and central erector spinae muscles. The largest adjusted effects were observed for the right upper trapezius and right lower trapezius. The inferior erector spinae showed the least consistent response, with no statistically significant adjusted between-group effects. Because significant group × baseline interactions were detected for the upper trapezius and central erector spinae variables, these adjusted effects should be interpreted with caution.

3.2. Muscle Fatigue

Table 2 presents EMG-derived fatigue slopes before and after the intervention. Less negative slope values indicate a smaller decline in median frequency during sustained contraction and therefore greater fatigue resistance. The intervention effect was assessed using ANCOVA, with the post-intervention fatigue slope as the dependent variable, group as the fixed factor, and the corresponding baseline fatigue slope as the covariate.

Table 2. Electromyographic fatigue slopes (Hz/s) of the trapezius and erector spinae muscles before and after the physiotherapeutic intervention in the intervention and control groups. Descriptive values are presented as mean ± standard deviation (SD). The intervention effect was assessed using ANCOVA, with the post-intervention fatigue slope as the dependent variable, group as the fixed factor, and the corresponding baseline fatigue slope as the covariate. ANCOVA results are presented as F-values, *p*-values, and partial eta-squared (ηp^2) for the adjusted between-group effect. Statistical significance was defined as $p < 0.05$.

	Intervention		Control					
Muscle/Variable	**Pre Mean ± SD**	**Post Mean ± SD**	**Pre Mean ± SD**	**Post Mean ± SD**	**ANCOVA F**	***p*-Value**	**ηp^2**	**Group × Baseline *p***
Upper trapezius, L	−0.08 ± 0.07	−0.07 ± 0.06	−0.08 ± 0.06	−0.11 ± 0.10	18.875	<0.001	0.486	0.412
Upper trapezius, R	−0.17 ± 0.19	−0.03 ± 0.02	−0.15 ± 0.10	−0.18 ± 0.19	15.389	<0.001	0.381	0.046
Lower trapezius, L	−0.08 ± 0.08	−0.02 ± 0.01	−0.09 ± 0.05	−0.14 ± 0.09	30.585	<0.001	0.531	0.302
Lower trapezius, R	−0.16 ± 0.11	−0.02 ± 0.02	−0.11 ± 0.09	−0.12 ± 0.12	12.414	0.002	0.395	0.672
Erector spinae, thoracic, L	−0.16 ± 0.13	−0.01 ± 0.01	−0.15 ± 0.20	−0.05 ± 0.04	5.462	0.034	0.267	0.877
Erector spinae, thoracic, R	−0.16 ± 0.13	−0.01 ± 0.01	−0.15 ± 0.08	−0.06 ± 0.08	9.036	0.006	0.282	0.304
Erector spinae, lumbar, L	−0.10 ± 0.11	−0.01 ± 0.01	−0.22 ± 0.20	−0.15 ± 0.15	16.451	0.002	0.599	0.019
Erector spinae, lumbar, R	−0.16 ± 0.10	−0.01 ± 0.02	−0.17 ± 0.14	−0.12 ± 0.14	6.963	0.017	0.291	0.141

The homogeneity of regression slopes assumption was tested using the group × baseline interaction term before fitting the final ANCOVA model. Significant group × baseline interactions indicate that the adjusted group effect should be interpreted with caution.

For the upper trapezius, significant adjusted between-group effects were observed on both sides. On the left side, ANCOVA showed a significant group effect for Trap.Thor.L, $F = 18.875$, $p < 0.001$, $\eta p^2 = 0.486$. The intervention group showed a slight improvement from −0.08 ± 0.07 Hz/s to −0.07 ± 0.06 Hz/s, whereas the control group deteriorated from −0.08 ± 0.06 Hz/s to −0.11 ± 0.10 Hz/s. On the right side, the adjusted group effect was also significant, Trap.Thor.R, $F = 15.389$, $p < 0.001$, $\eta p^2 = 0.381$. The intervention group improved substantially from −0.17 ± 0.19 Hz/s to −0.03 ± 0.02 Hz/s, whereas the control group showed a slight deterioration from −0.15 ± 0.10 Hz/s to −0.18 ± 0.19 Hz/s. The group × baseline interaction was significant for Trap.Thor.R, indicating that this adjusted effect should be interpreted with caution.

For the lower trapezius, significant adjusted between-group effects were also observed bilaterally. On the left side, ANCOVA showed a significant effect for Trap.Lumb.L, $F = 30.585$, $p < 0.001$, $\eta p^2 = 0.531$. In the intervention group, fatigue slopes became less negative from −0.08 ± 0.08 Hz/s to −0.02 ± 0.01 Hz/s, whereas in the control group they deteriorated from −0.09 ± 0.05 Hz/s to −0.14 ± 0.09 Hz/s. On the right side, a significant adjusted group effect was also found, Trap.Lumb.R, $F = 12.414$, $p = 0.002$, $\eta p^2 = 0.395$. The

intervention group improved from −0.16 ± 0.11 Hz/s to −0.02 ± 0.02 Hz/s, while the control group changed only minimally, from −0.11 ± 0.09 Hz/s to −0.12 ± 0.12 Hz/s. The group × baseline interaction was not significant for either lower trapezius variable, supporting the standard ANCOVA interpretation for these outcomes.

For the thoracic erector spinae, significant adjusted between-group effects were observed on both sides. For ESpin.Thor.L, ANCOVA showed a significant group effect, F = 5.462, p = 0.034, ηp^2 = 0.267. Both groups showed less negative slopes after the intervention period, but the intervention group reached values closer to zero, improving from −0.16 ± 0.13 Hz/s to −0.01 ± 0.01 Hz/s, whereas the control group improved from −0.15 ± 0.20 Hz/s to −0.05 ± 0.04 Hz/s. For ESpin.Thor.R, the adjusted group effect was also significant, F = 9.036, p = 0.006, ηp^2 = 0.282. The intervention group improved from −0.16 ± 0.13 Hz/s to −0.01 ± 0.01 Hz/s, while the control group improved from −0.15 ± 0.08 Hz/s to −0.06 ± 0.08 Hz/s. Similarly, the group × baseline interaction was not significant for either thoracic erector spinae outcome.

Lastly, for the lumbar erector spinae, significant adjusted between-group effects were also observed bilaterally. For ESpin.Lumb.L, ANCOVA showed a significant group effect, F = 16.451, p = 0.002, ηp^2 = 0.599. The intervention group improved from −0.10 ± 0.11 Hz/s to −0.01 ± 0.01 Hz/s, whereas the control group improved from −0.22 ± 0.20 Hz/s to −0.15 ± 0.15 Hz/s. However, the group × baseline interaction was significant for this variable, indicating that the adjusted effect should be interpreted cautiously. For ESpin.Lumb.R, the adjusted group effect was significant, F = 6.963, p = 0.017, ηp^2 = 0.291. The intervention group improved from −0.16 ± 0.10 Hz/s to −0.01 ± 0.02 Hz/s, whereas the control group improved from −0.17 ± 0.14 Hz/s to −0.12 ± 0.14 Hz/s. The group × baseline interaction was not significant for the right side.

Overall, EMG-derived fatigue outcomes indicated improved fatigue resistance after the physiotherapeutic programme. Significant baseline-adjusted between-group effects were observed for all trapezius and erector spinae fatigue variables. The strongest adjusted effects were found for the lower trapezius on the left side, the lumbar erector spinae on the left side, and the upper trapezius on the left side. In most variables, the intervention group reached slopes closer to zero after the intervention, indicating a smaller decline in median frequency during sustained contraction and therefore greater fatigue resistance. However, the significant group × baseline interactions observed for the right upper trapezius and left lumbar erector spinae indicate that these particular adjusted effects should be interpreted with caution.

4. Discussion

Our study evaluated the effects of a dedicated physiotherapeutic training programme on muscle stiffness and fatigue in administrative workers exposed to prolonged sitting. The main finding was that the intervention produced significant changes in several postural muscles, particularly in the trapezius and central erector spinae regions. The results partly supported the working hypothesis that targeted physiotherapeutic training would reduce muscle stiffness and improve fatigue resistance in muscles exposed to sustained postural loading during sedentary work.

4.1. Effects on Muscle Stiffness

Specifically, the stiffness results showed significant baseline-adjusted between-group effects for the upper trapezius, lower trapezius, and central erector spinae muscles. The strongest adjusted effect was observed for the right upper trapezius. The most pronounced interaction was observed for the right thoracic trapezius, indicating that this region was particularly responsive to the physiotherapeutic intervention. In the intervention group,

thoracic trapezius stiffness decreased bilaterally, whereas the control group showed either minimal change or increased stiffness. These findings are consistent with the assumption that the upper trapezius is one of the primary muscles affected by prolonged desk-based work, because it contributes to stabilisation of the head, neck, and shoulder girdle during sustained sitting and computer use [3,4]. The observed reduction in stiffness may reflect decreased tonic muscle overload and improved postural regulation following the intervention.

Exercises aimed at thoracic mobility, scapular stabilisation, cervical control, and shoulder-girdle strengthening may reduce excessive resting tension in the upper trapezius by improving load distribution across postural muscles. This interpretation is consistent with previous evidence indicating that prolonged static sitting is associated with increased mechanical strain and musculoskeletal symptoms in the neck, shoulder, and thoracolumbar regions [3,4]. However, for both upper trapezius variables, the group × baseline interaction was significant. Therefore, although the adjusted between-group effects were statistically significant, they should be interpreted with caution because the relationship between baseline and post-intervention stiffness differed between groups.

The lower trapezius showed a different but clinically relevant pattern. In the intervention group, stiffness remained relatively stable after training, whereas the control group showed a clear increase, particularly on the right side. After adjustment for baseline stiffness, significant between-group effects were found bilaterally, with a larger effect on the right side. This suggests that the intervention may have acted not only by reducing excessive stiffness in some muscles but also by preventing the deterioration observed in untreated participants. This distinction is important in sedentary workers, because when occupational exposure remains unchanged, the prevention of further increases in postural muscle stiffness may itself represent a meaningful therapeutic effect. In contrast to the upper trapezius, the group × baseline interaction was not significant for either lower trapezius variable, supporting a more straightforward interpretation of the ANCOVA results for these outcomes.

Significant adjusted between-group effects were also observed for the central erector spinae bilaterally. In the intervention group, stiffness decreased, whereas the control group showed slight increases. Since the thoracic portion of the erector spinae contributes to trunk extension and seated postural stability, these findings suggest that physiotherapeutic training may improve the mechanical properties of muscles responsible for maintaining upright sitting posture. This agrees with the general concept that targeted exercise can modulate muscle tone and stiffness in postural muscles exposed to sustained low-load activation. Nevertheless, as in the upper trapezius, the group × baseline interaction was significant for both central erector spinae outcomes. These results should therefore be interpreted cautiously, as baseline stiffness influenced post-intervention stiffness differently across groups.

The inferior/lumbar erector spinae showed weaker and less consistent responses. The adjusted effect on the left side approached statistical significance, whereas the right side showed no significant adjusted effect. This may indicate that the applied intervention was more effective for cervical–thoracic and thoracic postural control than for the lumbar region. It may also reflect greater inter-individual variability in lumbar loading strategies, habitual sitting asymmetry, side dominance, or the need for more specific lumbar extensor conditioning. Therefore, future protocols should consider adding more targeted lumbar stabilisation and progressive loading if lumbar stiffness is a primary therapeutic outcome.

Overall, the stiffness findings support the hypothesis that physiotherapeutic training can modify the mechanical properties of selected postural muscles in sedentary administrative workers. The most consistent baseline-adjusted effects were observed in the upper trapezius, lower trapezius, and central erector spinae, whereas the inferior erector spinae

showed the least consistent response. At the same time, the significant group × baseline interactions observed for the upper trapezius and central erector spinae indicate that these effects should be interpreted with caution. Taken together, the results suggest that the intervention may be most effective for muscles involved in cervical–thoracic and thoracic postural control, while additional or more specific exercise components may be required to produce robust changes in the lumbar region.

4.2. Effects on Muscle Fatigue

The EMG results showed that the intervention was associated with improved fatigue resistance across all analysed trapezius and erector spinae fatigue variables after adjustment for baseline values. Since less negative median frequency slopes indicate a slower decline in frequency content during sustained contraction, these findings suggest improved muscular endurance and more efficient neuromuscular performance after training. The strongest adjusted effects were observed in the trapezius muscles, particularly the left lower trapezius and the left upper trapezius, which supports the interpretation that the intervention was especially effective in muscles involved in scapular control, shoulder-girdle stabilisation, and postural support during seated work.

The largest fatigue-related adjusted effect was observed in the lower trapezius on the left side, with a substantial improvement in the intervention group and a deterioration in the control group. A significant adjusted effect was also observed on the right side. This is biomechanically plausible because the lower trapezius is important for scapular control and postural support but may be underactive or insufficiently recruited during prolonged sitting. Targeted exercises involving shoulder-girdle stabilisation, resisted external rotation, postural correction, and thoracic extension may improve the endurance capacity of this region. Improved lower trapezius function may also help reduce compensatory overload of the upper trapezius during static seated work.

The upper trapezius also showed significant baseline-adjusted improvements on both sides. On the left side, the intervention group showed a slight improvement, whereas the control group deteriorated. On the right side, the intervention group improved substantially, while the control group again showed a more negative post-intervention fatigue slope. This supports the interpretation that the intervention reduced fatigue development in muscles chronically exposed to low-load static activation. These findings are relevant because prolonged low-level contraction is a recognised mechanism contributing to perceived fatigue, discomfort, and impaired postural tolerance in office workers. The significant group × baseline interaction for the right upper trapezius suggests that the magnitude of the adjusted intervention effect varied according to baseline fatigue slope; therefore, this finding should be interpreted cautiously.

The erector spinae fatigue outcomes were also significant after baseline adjustment, although their interpretation is somewhat more nuanced. For the thoracic erector spinae, significant adjusted effects were observed bilaterally. Both groups showed less negative fatigue slopes after the intervention period, but the intervention group reached values closer to zero, suggesting a greater improvement in fatigue resistance. This may indicate that the physiotherapeutic programme improved endurance capacity in muscles responsible for trunk extension and seated postural control. It is also possible that part of the improvement observed in the control group reflected increased postural awareness after baseline testing, spontaneous behavioural changes, measurement familiarisation, or variability in endurance-task performance.

For the lumbar erector spinae, significant adjusted effects were also observed on both sides. The intervention group reached post-intervention slopes close to zero bilaterally, whereas the control group remained more negative. This suggests that the training pro-

gramme may have had a favourable effect on lumbar extensor fatigue resistance, although this effect was not uniform. In particular, the group × baseline interaction was significant for the left lumbar erector spinae, indicating that the adjusted group effect for this variable should be interpreted cautiously. The lumbar erector spinae may be more strongly influenced by individual sitting strategies, habitual asymmetry, pelvic position, and baseline endurance capacity than the trapezius muscles. Therefore, although the present results suggest beneficial changes, future protocols may require more specific lumbar strengthening, motor-control training, or longer intervention duration to produce more stable fatigue-related adaptations.

Taken together, the fatigue results support the hypothesis that dedicated physiotherapeutic training improves fatigue resistance in sedentary administrative workers. The ANCOVA results indicate significant baseline-adjusted between-group effects not only for the trapezius muscles but also for the thoracic and lumbar erector spinae. Nevertheless, the strongest and most consistent effects were observed in muscles related to scapular and cervical–thoracic postural control. The findings also indicate that not all postural muscles respond uniformly to the same intervention, which supports the need for region-specific exercise design in workplace physiotherapy. The significant group × baseline interactions observed for the right upper trapezius and left lumbar erector spinae further suggest that baseline neuromuscular status may influence responsiveness to training and should be considered in future intervention studies.

4.3. Comparison with Previous Literature

The present findings are consistent with literature indicating that prolonged sitting and static postures are associated with musculoskeletal discomfort and altered mechanical loading of the neck, shoulder, and back muscles [3,4]. They also align with studies suggesting that workplace physical activity and ergonomic interventions may improve selected musculoskeletal outcomes, although effects vary considerably according to intervention type, population, and outcome measures [16–18,25,26].

The use of myotonometry strengthens the biomechanical interpretation of the present results. Myotonometry provides non-invasive assessment of mechanical muscle properties and has been increasingly used in rehabilitation, sports science, and musculoskeletal diagnostics. Previous reviews and validation studies have indicated that myotonometric measures can reflect changes in muscle tone and stiffness and may be useful for monitoring soft-tissue responses to posture, loading, or therapeutic intervention [46–48]. In this study, myotonometry allowed detection of muscle-specific changes that would be difficult to capture using subjective pain or discomfort scales alone.

The EMG findings are also consistent with the use of median frequency slope as an indicator of muscle fatigue. A shift toward less negative slopes after intervention suggests a slower development of fatigue during sustained contraction. In practical terms, this may indicate improved endurance capacity of postural muscles. Although significant baseline-adjusted effects were observed for both trapezius and erector spinae fatigue outcomes, the interpretation of selected variables should remain cautious where significant group × baseline interactions were detected.

Compared with previous workplace intervention studies, the present study contributes by combining physiotherapeutic training with objective biomechanical outcomes. Many workplace health studies rely primarily on self-reported pain, well-being, productivity, or general physical activity indicators. Although such outcomes are important, they do not directly quantify changes in muscle mechanical properties or fatigue behaviour. The present results therefore provide additional evidence that targeted exercise may produce measurable neuromuscular adaptations in sedentary employees.

4.4. Practical Implications

The findings support the practical value of structured physiotherapeutic programmes for office and administrative workers. The most consistent improvements were observed in the trapezius and central erector spinae, suggesting that workplace interventions should prioritise muscles involved in head, shoulder-girdle, and thoracic postural control. Such programmes may include thoracic mobility, scapular stabilisation, cervical motor-control exercises, stretching, and endurance-based strengthening.

For physiotherapists and occupational health practitioners, the results indicate that interventions should be tailored to the biomechanical demands of sedentary work rather than limited to general physical activity advice. The differential responses between muscle regions suggest that assessment-based exercise prescription may be preferable to uniform workplace exercise protocols. In particular, employees with elevated trapezius stiffness or fatigue may benefit from targeted scapular and cervical–thoracic training.

The results may also have relevance for workplace health promotion. Musculoskeletal symptoms are associated with impaired well-being, reduced work ability, absenteeism, and presenteeism [28–32]. Although the present study did not directly assess productivity or mental health outcomes, reductions in biomechanical indicators of stiffness and fatigue may contribute to improved comfort and functional tolerance during desk work. Therefore, physiotherapeutic training could be considered as one component of broader workplace wellness and ergonomics strategies.

However, claims about productivity, stress reduction, or long-term behavioural change should remain cautious in this manuscript unless these outcomes were directly measured. The present study provides evidence for biomechanical and neuromuscular effects, not direct evidence for improved work performance or psychological well-being.

4.5. Limitations and Future Research

This study has several limitations. First, the sample size was relatively small, which may limit statistical power and generalisability. Second, the study included only female administrative workers, so the findings cannot be directly generalised to male employees, mixed occupational groups, or workers with different physical demands. Third, allocation to groups was not randomised, which increases the risk of selection bias. Participants in the intervention group may have differed from controls in motivation, availability, or readiness to participate in exercise. Although ANCOVA was used to adjust post-intervention outcomes for baseline values, this approach cannot fully account for unmeasured differences between groups; therefore, the findings should be interpreted as baseline-adjusted between-group differences rather than definitive causal effects. Fourth, the intervention duration was relatively short. Although significant changes were observed, longer programmes with follow-up measurements are needed to determine whether these effects represent stable neuromuscular adaptations rather than short-term responses. This may be particularly relevant for the lumbar erector spinae, where stronger or more specific adaptations may require a longer intervention period. Fifth, surface EMG is sensitive to electrode placement, skin preparation, subcutaneous tissue thickness, and signal-processing decisions. Although standardised procedures were used, some measurement variability cannot be excluded. Sixth, the study did not include participant blinding, and the control group received no sham or alternative intervention. This limits control over expectancy effects and behavioural changes induced by study participation.

Given the short intervention period and non-randomised allocation, the observed changes should be interpreted as preliminary short-term responses rather than definitive evidence of stable neuromuscular adaptation. Familiarisation with the exercises or testing procedures, increased postural awareness, or behavioural changes during the study period

may also have contributed to the observed effects. Future studies should use randomised allocation, larger and more diverse samples, longer intervention periods, and follow-up measurements to determine whether the observed effects are sustained. Future research should also include subjective outcomes such as discomfort, pain intensity, work ability, and perceived fatigue, together with objective measures such as EMG and myotonometry. This would allow stronger conclusions about the relationship between biomechanical adaptation and perceived occupational health benefits.

5. Conclusions

A dedicated physiotherapeutic training programme was associated with significant improvements in selected biomechanical indicators of postural muscle function in sedentary administrative workers. Muscle stiffness decreased or was stabilised in several regions, with the strongest baseline-adjusted effects observed in the upper trapezius, lower trapezius, and central erector spinae. EMG-derived fatigue indices also improved after training, with significant adjusted effects observed for both trapezius and erector spinae muscles, indicating enhanced fatigue resistance in several postural muscle regions.

These findings suggest that targeted physiotherapeutic exercise may help counteract selected biomechanical consequences of prolonged sitting in administrative workers. The muscle-specific pattern of responses indicates that such programmes should be designed with attention to the anatomical regions most exposed to sustained postural load. Given the non-randomised design and baseline-dependent effects observed for some outcomes, these results should be treated as preliminary. Larger randomised studies with longer follow-up are needed to verify whether the observed biomechanical changes translate into sustained clinical and occupational benefits.

Author Contributions: Conceptualisation, S.W. and D.M.-W.; methodology, S.W.; software, S.W.; validation, S.W. and D.M.-W.; formal analysis, S.W. and D.M.-W.; investigation, S.W. and D.M.-W.; resources, D.M.-W.; data curation, S.W.; writing—original draft preparation, S.W. and D.M.-W.; writing—review and editing, S.W. and D.M.-W.; visualisation, S.W.; supervision, S.W. and D.M.-W.; project administration, D.M.-W.; funding acquisition, S.W. and D.M.-W. All authors have read and agreed to the published version of the manuscript.

Funding: This research was financed by the Ministry of Science and Higher Education in Poland under the "Regional Initiative of Excellence" programme 2019–2022, project number 015/RID/2018/19.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Rector's Commission on Research Ethics at the Wroclaw University of Economics and Business, Poland (Decision no. 44/2024), issued on 12 December 2024. The laboratory procedures were performed in accordance with the PN-EN ISO 9001-certified quality management system. The trial was registered under the Australian New Zealand Clinical Trials Registry number ACTRN12624001311549.

Informed Consent Statement: Written informed consent was obtained from all subjects involved in the study before participation.

Data Availability Statement: The datasets generated and analysed during the current study are available from the corresponding author upon reasonable request. Public deposition of the raw individual-level data is restricted because the dataset contains information obtained from human participants. Any data shared will be pseudonymised before release and provided in accordance with applicable ethical and data-protection requirements. The physiotherapeutic training protocol and measurement procedures are described in the manuscript with sufficient detail to allow replication.

Acknowledgments: The authors would like to thank the university staff for their organisational and technical support during the study. The authors also thank all participants for their time, commitment, and cooperation throughout the research procedures. During the preparation of this manuscript, the

authors used ChatGPT (OpenAI, San Francisco, CA, USA; GPT-5.5 Thinking) exclusively for language editing, structural refinement, and formatting support, and Grammarly (Superhuman Platform Inc., San Francisco, CA, USA) for grammar, spelling, and punctuation checking. The authors reviewed and edited the output and take full responsibility for the content of this publication.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Abbreviations

The following abbreviations are used in this manuscript:

PT	Physiotherapeutic training
sEMG	Surface electromyography
EMG	Electromyography
VAS	Visual Analogue Scale for Pain
ANOVA	Analysis of variance
SD	Standard deviation
CI	Confidence interval
WMSDs	Work-related musculoskeletal disorders
ISO	International Organization for Standardization
PN-EN ISO 9001	Polish and European implementation of ISO 9001 quality management system quality standard

References

1. World Health Organization. Nearly 1.8 Billion Adults at Risk of Disease from Not Doing Enough Physical Activity. Available online: https://www.who.int/news/item/26-06-2024-nearly-1.8-billion-adults-at-risk-of-disease-from-not-doing-enough-physical-activity (accessed on 19 May 2026).
2. Eurostat. Actual and Usual Hours of Work. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Actual_and_usual_hours_of_work (accessed on 19 May 2026).
3. Bontrup, C.; Taylor, W.R.; Fliesser, M.; Visscher, R.; Green, T.; Wippert, P.-M.; Zemp, R. Low Back Pain and Its Relationship with Sitting Behaviour among Sedentary Office Workers. *Appl. Ergon.* **2019**, *81*, 102894. [CrossRef] [PubMed]
4. Davis, K.G.; Kotowski, S.E.; Daniel, D.; Gerding, T.; Naylor, J.; Syck, M. The Home Office: Ergonomic Lessons From the "New Normal". *Ergon. Des. Q. Hum. Factors Appl.* **2020**, *28*, 4–10. [CrossRef] [PubMed]
5. Chaudhary, N.; Jones, M.; Rice, S.P.M.; Zeigen, L.; Thosar, S.S. Transitioning to Working from Home Due to the COVID-19 Pandemic Significantly Increased Sedentary Behavior and Decreased Physical Activity: A Meta-Analysis. *Int. J. Environ. Res. Public Health* **2024**, *21*, 851. [CrossRef] [PubMed]
6. Kett, A.R.; Milani, T.L.; Sichting, F. Sitting for Too Long, Moving Too Little: Regular Muscle Contractions Can Reduce Muscle Stiffness During Prolonged Periods of Chair-Sitting. *Front. Sports Act. Living* **2021**, *3*, 760533. [CrossRef] [PubMed]
7. Kett, A.R.; Sichting, F. Sedentary Behaviour at Work Increases Muscle Stiffness of the Back: Why Roller Massage Has Potential as an Active Break Intervention. *Appl. Ergon.* **2020**, *82*, 102947. [CrossRef] [PubMed]
8. Sipko, T.; Barczyk-Pawelec, K.; Piksa, M.; Mencel, J. Impact of Standing and Sitting Postures on Spinal Curvature and Muscle Mechanical Properties in Young Women: A Photogrammetric and MyotonPro Analysis. *Med. Sci. Monit.* **2024**, *30*, e944930. [CrossRef] [PubMed]
9. Daneshmandi, H.; Choobineh, A.R.; Ghaem, H.; Alhamd, M.; Fakherpour, A. The Effect of Musculoskeletal Problems on Fatigue and Productivity of Office Personnel: A Cross-Sectional Study. *J. Prev. Med. Hyg.* **2017**, *58*, E252. [PubMed]
10. Abdin, S.; Welch, R.K.; Byron-Daniel, J.; Meyrick, J. The Effectiveness of Physical Activity Interventions in Improving Well-Being across Office-Based Workplace Settings: A Systematic Review. *Public Health* **2018**, *160*, 70–76. [CrossRef] [PubMed]
11. Conn, V.S.; Hafdahl, A.R.; Cooper, P.S.; Brown, L.M.; Lusk, S.L. Meta-Analysis of Workplace Physical Activity Interventions. *Am. J. Prev. Med.* **2009**, *37*, 330–339. [CrossRef] [PubMed]
12. Brown, H.E.; Gilson, N.D.; Burton, N.W.; Brown, W.J. Does Physical Activity Impact on Presenteeism and Other Indicators of Workplace Well-Being? *Sports Med.* **2011**, *41*, 249–262. [CrossRef] [PubMed]
13. Rathi, M.; Joshi, R.; Munot, P.V. Effect of Mini-Trampoline Exercises on Body Composition, Reaction Time and Motor Proficiency in Overweight and Obese Adolescents—A Randomised Controlled Trial. *Physiother. Q.* **2026**, *34*, 31–36. [CrossRef]

14. Rodrigues Matos, A.; Siqueira Ribeiro, H.; De Luca Corrêa, H.; Pimentel Ferreira, A.; Vieira, E. Strength Training Promotes Anthropometric and Functional Benefits in Sedentary Subjects: Does a Personal Trainer Matter? *Hum. Mov.* **2021**, *22*, 20–27. [CrossRef]
15. Clemente, F.M.; González-Fernández, F.T.; Ceylan, H.I.; Silva, R.; Ramirez-Campillo, R. Effects of Recreational Soccer on Fat Mass in Untrained Sedentary Adults: A Systematic Review with Meta-Analysis. *Hum. Mov.* **2021**, *23*, 15–32. [CrossRef]
16. Abraham, C.; Graham-Rowe, E. Are Worksite Interventions Effective in Increasing Physical Activity? A Systematic Review and Meta-Analysis. *Health Psychol. Rev.* **2009**, *3*, 108–144. [CrossRef]
17. Buckley, J.P.; Hedge, A.; Yates, T.; Copeland, R.J.; Loosemore, M.; Hamer, M.; Bradley, G.; Dunstan, D.W. The Sedentary Office: An Expert Statement on the Growing Case for Change towards Better Health and Productivity. *Br. J. Sports Med.* **2015**, *49*, 1357–1362. [CrossRef] [PubMed]
18. Parry, S.P.; Coenen, P.; Shrestha, N.; O'Sullivan, P.B.; Maher, C.G.; Straker, L.M. Workplace Interventions for Increasing Standing or Walking for Decreasing Musculoskeletal Symptoms in Sedentary Workers. *Cochrane Database Syst. Rev.* **2019**, *2019*, CD012487. [CrossRef] [PubMed]
19. Kallings, L.V.; Blom, V.; Ekblom, B.; Holmlund, T.; Eriksson, J.S.; Andersson, G.; Wallin, P.; Ekblom-Bak, E. Workplace Sitting Is Associated with Self-Reported General Health and Back/Neck Pain: A Cross-Sectional Analysis in 44,978 Employees. *BMC Public. Health* **2021**, *21*, 875. [CrossRef] [PubMed]
20. Grande, A.J.; Cieslak, F.; Silva, V. Workplace Exercise for Changing Health Behavior Related to Physical Activity. *Work* **2016**, *53*, 479–484. [CrossRef] [PubMed]
21. Hamilton, K.; Fraser, E.; Hannan, T. Habit-Based Workplace Physical Activity Intervention: A Pilot Study. *Occup. Med.* **2019**, *69*, 471–474. [CrossRef] [PubMed]
22. Sjøgaard, G.; Christensen, J.R.; Justesen, J.B.; Murray, M.; Dalager, T.; Fredslund, G.H.; Søgaard, K. Exercise Is More than Medicine: The Working Age Population's Well-Being and Productivity. *J. Sport Health Sci.* **2016**, *5*, 159–165. [CrossRef] [PubMed]
23. Díaz-Benito, V.J.; Moro, M.I.B.; Vanderhaegen, F.; Remón, Á.L.C.; Lozano, J.A.S.; Fernández-Pola, E.C.; Pérez, J.P.H. Intervention of Physical Exercise in the Workplace on Work Ability, Depression, Anxiety and Job Satisfaction in Workers with Sedentary Tasks. *Work* **2022**, *72*, 921–931. [CrossRef] [PubMed]
24. Vitoulas, S.; Konstantis, V.; Drizi, I.; Vrouva, S.; Koumantakis, G.A.; Sakellari, V. The Effect of Physiotherapy Interventions in the Workplace through Active Micro-Break Activities for Employees with Standing and Sedentary Work. *Healthcare* **2022**, *10*, 2073. [CrossRef] [PubMed]
25. Lu, L.; Megahed, F.M.; Cavuoto, L.A. Interventions to Mitigate Fatigue Induced by Physical Work: A Systematic Review of Research Quality and Levels of Evidence for Intervention Efficacy. *Hum. Factors J. Hum. Factors Ergon. Soc.* **2021**, *63*, 151–191. [CrossRef] [PubMed]
26. Hoe, V.C.W.; Urquhart, D.M.; Kelsall, H.L.; Zamri, E.N.; Sim, M.R. Ergonomic Interventions for Preventing Work-Related Musculoskeletal Disorders of the Upper Limb and Neck among Office Workers. *Cochrane Database Syst. Rev.* **2018**, *2018*, CD008570. [CrossRef] [PubMed]
27. Sundstrup, E.; Seeberg, K.G.V.; Bengtsen, E.; Andersen, L.L. A Systematic Review of Workplace Interventions to Rehabilitate Musculoskeletal Disorders Among Employees with Physical Demanding Work. *J. Occup. Rehabil.* **2020**, *30*, 588–612. [CrossRef] [PubMed]
28. Chen, G.; Wu, J.; Chen, G.; Lu, Y.; Ren, W.; Xu, W.; Xu, X.; Wu, Z.; Guan, Y.; Zheng, Y.; et al. Reliability of a Portable Device for Quantifying Tone and Stiffness of Quadriceps Femoris and Patellar Tendon at Different Knee Flexion Angles. *PLoS ONE* **2019**, *14*, e0220521. [CrossRef] [PubMed]
29. Garcia-Bernal, M.I.; Heredia-Rizo, A.M.; Gonzalez-Garcia, P.; Cortés-Vega, M.D.; Casuso-Holgado, M.J. Validity and Reliability of Myotonometry for Assessing Muscle Viscoelastic Properties in Patients with Stroke: A Systematic Review and Meta-Analysis. *Sci. Rep.* **2021**, *11*, 5062. [CrossRef] [PubMed]
30. Lettner, J.; Królikowska, A.; Ramadanov, N.; Oleksy, Ł.; Hakam, H.T.; Becker, R.; Prill, R. Evaluating the Reliability of MyotonPro in Assessing Muscle Properties: A Systematic Review of Diagnostic Test Accuracy. *Medicina* **2024**, *60*, 851. [CrossRef] [PubMed]
31. Crombie, K.M.; Almassi, N.E.; Leitzelar, B.N.; Koltyn, K.F. Sedentary Behavior And Physical Function In Older Adults Following A Randomized Controlled Sedentary Behavior Intervention. *Med. Sci. Sports Exerc.* **2020**, *52*, 741. [CrossRef]
32. Barwais, F.A.; Cuddihy, T.F.; Tomson, L.M. Physical Activity, Sedentary Behavior and Total Wellness Changes among Sedentary Adults: A 4-Week Randomized Controlled Trial. *Health Qual. Life Outcomes* **2013**, *11*, 183. [CrossRef] [PubMed]
33. Haşıl Korkmaz, N.; Çoruh, H. Time to Move: A 4-Week Gamified Mobile Application Intervention to Promote Physical Activity in Secondary School Students. *Eur. J. Sport Sci.* **2025**, *25*, e70027. [CrossRef] [PubMed]
34. Van Hoye, K.; Boen, F.; Lefevre, J. The Impact of Different Degrees of Feedback on Physical Activity Levels: A 4-Week Intervention Study. *Int. J. Environ. Res. Public Health* **2015**, *12*, 6561–6581. [CrossRef] [PubMed]
35. Hermens, H.J.; Freriks, B.; Disselhorst-Klug, C.; Rau, G. Development of Recommendations for SEMG Sensors and Sensor Placement Procedures. *J. Electromyogr. Kinesiol.* **2000**, *10*, 361–374. [CrossRef] [PubMed]

36. Feng, Y.; Grooten, W.; Wretenberg, P.; Arborelius, U.P. Effects of Arm Support on Shoulder and Arm Muscle Activity during Sedentary Work. *Ergonomics* **1997**, *40*, 834–848. [CrossRef] [PubMed]
37. Gao, Y.; Silvennoinen, M.; Pesola, A.J.; Kainulainen, H.; Cronin, N.J.; Finni, T. Acute Metabolic Response, Energy Expenditure, and EMG Activity in Sitting and Standing. *Med. Sci. Sports Exerc.* **2017**, *49*, 1927–1934. [CrossRef] [PubMed]
38. Pesola, A.J.; Laukkanen, A.; Tikkanen, O.; Finni, T. Heterogeneity of Muscle Activity during Sedentary Behavior. *Appl. Physiol. Nutr. Metab.* **2016**, *41*, 1155–1162. [CrossRef] [PubMed]
39. Merletti, R.; Botter, A.; Cescon, C.; Minetto, M.A.; Vieira, T.M.M. Advances in Surface EMG: Recent Progress in Clinical Research Applications. *Crit. Rev. Biomed. Eng.* **2010**, *38*, 347–379. [CrossRef] [PubMed]
40. Beretta-Piccoli, M.; Cescon, C.; D'Antona, G. Evaluation of Performance Fatigability through Surface EMG in Health and Muscle Disease: State of the Art. *Arab. J. Basic. Appl. Sci.* **2021**, *28*, 21–40. [CrossRef]
41. Rampichini, S.; Vieira, T.M.; Castiglioni, P.; Merati, G. Complexity Analysis of Surface Electromyography for Assessing the Myoelectric Manifestation of Muscle Fatigue: A Review. *Entropy* **2020**, *22*, 529. [CrossRef] [PubMed]
42. Muckelt, P.E.; Warner, M.B.; Cheliotis-James, T.; Muckelt, R.; Hastermann, M.; Schoenrock, B.; Martin, D.; MacGregor, R.; Blottner, D.; Stokes, M. Protocol and Reference Values for Minimal Detectable Change of MyotonPRO and Ultrasound Imaging Measurements of Muscle and Subcutaneous Tissue. *Sci. Rep.* **2022**, *12*, 13654. [CrossRef] [PubMed]
43. Agyapong-Badu, S.; Aird, L.; Bailey, L.; Mooney, K.; Mullix, J.; Warner, M.; Samuel, D.; Stokes, M. Interrater Reliability of Muscle Tone, Stiffness and Elasticity Measurements of Rectus Femoris and Bi-Ceps Brachii in Healthy Young and Older Males. *Work. Pap. Health Sci.* **2013**, *1*, 1–11.
44. Nguyen, A.P.; Detrembleur, C.; Fisette, P.; Selves, C.; Mahaudens, P. MyotonPro Is a Valid Device for Assessing Wrist Biomechanical Stiffness in Healthy Young Adults. *Front. Sports Act. Living* **2022**, *4*, 40. [CrossRef] [PubMed]
45. Trybulski, R.; Kużdżał, A.; Wilk, M.; Więckowski, J.; Fostiak, K.; Muracki, J. Reliability of MyotonPro in Measuring the Biomechanical Properties of the Quadriceps Femoris Muscle in People with Different Levels and Types of Motor Preparation. *Front. Sports Act. Living* **2024**, *6*, 1453730. [CrossRef] [PubMed]
46. McGowen, J.M.; Hoppes, C.W.; Forsse, J.S.; Albin, S.R.; Abt, J.; Koppenhaver, S.L. The Utility of Myotonometry in Musculoskeletal Rehabilitation and Human Performance Programming. *J. Athl. Train.* **2023**, *58*, 305–318. [CrossRef] [PubMed]
47. Melo, A.S.C.; Cruz, E.B.; Vilas-Boas, J.P.; Sousa, A.S.P. Scapular Dynamic Muscular Stiffness Assessed through Myotonometry: A Narrative Review. *Sensors* **2022**, *22*, 2565. [CrossRef] [PubMed]
48. Li, X.; Shin, H.; Li, S.; Zhou, P. Assessing Muscle Spasticity with Myotonometric and Passive Stretch Measurements: Validity of the Myotonometer. *Sci. Rep.* **2017**, *7*, 44022. [CrossRef] [PubMed]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.