Original Article

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Investigation of the Viscoelastic Properties of Selected Upper Extremity and Cervical Muscles and Movement-based Reaction Time in University Students with Smartphone Addiction

Akıllı Telefon Bağımlılığı Olan Üniversite Öğrencilerinde Seçilmiş Üst Ekstremite ve Servikal Kasların Viskoelastik Özellikleri ile Hareket Temelli Reaksiyon Sürelerinin İncelenmesi

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ABSTRACT

Objective: The aim of this study was to evaluate the relationship between smartphone addiction and the viscoelastic properties (tone, stiffness, elasticity) of selected upper extremity and cervical muscles and movement-based reaction time in university students.

Methods: This cross-sectional study included 216 university students. Participants were divided into addicted and non-addicted groups using the Smartphone Addiction Scale-Short Version (cut-off score: males ≥31, females ≥33). Muscle viscoelastic properties were assessed using the MyotonPRO device, and movement-based reaction time was evaluated via the SWAY application.

Results: Mostly low-level but significant positive correlations were found between muscle viscoelastic properties, screen time, and SWAY average scores. Moderate correlations were

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Amaç: Bu çalışmanın amacı, üniversite öğrencilerinde akıllı telefon bağımlılığı ile seçilmiş üst ekstremite ve servikal kasların viskoelastik özellikleri (tonus, sertlik, elastikiyet) ve hareket temelli reaksiyon süresi arasındaki ilişkiyi değerlendirmektir.

Yöntem: Bu kesitsel çalışmaya 216 üniversite öğrencisi dahil edilmiştir. Katılımcılar, Akıllı Telefon Bağımlılığı Ölçeği-Kısa Formu kullanılarak (kesme puanı erkek için ≥31, kadın için ≥33) bağımlı ve bağımlı olmayan gruplara ayrılmıştır. Kas viskoelastik özellikleri MyotonPRO cihazı kullanılarak değerlendirilmiş, hareket temelli reaksiyon süresi ise SWAY uygulaması aracılığıyla değerlendirildi.

Bulgular: Kasların viskoelastik özellikleri, ekran süresi ve SWAY ortalama puanları arasında çoğunlukla düşük düzeyde ancak istatistiksel olarak anlamlı pozitif yönde korelasyon bulundu. Fleksör karpi ulnaris ve ekstansör karpi radialis kaslarının bazı

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ABSTRACT

observed between some parameters of the flexor carpi ulnaris and extensor carpi radialis muscles and both the SWAY average and daily screen time.

Conclusion: Smartphone addiction was associated with changes in selected muscle viscoelastic properties, while only weak associations with movement-based reaction time were observed. These findings suggest that excessive smartphone use may be related to minimal neuromuscular adaptations rather than clinically definitive impairments.

Keywords: Muscle viscoelasticity, reaction time, smartphone addiction, university students

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parametreleri ile SWAY ortalama puanı hem de günlük ekran süresi arasında orta düzeyde korelasyonlar gözlendi.

Sonuç: Akıllı telefon bağımlılığı, seçilmiş kasların viskoelastik özelliklerindeki değişikliklerle ilişkili bulunurken, hareket temelli reaksiyon süresi ile yalnızca zayıf düzeyde ilişkiler gözlendi. Bu bulgular, aşırı akıllı telefon kullanımının klinik olarak belirgin bozukluklardan ziyade minimal nöromüsküler adaptasyonlarla ilişkili olabileceğini düşündürmektedir.

Anahtar Kelimeler: Kas viskoelastik özellikleri, reaksiyon süresi, akıllı telefon bağımlılığı, üniversite öğrencileri

Introduction

Smartphone use has increased rapidly worldwide over the past decade, driven by continuous technological advancements. The widespread adoption of smartphones has extended across both high-income and low- and middle-income countries, reflecting the growing accessibility and integration of mobile technologies into everyday life (1,2). Especially among young individuals, smartphones have become an integral part of daily life (3). Browsing the internet, social media applications, mobile games, and high-resolution screen features encourage prolonged usage of these devices, potentially leading to addiction-level usage (4).

Among young adults such as university students, the increasing frequency and duration of smartphone use has been associated with musculoskeletal pain and discomfort (4). Factors such as maintaining the same posture for extended periods, performing repetitive movements, and focusing on screens positioned below eye level contribute to increased mechanical load on the upper extremity and cervical musculoskeletal system (5). Continuous use of shoulder, forearm, and wrist muscles in this manner may increase the risk of musculoskeletal disorders and functional impairment of the upper extremity (6,7). Sharan et al. (7) reported that prolonged device usage was associated with musculoskeletal disorders in the upper extremity. Ha and Sung (8) reported that temporary forward head posture reduced cervical proprioceptive function. Son et al. (9) found that smartphone use exceeding 15 minutes negatively affected the viscoelastic properties of the masseter and digastric muscles.

These types of chronic musculoskeletal loadings can eventually lead to decreased movement efficiency and reduced functional capacity (10). Furthermore, movement-based reaction time, defined as the individual's response time to environmental stimuli, is closely related to neuromuscular coordination (11). Gada and Dhasal (12), in a study involving individuals aged 18-25, found no significant correlation between difference between smartphone screen time and reaction time. However, Jiménez-García et al. (13) found that muscle strength and physical performance were significantly associated with reaction time in older adults. Impaired sensorimotor control may adversely affect postural stability and movement performance (14).

Although previous studies have separately investigated the musculoskeletal effects of smartphone use (15,16) or its relationship with reaction time (11-13), no previous study has simultaneously examined the association between smartphone addiction, upper extremity muscle viscoelastic properties, and movement-based reaction time. In light of this information, the aim of this study is to evaluate the viscoelastic properties (tone, stiffness, elasticity) of selected upper extremity and cervical muscles and movement-based reaction times in university students with smartphone addiction, and to investigate the relationship between these variables. We hypothesized that higher levels of smartphone addiction would be associated with increased muscle tone and stiffness, decreased muscle elasticity, and prolonged movement-based reaction time.

Methods

This cross-sectional study was conducted in the practice laboratory of the Department of Physiotherapy and Rehabilitation, Faculty of Health Sciences, SANKO University. The study sample consisted of volunteer students from the Faculty of Health Sciences at SANKO University. Prior to the start of the study, ethical approval was obtained from the Non-Interventional Ethics Committee of SANKO University in accordance with the principles of the Declaration of Helsinki (decision no: 2025/03, date: 12.03.2025).

The study procedures were explained in detail to the participants, and written informed consent was obtained from all individuals. The entire research process adhered to the principles of the Strengthening the Reporting of Observational Studies in Epidemiology guideline. Sociodemographic data of the participants were collected using a personal information form developed by the researchers. Dominant upper extremity was determined based on participants' self-report (17). Daily and weekly screen time was recorded by checking the "settings" section of the participants' smartphones. In addition, the screen sizes of the phones were measured diagonally from the bottom-left to the top-right corner using a measuring tape, and results were calculated in both centimeters and inches. Participants' habitual physical activity level, ergonomic posture during smartphone use, and habitual sitting posture were not quantitatively assessed and therefore were not included in the statistical analyses. Inclusion criteria were: being between 18-35 years old, having used a touchscreen smartphone for at least 1 year, and using the smartphone for more than 60 minutes daily (18). Exclusion criteria included: having a neurological, rheumatological, or musculoskeletal disease or cognitive impairment; having had an upper extremity injury or surgery within the past 6 months; a body mass index >35 kg/m²; participation in an upper extremity exercise program within the past 6 months; presence of joint contracture in the upper extremity; inability to comply with the assessment protocol; incomplete participation; or refusal to participate in the study. To determine the level of smartphone addiction, the Smartphone Addiction Scale-Short Version (SAS-SV) was used. According to this scale, the cut-off score was ≥31 for males and ≥33 for females. Based on the results, participants were divided into two groups: addicted and non-addicted (19). The viscoelastic properties (tone, stiffness, elasticity) of the upper extremity muscles were assessed using the MyotonPRO device (Myoton Ltd., Tallinn, Estonia) (20). Movement-based reaction times were measured using the validated SWAY mobile application (21). The SWAY Cognitive Assessment application has been shown to provide valid and reliable movement-based reaction time measurements (22). VanRavenhorst-Bell et al. (22) demonstrated that SWAY reaction time metrics were comparable with the FDA-approved ImPACT Quick Test and operated reliably across different mobile devices and operating systems. The authors further reported that the motion-based, triaxial accelerometer system used by SWAY minimizes device latency and allows highly sensitive detection of sensorimotor responses, supporting its use for evaluating reaction time in research settings (22). During the assessment, participants were tested in a standardized upright standing position, holding the smartphone with both hands at chest level. Reaction time was evaluated using visually presented stimuli only, and participants were instructed to respond to the appearance of the stimulus on the screen as quickly as possible (21,22). To ensure data confidentiality, each participant was assigned a code number. Data were organized in Microsoft Excel and were accessible only to members of the research team.

SAS-SV

The level of smartphone addiction was assessed using the SAS-SV, developed by Kwon et al. (19) and adapted into Turkish by Noyan et al. (23). The scale consists of 10 items scored on a six-point Likert scale. Higher scores indicate an increased risk of smartphone addiction. Necessary permissions for the use of the scale were obtained Based on gender-specific cut-off scores, participants were divided into two groups: "addicted" and "non-addicted" (19,23).

Assessment of Muscle Viscoelastic Properties

The viscoelastic properties (tone, stiffness, and elasticity) of selected upper extremity and cervical muscles were evaluated using the MyotonPRO device (Myoton Ltd., Tallinn, Estonia), a non-invasive and digital measurement tool (20). This device enables objective evaluation of the mechanical properties of muscles, tendons, ligaments, skin, and other superficial soft tissues (20). Previous studies have demonstrated high intra-rater, inter-rater, and test-retest reliability for MyotonPRO measurements. A recent systematic review reported good to excellent reliability across different muscles and anatomical regions, with intraclass correlation coefficient (ICC) values ranging from -0.15 to 0.99 (24). In addition, Valenti et al. (25) showed good to excellent intra-rater (ICC: 0.88-0.91) and inter-rater reliability (ICC: 0.84-0.96) for lumbar erector spinae stiffness measurements using MyotonPRO.

The measurements obtained from the MyotonPRO were based on the following three core parameters: muscle tone (Hz); indicates the basic tension level of the muscle at rest. Stiffness (N/m); reflects the biomechanical resistance of the tissue to external force. Elasticity; refers to the speed at which tissue returns to its original shape after deformation, measured by the logarithmic decrement of oscillation (26). The following muscles were evaluated bilaterally using the MyotonPRO device: semispinalis capitis, biceps brachii, brachioradialis, extensor digitorum, extensor carpi radialis, flexor carpi radialis, and flexor carpi ulnaris. Measurement sites for all muscles were identified according to previously published anatomical protocols, and the anatomical landmarks and measurement procedures were applied as originally described in these studies (26,27).

All MyotonPRO assessments were performed after a 3-5-minute rest period while participants were seated in a standardized upright position. During the measurements, participants sat comfortably on a chair with the shoulder in a neutral position, the elbow flexed to 90°, the forearm resting on a support, and the wrist maintained in a neutral position to ensure complete muscle relaxation and to minimize involuntary muscle activation. Three consecutive measurements were obtained from each muscle, and the mean value was used for statistical analysis. All measurements were performed by the same experienced physiotherapist while the target muscles remained in a relaxed, passive state. To minimize order effects, both the sequence of muscle assessments and the dominant-non-dominant side measurement order were randomized for each participant. Measurement sites were determined according to previously published anatomical protocols (26-28).

Ethics Committee

This study was approved by the Non-Interventional Ethics Committee of SANKO University as item number 1 on the agenda of meeting number 2025/03, held on March 12, 2025.

Statistical Analysis

According to the power analysis, assuming $\alpha=0.05$ and $1-\beta$ (power) $=0.80$, and based on a 4.7-point difference in Smartphone Addiction Scale scores between group 1 (26.9±10.8) and group 2 (31.6±11.3), a minimum of 87 participants per group was required, for a total sample size of 174 university students (29). The sample size was calculated using the NCSS PASS 13 software. In addition, a post-hoc power analysis was conducted using the OpenEpi software (version 3) based on the observed group differences in right brachioradialis muscle tone (15.27±2.21 vs. 16.16±2.39). The achieved statistical power was 81.16%, confirming that the sample size was sufficient to detect meaningful differences in muscle viscoelastic properties (30). Descriptive statistics were presented as mean and standard deviation or median and minimum-maximum values for numerical variables, and frequencies and percentages for categorical variables. The Shapiro-Wilk test was used to assess the normality of numerical variables. Since parametric test assumptions were not met, the Mann-Whitney U test was used to compare two independent groups for numerical variables. The chi-square test was used to compare categorical variables. Relationships between two numerical variables were assessed using Spearman's rank correlation coefficient. A significance level of $p<0.05$ was considered statistically significant. All data were analyzed using IBM SPSS Statistics 23 software (31). Interpretation of Spearman correlation coefficients was as follows (32): 0.00-0.10: very weak or negligible correlation, 0.10-0.39: weak correlation, 0.40-0.69: moderate correlation, 0.70-0.89: strong correlation, 0.90-1.00: very strong correlation. Given the large number of statistical comparisons performed across multiple muscles, parameters (tone, stiffness, elasticity), sides (right/left), and sex-stratified analyses (total, male, female), the risk of type I error inflation was addressed using false discovery rate correction. Specifically, the Benjamini-Hochberg procedure was applied to the p-values obtained from each family of related tests. For each muscle, p-values from the total sample and sex-specific comparisons were adjusted within that muscle, rather than across all tests, in order to preserve anatomical and physiological interpretability while adequately controlling for multiple testing. Adjusted p-values (q-values) <0.05 were considered statistically significant. Statistically significant adjusted p-values are presented in bold in the tables (33,34).

Results

Demographic Characteristics of the Participants

A total of 216 university students were included in the study, of whom 51.9% were classified as smartphone-addicted. There were no statistically significant differences between the smartphone-addicted and non-addicted groups in terms of age, gender distribution, or dominant upper extremity (all $p>0.05$) (Table 1).

Viscoelastic Properties of the Participants' Muscles

Overall, most upper extremity muscle viscoelastic parameters did not differ significantly between the smartphone-addicted and non-addicted groups. Statistically significant between-group differences were limited to muscle tone in selected distal upper extremity muscles, including the brachioradialis, extensor digitorum, biceps brachii, flexor carpi radialis, and extensor carpi radialis. In addition, left-side muscle stiffness of the extensor carpi radialis was significantly higher in the smartphone-addicted group. These findings were more pronounced among female participants. Detailed numerical results are presented in (Table 1; Supplementary Table 1).

The Relationship Between the Viscoelastic Properties of Participants' Muscles and Movement-based Reaction Times

Spearman correlation analysis revealed that most associations between screen time, viscoelastic muscle properties, and movement-based reaction time were statistically significant but weak in magnitude. In addition, weak to moderate correlations were observed between movement-based reaction time and upper extremity muscle tone and stiffness; however, these associations were modest in magnitude Table 2; Supplementary Table 2 A-C.

Discussion

This study aimed to reveal the relationship between smartphone addiction, muscle viscoelastic properties, and movement-based reaction time in university students. Smartphone addiction was associated with selective differences in muscle tone in specific upper extremity muscles; however, given the cross-sectional design of the study, these findings should be interpreted as associative rather than causal.

These findings suggest that, even in young adults, smartphone use may be associated with early and subtle changes in muscle biomechanics. However, because of the cross-sectional design, these observations should be interpreted as preliminary associations rather than clinically definitive effects.

Table 1. Comparison of variables according to smartphone addiction in all participants

Variables			Non-smartphone-addicted (n=104)			Smartphone-addicted (n=112)			Total	Male	Female
			Total mean ± SD (min-max)	Male mean ± SD (min-max)	Female mean ± SD (min-max)	Total mean ± SD (min-max)	Male mean ± SD (min-max)	Female mean ± SD (min-max)	p	p	p
Age			20.4±1.5 (18.0-24.0)	20.7±1.5 (18.0-23.0)	20.3±1.5 (18.0-24.0)	20.5±1.6 (18.0-29.0)	20.5±1.4 (18.0-25.0)	20.5±1.7 (18.0-29.0)	0.704	0.483	0.420
Body mass index (kg/m²)			23.11±3.82 (17.57-34.19)	25.12±4.24 (17.87-34.19)	21.99±2.90 (17.57-32.14)	23.52±3.75 (17.69-34.19)	25.48±3.84 (19.38-34.19)	22.48±2.75 (17.69-33.20)	0.804	0.544	0.552
Daily screen time (hours)			4.7±2.0 (1.0-12.0)	4.8±2.6 (1.0-12.0)	4.7±1.7 (1.0-10.0)	6.0±3.1 (1.0-20.0)	7.1±4.0 (1.5-20.0)	5.4±2.3 (1.0-17.0)	**0.001**	**0.010**	**0.035**
Weekly screen time (hours)			30.7±14.0 (3.0-80.0)	33.3±17.3 (3.0-80.0)	29.6±12.4 (5.0-58.0)	34.7±17.5 (3.0-140.0)	38.1±22.3 (10.0-140.0)	32.7±13.7 (3.0-60.0)	0.70	0.485	0.098
Smartphone screen size (inch-cm)			6.65±0.32 (5.91-7.87)	6.70±0.21 (6.30-7.09)	6.64±0.36 (5.91-7.87)	6.65±0.30 (5.91-7.48)	6.58±0.31 (5.91-7.09)	6.69±0.28 (5.91-7.48)	0.628	0.062	0.475
Mean movement-based reaction time (SWAY)			267.17±37.40 (183.6-418.4)	264.71±35.90 (199.4-371.6)	268.16±38.18 (183.6-418.4)	268.42±41.22 (184.4-384)	281.99±43.72 (184.4-380)	260.28±37.66 (197.6-384.0)	0.883	0.068	0.183
SC	**Tone**	**Right**	14.4±1.7 (11.3-20.0)	14.2±1.5 (11.6-16.8)	14.4±1.7 (11.3-20.0)	14.1±1.1 (12.3-19.2)	14.3±0.9 (12.3-15.9)	13.9±1.2 (12.3-19.2)	0.397	0.736	0.138
		Left	15.2±2.0 (12.0-20.7)	15.3±1.7 (12.0-18.2)	15.2±2.2 (12.3-20.7)	15.7±1.9 (11.2-20.2)	15.9±1.7 (11.2-20.2)	15.6±2.0 (12.5-20.2)	0.037	0.073	0.220
	Stiffness	**Right**	225.2±44.8 (139-390)	219.3±35.5 (139-272)	227.5±48.1 (157-390)	215.8±38.7 (152-485)	224.6±28.1 (157-312)	210.6±43.2 (152-485)	0.090	0.702	0.044
		Left	244.9±54.3 (144-432)	248.9±42.0 (148-351)	243.3±58.7 (144-432)	251.9±49.3 (157-399)	256.9±45.7 (167-361)	248.9±51.4 (157-399)	0.225	0.482	0.392
	Elasticity	**Right**	1.11±0.13 (0.82-1.51)	1.09±0.14 (0.85-1.37)	1.12±0.12 (0.82-1.51)	1.10±0.14 (0.85-1.99)	1.14±0.17 (0.85-1.99)	1.07±0.12 (0.89-1.54)	0.213	0.390	0.014
		Left	1.09±0.13 (0.81-1.77)	1.06±0.09 (0.88-1.30)	1.11±0.15 (0.81-1.77)	1.07±0.18 (0.77-2.06)	1.09±0.17 (0.92-1.57)	1.06±0.19 (0.77-2.06)	0.12	0.868	0.003
BR	**Tone**	**Right**	14.7±1.7 (11.4-18.7)	14.7±1.3 (12.5-18.7)	14.7±1.9 (11.4-18.6)	15.3±1.5 (11.3-19.3)	14.7±0.8 (13.1-16.2)	15.7±1.7 (11.3-19.3)	**0.003**	0.267	0.002
		Left	15.21±2.21 (11.4-22.7)	16.28±2.23 (13.1-22.7)	14.78±2.06 (11.4-22.6)	16.04±1.52 (11.6-19)	16.51±1.33 (13.7-19)	15.75±1.57 (11.6-18.8)	**0.000**	0.150	**0.000**
	Stiffness	**Right**	243.5±52.3 (137-379)	244.6±40.9 (181-379)	243.1±56.5 (137-379)	256.7±43.5 (142-350)	248.4±32.3 (172-350)	261.7±48.6 (142-337)	0.015	0.202	0.028
		Left	257.0±63.2 (132-485)	282.3±59.5 (170-485)	246.8±62.2 (132-480)	273.9±41.0 (138-350)	285.4±42.7 (200-324)	267.0±38.7 (138-350)	**0.001**	0.373	0.002
	Elasticity	**Right**	0.93±0.12 (0.63-1.31)	0.92±0.11 (0.63-1.12)	0.94±0.12 (0.66-1.31)	0.93±0.10 (0.72-1.29)	0.94±0.08 (0.73-1.10)	0.92±0.12 (0.72-1.29)	0.809	0.344	0.382
		Left	1.00±0.20 (0.70-1.67)	0.96±0.15 (0.78-1.67)	1.02±0.21 (0.70-1.67)	0.97±0.15 (0.68-1.63)	0.97±0.12 (0.78-1.40)	0.97±0.16 (0.68-1.63)	0.674	0.744	0.593

Table 1. continued

Variables			Non-smartphone-addicted (n=104)			Smartphone-addicted (n=112)			Total	Male	Female
			Total mean ± SD (min-max)	Male mean ± SD (min-max)	Female mean ± SD (min-max)	Total mean ± SD (min-max)	Male mean ± SD (min-max)	Female mean ± SD (min-max)	p	p	p
ED	Tone	Right	19.89±3.34 (12.6-27.2)	20.37±2.91 (13.7-25.4)	19.69±3.50 (12.6-27.2)	20.83±3.51 (12.9-27.9)	21.29±2.41 (15.70-25.80)	20.56±4.01 (12.90-27.90)	**0.040**	0.184	0.183
		Left	19.2±3.5 (12.7-27.6)	19.7±2.8 (12.7-25.0)	19.0±3.7 (13.5-27.6)	22.9±1.2 (12.9-28.1)	20.6±2.1 (13.2-24.0)	24.3±6.7 (12.9-26.1)	**0.001**	0.190	0.004
	Stiffness	Right	467.5±155.6 (204-779)	464.8±126.44 (204-662)	468.6±166.7 (219-779)	494.8±157.3 (199-739)	510.4±111.2 (264-695)	485.4±179.5 (199-739)	0.158	0.132	0.503
		Left	445.78±155.9 (222-772)	482.77±142.15 (231-689)	430.78±159.67 (222-772)	510.91±171.87 (193-781)	536.98±110.03 (224-624)	495.27±199.16 (182.1-781.0)	0.002	0.087	0.036
	Elasticity	Right	1.15±0.19 (0.80-1.94)	1.17±0.21 (0.81-1.55)	1.14±0.19 (0.80-1.94)	1.15±0.19 (0.80-1.57)	1.26±0.22 (0.88-1.57)	1.09±0.14 (0.80-1.50)	0.766	0.075	0.145
		Left	1.10±0.20 (0.62-1.70)	1.10±0.20 (0.62-1.38)	1.10±0.21 (0.70-1.70)	1.27±1.71 (0.70-1.91)	1.17±0.15 (0.72-1.37)	1.33 ±0.16 (0.70-1.91)	0.423	0.229	0.669

SD: Standard deviation, SC: Semispinalis capitis, BR: Brachioradialis, ED: Extensor digitorum, kg: Kilogram, m: Meter, cm: Centimeter, Bold values indicate statistical significance after Benjamini-Hochberg false discovery rate correction (q<0.05)

Viscoelastic Properties of Muscles in Participants

Although no previous study has directly examined the effects of smartphone addiction on the viscoelastic properties of muscles, several studies have investigated the musculoskeletal consequences of prolonged smartphone use (5-7). These studies have shown that increased screen time, prolonged static postures may contribute to musculoskeletal symptoms, postural deviations and neck disability (5,6).

In this context, significant differences were limited to muscle tone in the brachioradialis, extensor digitorum,

biceps brachii, flexor carpi radialis, and extensor carpi radialis muscles. These selective increases in muscle tone may reflect adaptive neuromuscular responses to sustained gripping, repetitive finger movements, and prolonged wrist flexion postures commonly adopted during smartphone use. Such changes may contribute to impaired muscle function and increase the risk of musculoskeletal discomfort, fatigue, and postural alterations over time (6,7).

The fact that a greater number of muscle groups and parameters showed statistical significance among female participants suggests that neuromuscular responses to smartphone use may differ by gender. Testosterone has been shown to be positively associated with muscle strength and mass, and its lower circulating levels in females may contribute to altered connective tissue composition and increased susceptibility to mechanical loading (35). In addition to hormonal influences, postural and ergonomic factors may play an important role. Previous studies have indicated that women tend to adopt greater cervical and wrist flexion angles and more sustained static postures during smartphone use, resulting in higher cumulative mechanical stress on upper extremity muscles (36). Differences in postural habits, device handling, and prolonged unilateral use patterns may further exacerbate this vulnerability. Together, these hormonal, biomechanical, and ergonomic factors may partially explain why viscoelastic muscle alterations were more pronounced in female participants in the present study (35,36).

Furthermore, muscle viscoelastic properties are influenced by physiological factors such as muscle fatigue and the level of muscle activation (37). In addition to individual differences in muscle structure, it has been reported that whether a muscle is evaluated in a horizontal or vertical position can influence measurement outcomes (38). Therefore, in this study, all assessments were performed in a standardized seated position and with muscles in a passive state to ensure measurement standardization. Differences observed between right and left side muscles may also be attributed to dominant limb discrepancies (20).

Table 2. The relationship between muscle viscoelastic properties and movement-based reaction time

				Total (n=216)						Non-smartphone-addicted (n=104)						Smartphone-addicted (n=112)					
				SWAY	Age	BMI (kg/m²)	Daily screen time (hours)	Weekly screen time (hours)	Smartphone screen size (inch-cm)	SWAY	Age	BMI (kg/m²)	Daily screen time (hours)	Weekly screen time (hours)	Smartphone screen size (inch-cm)	SWAY	Age	BMI (kg/m²)	Daily screen time (hours)	Weekly screen time (hours)	Smartphone screen size (inch-cm)
SWAY			r	1	-0.02	0.09	0.28*	0.03	0.16	1	0.12	0.09	0.31*	0.21*	-0.03	1	-0.05	0.05	0.10	-0.04	-0.01
			p		0.87	0.43	0.01	0.791	0.17	.	0.22	0.32	0.00	0.03	0.75	.	0.54	0.55	0.25	0.65	0.86
Age			r	-0.02	1	0.27*	0.14	0.24*	-0.06	0.12	1	0.347*	0.02	0.03	-0.15	-0.05	1	-0.02	0.10	0.09	-0.06
			p	0.87		0.01	0.22	0.03	0.60	0.22	.	0.0	0.83	0.76	0.10	0.54	.	0.80	0.25	0.30	0.47
BMI (kg/m²)			r	0.09	0.27*	1	0.15	0.03	0.07	0.09	0.34*	1	0.00	0.04	0.14	0.05	-0.02	1	0.11	-0.01	-0.06
			p	0.43	0.01		0.20	0.74	0.54	0.32	0.00	.	0.98	0.64	0.14	0.55	0.80	.	0.21	0.86	0.50
Daily screen time (hours)			r	0.28*	0.14	0.15	1	0.71*	-0.04	0.31*	0.02	0.00	1	0.86*	-0.01	0.10	0.10	0.11	1	0.69*	-0.06
			p	0.01	0.22	0.20		0.0	0.68	0.00	0.83	0.98	.	0.0	0.91	0.25	0.25	0.21	.	0	0.47
Weekly screen time (hours)			r	0.03	0.24*	0.03	0.71*	1	0.09	0.21*	0.03	0.04	0.86*	1	0.07	-0.04	0.09	-0.01	0.69*	1	-0.07
			p	0.79	0.03	0.74	0.0		0.44	0.03	0.76	0.64	0.0	.	0.45	0.65	0.30	0.86	0.0	.	0.44
Smartphone screen size (inch-cm)			r	0.16	-0.06	0.07	-0.04	0.09	1	-0.03	-0.15	0.14	-0.01	0.07	1	-0.01	-0.06	-0.06	-0.06	-0.07	1
			p	0.17	0.60	0.54	0.68	0.44	-	0.75	0.10	0.14	0.91	0.45	.	0.86	0.47	0.50	0.47	0.44	.
SC	Tone	Right	r	0.22	0.13	0.02	0.12	-0.00	0.03	-0.02	0.06	0.07	0.09	0.03	0.10	0.03	0.11	0.18	0.04	-0.14	-0.09
			p	0.05	0.26	0.85	0.28	0.94	0.77	0.83	0.50	0.46	0.32	0.76	0.26	0.68	0.24	0.05	0.66	0.13	0.32
		Left	r	0.27*	0.03	0.19	0.12	0.00	0.00	0.17	0.06	0.02	0.17	0.23*	0.19*	0.27*	0.11	0.12	-0.07	-0.02	0.01
			p	0.02	0.74	0.10	0.28	0.95	0.97	0.07	0.48	0.80	0.07	0.01	0.04	0.00	0.22	0.17	0.43	0.83	0.84
	Stiffness	Right	r	0.31*	0.11	0.06	0.15	0.05	0.04	-0.02	0.05	0.07	0.10	0.03	0.06	0.15	-0.02	0.28*	0.08	-0.11	-0.06
			p	0.00	0.32	0.59	0.18	0.64	0.70	0.77	0.59	0.43	0.27	0.69	0.53	0.09	0.82	0.00	0.38	0.22	0.52
		Left	r	0.12	0.00	0.17	0.01	-0.07	-0.00	0.18	-0.00	-0.00	0.11	0.12	0.12	0.17	0.16	0.08	-0.10	-0.07	0.02
			p	0.31	0.96	0.13	0.91	0.56	0.96	0.06	0.98	0.95	0.26	0.21	0.21	0.06	0.07	0.38	0.28	0.41	0.82
	Elasticity	Right	r	0.27*	0.00	0.15	0.06	-0.05	0.05	0.10	0.10	0.24*	0.06	-0.03	0.07	0.25*	0.13	0.26*	0.06	0.01	-0.08
			p	0.01	0.94	0.20	0.58	0.65	0.66	0.30	0.26	0.01	0.49	0.75	0.45	0.00	0.14	0.00	0.52	0.91	0.37
		Left	r	-0.15	0.01	0.02	-0.17	-0.16	-0.00	-0.08	0.03	0.00	-0.11	-0.20*	-0.04	-0.00	0.09	0.12	-0.06	-0.13	-0.04
			p	0.20	0.91	0.85	0.14	0.17	0.93	0.41	0.76	0.92	0.25	0.04	0.66	0.93	0.34	0.17	0.47	0.15	0.61
BR	Tone	Right	r	-0.16	-0.02	-0.07	-0.22	-0.31*	0.04	0.08	0.04	-0.05	-0.03	0.03	-0.07	-0.07	0.23*	-0.26*	-0.20*	-0.11	0.17
			p	0.15	0.83	0.53	0.06	0.00	0.71	0.39	0.66	0.60	0.73	0.72	0.46	0.42	0.01	0.00	0.03	0.24	0.06
		Left	r	0.38*	0.15	0.07	0.25*	0.08	0.26*	0.19*	0.26*	0.17	0.22*	0.28*	-0.05	0.35*	0.03	0.07	0.13	0.07	0.18*
			p	0.00	0.20	0.55	0.03	0.50	0.02	0.04	0.00	0.08	0.02	0.00	0.60	0.0	0.71	0.43	0.15	0.43	0.04

BMI: Body mass index, kg: Kilogram, m: Meter, cm: Centimeter, SC: Semispinalis capitis, BR: Brachioradialis, BB: Biceps brachii, FDS: Flexor digitorum superficialis, FCU: Flexor carpi ulnaris, FCR: Flexor carpi radialis, ECR: Extansor carpi radialis, *: $p<0.05$ indicates statistically significant results

In conclusion, these findings indicate early and subtle neuromuscular adaptations rather than clinically definitive impairments. The findings suggest that smartphone use may be associated with subtle alterations in the neuromuscular system, which may represent early biomechanical adaptations. This highlights the need for the development of preventive physiotherapy strategies and the management of smartphone use duration, especially in young populations. The results should be supported by more advanced biochemical and neurophysiological evaluations and confirmed by longitudinal studies involving different age groups. From a preventive perspective, even subtle increases in muscle tone during early adulthood may, if sustained over time, contribute to cumulative neuromuscular loading, reduced movement efficiency, and impaired motor responsiveness in later years. Early identification of these changes provides an opportunity for physiotherapists to implement targeted interventions such as postural education, activity pacing, and exercise-based strategies to mitigate the long-term neuromuscular consequences of intensive smartphone use (39).

Relationship Between Muscle Viscoelastic Properties and Movement-based Reaction Times

This study aimed to shed light on the effects of digital habits on the neuromuscular system by examining the relationship between smartphone use duration, muscle viscoelastic properties, and movement-based reaction time. The findings revealed that muscle tone, stiffness, and elasticity parameters were significantly, though mostly weakly, associated with variables such as daily screen exposure, screen size, and age. This suggests the presence of early biomechanical changes that may not yet manifest as clinical symptoms. In particular, the correlations observed between SWAY data and certain muscle parameters (e.g., FCU and ECR), although mostly weak in magnitude, may indicate early trends in neurophysiological adaptations that warrant further investigation. Although several correlations reached statistical significance, most of the correlation coefficients were weak ($r<0.40$). This indicates that, while smartphone use and muscle viscoelastic parameters are related to movement-based reaction time, these associations are modest and other unmeasured factors are also likely to contribute to reaction time performance.

In the literature, the impact of technology interaction on postural control has received increasing attention in recent years. Numerous studies have reported that smartphone use, being a dual-task activity, may impair postural stability, motor coordination, and movement-based reaction time by dividing attention (40-42). These findings are consistent with the correlations observed in our study and suggest that digital habits may significantly affect muscle function and motor control capacity, especially in young adults.

Considering the participants' age range and screen time criteria, these findings suggest a possible association between intensive smartphone use and altered neuromuscular responses. Although the literature has not consistently shown a direct significant relationship between screen time and reaction time (12), this may be due to the limitations of measuring acute effects. Previous studies in older adults have reported that higher levels of smartphone addiction were associated with shorter reaction times (42). However, such conflicting findings suggest that neuromuscular adaptations may vary based on age, usage habits, and assessment methodologies.

Changes in muscle tone, stiffness, and elasticity are known to influence motor unit activation and the muscle's ability to respond rapidly (43,44). Reaction time is a function not only of cognitive processes but also of the mechanical properties of muscles (45). Therefore, deviations in viscoelastic parameters may influence movement initiation and affect muscle performance in time-sensitive motor tasks. This should be carefully considered in individuals exhibiting increased muscle rigidity due to prolonged screen exposure.

In this study, moderate correlations observed between reaction time and elasticity/stiffness parameters of distal muscle groups such as the FCU and ECR suggest a potential contribution of upper extremity muscle structure in reflexive motor responses. Altered muscle mechanical properties may adversely affect performance during tasks requiring rapid motor responses and efficient sensorimotor control (46). These findings suggest that muscle viscoelastic properties may contribute to movement-based reaction time performance not only for force generation and postural support but also for timing-based motor performance.

From a clinical perspective, viscoelastic changes in muscle tissue associated with smartphone use may warrant consideration not only in terms of ergonomics or pain, but also with regard to reaction time, motor acceleration capacity, and postural balance performance; however, the present findings represent preliminary associations rather than strong clinical effects. In this context, the potential effects of a technology-based lifestyle on the muscular and nervous systems in young individuals should be assessed at an early stage and supported with appropriate physiotherapy strategies.

Study Limitations

Several limitations of this study may affect the generalizability of the findings. Firstly, the sample consisted solely of university students, which limits the applicability of the results to individuals from different age groups or occupational backgrounds. In addition, the use of a cross-sectional design restricts the ability to establish cause-and-effect relationships and only allows for correlational interpretations.

Furthermore, participants' habitual physical activity levels, posture habits, and ergonomic behaviors during smartphone use were not assessed. These factors are known to influence both muscle viscoelastic properties and reaction time and may therefore have acted as potential confounders in the present study. Another limitation of this study is the absence of intra-rater or test-retest reliability analysis within the current sample. Although MyotonPRO has been shown to provide good to excellent reliability in previous studies, the lack of device-specific reliability testing in our cohort should be considered when interpreting the results.

Reaction time was assessed solely based on the SWAY average, and cognitive and environmental variables that may influence this parameter were not controlled. Similarly, muscle viscoelastic properties were evaluated only in selected muscle groups, which may not provide a comprehensive picture of overall muscle function.

Future studies should consider employing longitudinal research designs involving different age groups to track the effects of smartphone use on the neuromuscular system over time. Moreover, assessments should not be limited to tone, stiffness, and elasticity; a broader range of muscle performance parameters such as strength, endurance, and motor control should also be evaluated. Reaction time, on the other hand, should be examined in a multidimensional manner, incorporating both cognitive and physical components.

From a preventive perspective, ıf confirmed by longitudinal studies, alterations in muscle viscoelastic properties could potentially contribute young individuals to early fatigue during fine motor tasks, reduced hand dexterity, impaired academic performance, and decreased postural control. Over time, these neuromuscular alterations may contribute to the development of chronic neck-upper extremity pain syndromes, reduced movement efficiency, and a higher risk of cumulative trauma disorders. Therefore, prolonged exposure to digital devices in early adulthood should not only be considered a behavioral issue but also a potential risk factor for long-term neuromuscular health.

Conclusion

This study demonstrated that smartphone addiction was associated with selected changes in muscle viscoelastic properties. Weak associations were also observed between certain muscle viscoelastic parameters and movement-based reaction time. Because of the cross-sectional design, these findings should be interpreted as associative rather than causal. Further longitudinal studies are required to clarify whether these biomechanical alterations have clinically meaningful consequences.

Ethics

Ethics Committee Approval: Prior to the start of the study, ethical approval was obtained from the Non-Interventional Ethics Committee of SANKO University in accordance with the principles of the Declaration of Helsinki (decision no: 2025/03, date: 12.03.2025).

Informed Consent: The study procedures were explained in detail to the participants, and written informed consent was obtained from all individuals.

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Footnotes

Authorship Contributions

Concept: E.R., S.G., M.Y., B.H.Ç., İ.B., N.D.T.G., Design: E.R., S.G., M.Y., B.H.Ç., İ.B., N.D.T.G., Data Collection or Processing: E.R., S.G., M.Y., B.H.Ç., İ.B., N.D.T.G., Analysis or Interpretation: E.R., Literature Search: E.R., Writing: E.R., S.G., M.Y., B.H.Ç., İ.B., N.D.T.G.

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