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Smartphone addiction and musculoskeletal associated disorders in university students: biomechanical measures and questionnaire survey analysis

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Abstract

Background Smartphone addiction significantly impacts the musculoskeletal system, with 79% of younger adults aged 18–44 reporting excessive cell phone use. In addition, rare data exist on the roles of biological markers like 5-HT receptors, oxidative stress markers (TAC, MDA), collagen biomarkers (TIMP-1, TIMP-2), and triglycerides (TG) in the effects of smartphone addiction on the musculoskeletal system, particularly among university students.

Objective Thus, the study aimed to investigate the potential link between smartphone addiction levels and certain biological indicators related to musculoskeletal injuries in the hands and necks of young, healthy university students.

Methods A total of 250 healthy university students aged 17–30 years old were randomly invited to participate in this descriptive cross-sectional analytical study. All participants were categorized into two groups based on their smartphone usage duration: non-addicted (1–3h./day; $n=48$) and addicted (≥5h./day; $n=12$). Smartphone addiction, musculoskeletal discomfort in the neck and hands, adiposity-related outcomes, and musculoskeletal disorder (MSD) biomarkers, like matrixmetalloproteinases (MMPs); TIMP-1,TIMP-2;5-hydroxytryptophans (5-HT), triglyceride (TG), malondialdehyde (MDA), and total antioxidant capacity (TAC) were assessed using validated questionnaires like the Neck Disability Index (NDI), Cornell Hand Discomfort Questionnaire (CHDQ), and Visual Analogue Scale (VAS), respectively, and ELISA immunoassay analysis.

Results A significant link was reported between smartphone addiction and neck pain, hand discomfort, and adiposity markers in 64%of the participant cohort. Moreover, females exhibited higher rates of addiction and susceptibility compared to their male counterparts (62.5% vs. 37.5%). Overall, the outcomes score of prolonged smartphone usage was positively correlated with adiposity, musculoskeletal disorders, and pain measured by the NDI, CHDQ, and VAS, respectively. Smartphone-addicted students demonstrated lower levels of TIMP-1, TIMP-2, and TAC activity, along with elevated 5-HT, TG, and MDA levels, compared to non-addicted controls.

Conclusion Smartphone addiction is positively associated with adiposity and musculoskeletal issues, particularly in the neck, shoulders, and hands, among university students. Key biomarkers (TIMP-1, TIMP-2, 5-HT, TG, MDA, TAC) significantly correlate with the severity of neck and hand MSD, as indicated by NDI, CHDQ, and VAS scores. Thus, public health initiatives are essential to raise awareness of the physical and biological risks of excessive smartphone use.

Keywords Smartphone addiction, Musculoskeletal disorders, Adolescents, Pain, Biological markers

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Introduction

Smartphone devices with touchscreen interfaces, internet access, gaming applications, social networks, and gaming applications are the most popular means for performing fast communications and complicated tasks worldwide [1]. In common, Smartphone applications like text messaging (SMS) were extensively employed for fast communication among adolescents and university students [1, 2]. In younger ages, the use of smartphone devices like cell phones was significantly increased, whereas more than 79% of younger ages (18–44) years old use their cell phones most of the day with only a little time apart from it [1–4]. The use of smartphone communication technologies for a long time leads to smartphone addiction with severe risks to human health reported [1, 3], like significant and persistent functional impairments with distress and behavioral addiction among users [3–5]. Moreover, neurological disorders, physical and mental health, and psychological challenges such as anxiety and depression, fatal accidents on the road, and social issues like strained family, and peer interactions were significantly associated with smartphone addiction [5–8].

Furthermore, prolonged use of smartphone technology can significantly impact the musculoskeletal system, whereas the repetitive and continuous motions of the thumb and fingers can lead to thumb-related disorders and muscular issues, such as the extensor policies longus tendinosis or myofascial pain syndrome in the hand [8, 9]. In addition, non-traumatic musculoskeletal pain and inflammatory changes in healthy joints due to repetitive joint overuse were significantly associated with prolonged use of smartphones [9–11]. Previous studies have reported that the use of smartphone technologies requires significant body positions, such as staring sharply downward or holding arms out in a front position to read the screen, which in turn, strains the cervical spine and the neck muscles, as evidenced by prior research [9–13]. Also, it was reported previously that improper positioning of the head and neck was significantly associated with persistent musculoskeletal discomfort, with forward head posture being widely acknowledged as a prevalent poor posture in the sagittal plane [12–14]. Thus, the rise in musculoskeletal disorders (MSD) affecting the hand, wrist, forearm, arm, and neck on a global scale was showed to be associated with the frequent utilization of handheld devices (HHD), including smartphones [11–15], whereas, uneasiness and fatigue in the hand, elbow, and shoulder were reported during the use of HHD [13–15]. Additionally, the longer use of computer and smartphone applications showed effects on the soft tissues of the neck, shoulders, arms, and hands which might be related to a significant increase in MSD in smartphone holders [13–18]. These consequences collectively cause severe pain, which leads to disability, absence from work, and a large economic burden on society [18–21]. The incidence of MSD among smartphone users results in prolonged discomfort and may lead to physical impairment, encompassing conditions like tendinopathies, nerve compression syndromes, as well as muscular and joint ailments [23–25]. Thus, observations of restricted choices like self-reported or functional ability symptoms for screening and diagnosing MSD patients are still unsatisfactory and need for more confirmatory biological markers [21, 22]. Consequently, there is a recognized necessity for enhanced diagnostic and screening techniques rooted in biological markers to assess MSD more effectively [26–28].

Serum biomarkers measuring significant inflammation, fibrosis, collagen like a tissue inhibitor of metalloproteinases (TIMP-1 and TIMP-2), oxidative stress (TAC, MDA), and degeneration in serum and musculotendinous tissues were significantly investigated in people with MSDs, like in workers with upper extremity-related MSDs (WMSDs) [29–35]. Furthermore, there is evidence indicating that collagen repair marker (TIMP-1) exhibits decreased levels in fibroproliferative disorders, while serotonin (5-HT) and triglyceride levels are elevated in trapezius myalgia associated with various MSD conditions [36–41].

Although the impact of smartphone addiction on musculoskeletal symptoms, and the association of smartphone addiction with pain in the dorsum, neck, wrist, hand, and discomfort in various parts of the body due to prolonged smartphone use was explored [41–46], the correlations between the effects of smartphones use on the biological markers of MSD like TIMP-1 and TIMP-2, oxidative stress, and serotonin (5-HT) and triglyceride levels as well as identifying their values in the blood are not explained or studied as well.

So, in this study, it was hypothesized that the identifying of some blood biomarkers of MSD and their relation with use of smartphones smartphone use abdication could be of interest for diagnosis, and treatment strategies of patients with MSD and open in such a way to understand the influence of prolonged use of smartphones based upon physiological changes in diagnosis, treatment, and research studies as well [41–46].

Smartphone use abdication is becoming a growing problem, greatly impacting the development of hand and shoulder muscles, and musculoskeletal discomfort among university adolescents. In addition, no or little data reports the correlation between MSD-related biomarkers and smartphone use severity. Therefore, the study's primary objective was to investigate the potential link between self-reported smartphone addiction levels and specific biological markers for musculoskeletal injuries in the neck and hands of young and healthy university students.

Materials and methods

Study design

The study was based on a descriptive cross-sectional design intended to perform a biomechanical and questionnaire-based survey analysis.

Study setting

Two hundred seventy healthy university students from different colleges with similar sociocultural environments were randomly invited between January 2022 and June 2022 to participate in this study. Only, 250 participants were eligible to participate in this study and the rest 20 participants are ineligible for participation (12 refused to participate; 8 are suffering from upper extremity musculoskeletal injuries which could interfere with the identified MSD biomarkers). Participants who were approached for screening using banners and handbills' distribution inside the university campus that explained the study purpose, outcomes, personal and social benefits, and potential hazards in details. The entire research steps were performed in the period of January 2022 and June 2022 in RRC lab, CAMS, King Saud University. In addition, supervision, follow-up, and diagnosis of the participants were performed with an expert physiotherapist with > 10 years of experience in his respective field.

Participants

Two hundred fifty healthy university students aged 17–30 years old who engaged in a minimum of 1 h of smartphone use daily and possessed the capacity to comprehend and complete the questionnaires in English were considered for inclusion in this investigation. Individuals with prior neck or upper extremity musculoskeletal injuries, spinal cord trauma predating the study, any underlying medical conditions, or known ailments that might contribute to neck or upper limb discomfort were excluded from the study. In addition, participants with recent fracture in neck and upper limb, congenital abnormalities, and severe surgical and neurological disorders were excluded from this study.

Ethical consideration

The study was performed between January and June 2022. The study protocol conformed to the ethical guidelines of the 1975 Declaration of Helsinki and was reviewed and approved by the Ethics Sub-Committee of King Saud University, Kingdom of Saudi Arabia, under file number ID: RRC-2022-028; dated: 15 January 2022. The study's objectives and intent were elucidated, and participants were provided with clear explanations. Subsequently, informed verbal consent was obtained from all the individuals involved.

Anthropometric measurements

The study's participants were categorized into four groups based on predefined BMI threshold values, as outlined in earlier studies: underweight (BMI < 18.5 kg/m2), normal weight (BMI 18.5–24.9 kg/m2), overweight (BMI 25–30 kg/m2), and obese (BMI ≥ 30 kg/m2) [47]. Additionally, the waist-to-height ratio (WHtR) was computed following the methodology described in the referenced literature [47–49].

Smartphone addiction, neck, and hand fatigue assessments

The data were collected from each subject using a questionnaire reported as validated previously [25]. The questionnaires are classified into four main parts; demographics (name, age, gender, hand dominance, hours of mobile usage per day), Cornell Hand Discomfort Questionnaire (CHDQ), Neck Disability Index (NDI) score, and Smartphone Addiction Scale (SAS) [2, 50–53].

Smartphone Addiction Scale (SAS)

All participants' levels of smartphone addiction were assessed employing a reliable and validated self-report measurement tool known as the Smartphone Addiction Scale (SAS), as previously documented [54]. This scale comprises six domains and a total of 33 items, each rated on a six-point Likert scale (ranging from 1, "strongly disagree", to 6, "strongly agree"). These six domains encompass daily-life disturbance, positive anticipation, withdrawal, cyberspace-oriented relationships, overuse, and tolerance. When utilizing the SAS scale, students select the statement that best aligns with their smartphone usage characteristics. The SAS score spans from 33 to 198, with higher scores indicating a more pronounced degree of pathological smartphone use [55].

Neck Disability Index (NDI)

To evaluate the impact of smartphone usage on neck pain and related symptoms across various daily activities, all students were administered a well-established 10-item questionnaire known as the Neck Disability Index (NDI), which has been previously validated [56]. This index stands as the most widely utilized and rigorously validated tool for assessing self-reported disability among individuals experiencing neck pain [56]. The ten items are categorized into four addressing subjective symptoms (pain intensity, headache, concentration, sleep quality), four related to daily functional activities (lifting, work, driving, recreation), and two discretionary daily activities (personal care, reading). Each item is evaluated on a scale from 0 (indicating "No pain") to 5 (representing "Worst imaginable pain") [56].

Cornell Hand Discomfort Questionnaire (CHDQ)

To assess hand discomfort among participating students who use smartphones, a previously validated 6-item questionnaire known as the Cornell Hand Discomfort Questionnaire (CHDQ) was employed in accordance with prior literature [27]. This questionnaire includes a hand diagram with six shaded areas and corresponding inquiries regarding the following aspects: 1. prevalence of musculoskeletal pain, 2. discomfort, and 3. interference with work experienced over the past week [57]. The total discomfort score was determined using the formula: {[Frequency × discomfort × interference]} [50], with higher scores indicating a greater level of discomfort. Each area could achieve a maximum score of 90, and the total score for all six areas is 560 (higher scores signifying more pronounced discomfort) [57]. Furthermore, the participants' neck and hand pain were evaluated using a validated 100 mm Visual Analog Scale (VAS) [58].

Assessment of musculoskeletal disorder (MSD) predictive biological markers

Before performing the biochemical parameters of MSD, heparinized syringes were utilized to collect blood samples from all subjects. Subsequently, serum samples were extracted through centrifugation, lasting for 1 min at 1400 rpm. These samples were assigned coded study identification numbers and were then promptly frozen at − 20 °C for subsequent analysis.

Oxidative stress biomarkers Malondialdehyde (MDA) levels in serum samples were assessed utilizing a previously documented colorimetric standard method [59]. The MDA concentration (nmol/g wet tissue) in each tissue sample was determined based on the absorbance at 535 nm, and the data were subsequently computed using a conventional calibration curve [59]. For the measurement of serum total antioxidant capacity (TAC), a Colorimetric Assay Kit (Catalog #K274-100; BioVision Incorporated; CA 95035 USA) was employed. Antioxidant equivalent concentrations were gauged at 570 nm, with Trolox concentration as the reference, per the manufacturer's instructions [59]. The formula used for calculation was {Sa/Sv = nmol/μl or mM Trolox equivalent} [59], where Sa represents the sample amount (in nmol) read from the standard curve, and Sv is the undiluted sample volume added to the wells.

Collagen biomarkers Serum concentrations of TIMP-1 and MMP-2 (obtained from Fuji Chemical Industries, Toyama, Japan) were quantified using commercially available sandwich ELISA kits, following the manufacturer's guidelines [60]. To determine serotonin levels (5-HT), in the participants' serum, an ELISA kit (Serotonin ELISA; Immuno-Biological Laboratories; Minneapolis, MN) was employed. The intra-assay and inter-assay coefficients of variation (CV ± SE) were recorded as 9.1 ± 2.4% and 25.9 ± 5.5%, respectively [61]. These CV values were calculated in adherence to the manufacturer's instructions [61]. Additionally, triglyceride levels in the serum of all participants were assessed through an enzymatic (GPO-PAP) method [62].

Sample size calculation

In this study, the power of the sample size was estimated by using the G ∗ Power program for Windows (version 3.1.9.7). A sample comprising 250 of subjects was included in this study. Using the two tailed T-test with a significance level of 0.05, the total sample of 250 achieves a power of 90% with effective size d of 0.206, Df = 249, critical $t = 1.97$, and noncentrality − $\alpha = 3.26$.

Statistical analysis

This study employed the SPSS statistical software for Windows, version 20, to compute the variables' frequencies under investigation. Firstly, the descriptive scores for the outcome variables (SAS, NDI, and CHDQ) and various demographic factors were reported as mean ± SD. Next, the prevalence of upper body musculoskeletal symptoms in sitting position and smartphone addiction were analyzed using percentages with a 95% confidence interval for each age group and gender. In both smartphones adducted and non-adducted participants, the χ2 or Mann–Whitney U test was used to test association between smartphone addition, age, gender, and biological biomarkers like TMPS-1, and TMPS-2, MDA, TAC, TG, and 5-HT (serotonin) with upper body musculoskeletal symptoms. Afterwards, the Chi-square test, multiple logistic regression was used to discover the association between smartphone addiction and upper body musculoskeletal symptoms based up on the variables (i.e., SAS and NDI, as well as SAS and CHDQ scores) and the levels of MSD biological markers. The Hosmer–Lemeshow test was used to assess the fit. The confidence interval level α was set at 95%, i.e., $p < 0.05$ was considered to be significant [21, 35].

Results

In this observational analytical investigation, it was observed that smartphone addiction was prevalent among 64% (n = 160) of the study cohort, with a majority of them being females (62.5% compared to 37.5% for males), as indicated in Table 1 and Fig. 1. Conversely, only 36% of the students exhibited regular smartphone usage (non-addicted students; $n=90$), as presented in Table 1.

Significant increases in adiposity markers (BMI, WHR, and WHtR) were noted among individuals with extended smartphone usage (2–3 h/d; $P=0.05$, 3–5 h/day; $P=0.01$ & ≥ 5 h/d; $P=0.001$) compared to those with mild or normal smartphone usage (1–2 h/d), as detailed in Table 1. Notably, adiposity appeared to be notably linked with smartphone use, especially among females ($P=0.01$), as illustrated in Fig. 1B.

In both genders, a pronounced association was found between smartphone addiction and neck pain and hand discomfort, as assessed by NDI, CHDQ, and VAS pain scores in Fig. 1D. The data revealed a positive correlation between smartphone addiction, adiposity (BMI/ WHtR), and musculoskeletal discomfort, as measured by NDI, CHDQ, and VAS pain scores (Table 1 and Fig. 1D). Furthermore, when compared to males, females exhibited higher rates of smartphone addiction, which was significantly linked to neck disability, hand discomfort, and severe musculoskeletal pain (Table 1 and Fig. 1C).

Furthermore, prolonged smartphone usage, as assessed by SAS scores, exhibited a significant association with neck disability and pain (NDI; $P=0.001$ & VAS; $p=0.001$) as well as hand discomfort (CHDQ; $P=0.001$) among individuals who used smartphones extensively compared to those with milder usage (1–2 h./d), as depicted in Fig. 2A.

In the case of smartphone-addicted students, potential biological markers for musculoskeletal pain in the neck and hand were thoroughly assessed in the serum samples of all participants. The findings indicated significant correlations between TIMP-1, TIMP-2, 5-HT (serotonin), and TG (triglycerides) levels with musculoskeletal disorder (MSD) outcomes in the neck and hand among students with prolonged smartphone usage. Notably, smartphone-addicted students displayed a significant decline in TIMP-1 and TIMP-2 levels, coupled with elevated 5-HT and TG levels compared to their

Table 1 Classification of subjects based on smartphone addiction scores (average ± standard deviation), along with their anthropometric and demographic measurements

Parameters	Hours of smartphone use/day			
	Not addicted (36%; $n=90$)		Addicted (64%; $n=160$)	
	1–2 h./day	2–3 h/day	3–5 h./day	≥ 5 h./day
No (%)	40 (44.4)	50 (55.5)	70 (43.7)	90 (56.3)
Age (years)	17.6 ± 1.4	21.1 ± 1.6	19.6 ± 1.9	18.9 ± 1.3
Gender (M/F)	25/15	32/18	25/45	35/55
Weight (kg)	61.6 ± 3.6	79.5 ± 5.3[a]	86.4 ± 3.1[b]	95.5 ± 3.8[c]
Height (m)	1.52 ± 1.5	1.6 ± 1.2	1.7 ± 4.9	1.82 ± 38
BMI (kg/m^2)	18.6 ± 1.8	21.5 ± 1.6[a]	23.3 ± 7.5[b]	27.2 ± 1.5[c]
WHR	0.49 ± 0.6	0.53 ± 1.0[a]	0.72 ± 4.2[b]	0.86 ± 5.1[c]
WHtR	0.46 ± 0.5	0.61 ± 0.89[a]	0.91 ± 0.73[b]	0.97 ± 0.782[c]
SAS	18.6 ± 9.5	36.1 ± 11.5[b]	158.8 ± 32.2[c]	175.4 ± 21.5[c]
MSD in neck and hand				
NDI score	12.2 ± 1.6	45.6 ± 12.3[b]	56.1 ± 21.7[c]	86.9 ± 26.3[c]
CHDQ score	35.4 ± 3.8	85.4 ± 15.9[b]	88.9 ± 22.7[c]	96.3 ± 32.4[c]
VAS pain score	4.6 ± 0.75	15.9 ± 5.8[b]	25.3 ± 9.3[c]	36.4 ± 11.2[c]
MSD biomarkers				
TIMP-1 (ng/mL)	28.7 ± 5.7	21.5 ± 2.5[b]	16.4 ± 3.8[c]	11.3 ± 4.8[c]
TIMP-2 (ng/mL)	42.1 ± 11.2	32.7 ± 5.6[b]	28.7 ± 6.4[c]	20.4 ± 2.4[c]
5-HT (serotonin; ng/ml)	15.6 ± 4.7	19.4 ± 6.1[b]	25.4 ± 3.7[c]	32.7 ± 4.7[c]
TG	8.4 ± 2.7	11.7 ± 1.4[b]	18.7 ± 2.7[c]	28.1 ± 3.7[c]
MDA (µ mole/L)	31.4 ± 9.6	12.2 ± 4.3[b]	25.3 ± 9.1[c]	38.4 ± 6.1[c]
TAC				

Data presented using number (%) for categorical data and using mean ± SD and median (min–max) for continuous data. Significance levels are denoted as [a]$p < 0.05$, [b]$p < 0.01$, and [c]$p < 0.001$. The acronyms stand for: BMI (body mass index), WHR and WHtR (waist-to-height ratio), MSD (musculoskeletal disorders), SAS (Smartphone Addiction Scale), NDI (Neck Disability Index), CHDQ (Cornell Hand Discomfort Questionnaire), and VAS (Visual Analogue Scale)

TIMP-1/TIMP-2: metallopeptidase inhibitor 1/2 (a tissue inhibitor of metalloproteinase); MDA: malondialdehyde; TAC: total antioxidant capacity; TG: triglycerides. 5-HT: 5-hydroxytryptamine (serotonin)

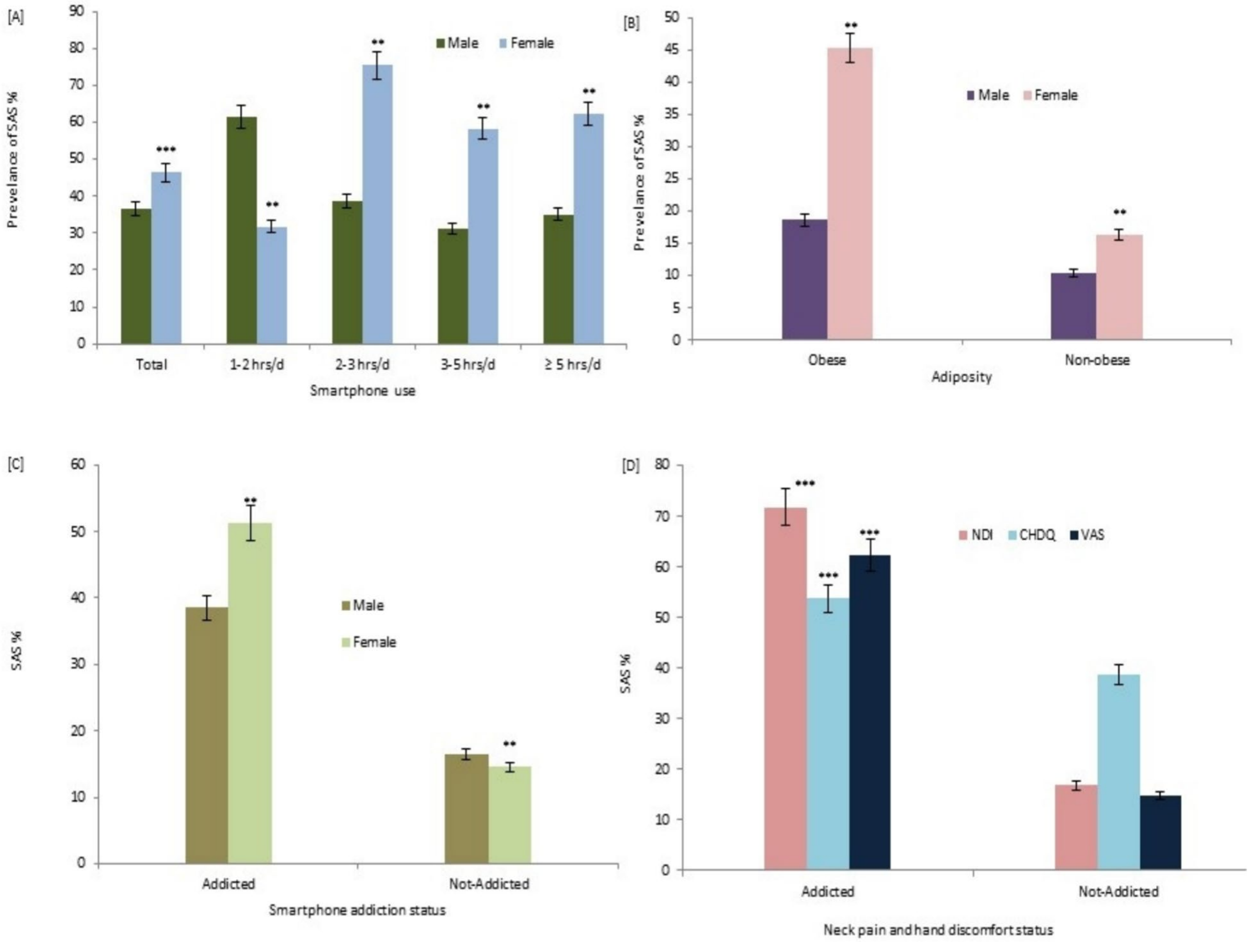

Fig. 1 **A**–**D** Smartphone addiction (SAS score %) associated with musculoskeletal discomfort among university students aged (18–25) years old (**A**) females demonstrated significantly higher smartphone usage rates (as indicated by SAS scores) compared to males; **B** the link between adiposity and SAS-based addiction was notably stronger in females than in males; **C** additionally, females exhibited higher addiction rates than males; **D** in both genders, a significant association was observed between smartphone use addiction and neck pain as well as hand discomfort, as assessed by NDI, CHDQ, and VAS anlage scores. ** denotes $p < 0.01$, *** denotes $p < 0.001$

healthy, non-addicted counterparts, as presented in Fig. 2B. Similarly, oxidative stress parameters, including MDA and TAC, were measured in the serum of all subjects. Smartphone-addicted students exhibited notably higher MDA values and lower TAC activity than those with regular smartphone use (Fig. 2C).

In smartphone-addicted students, adiposity, TIMP-1, TIMP-2, 5-HT, TG, MDA, and TAC biomarkers, as well as MSD in neck and hands measured by NDI, CHDQ, and VAS scores were significantly correlated with SAS-addicted scores in students who use smartphones for longer times, as shown in Fig. 2D and Table 2.

In addition, the severity of MSD in the neck and hands of smartphone-addicted students measured by NDI, CHDQ, and VAS pain scores were significantly associated with identified serum biomarkers like TIMP-1, TIMP-2, 5-HT, TG, MDA, and TAC as shown in Table 3. Thus, TIMP-1, TIMP-2, 5-HT, TG, MDA, and TAC could be useful as biological bio-predictive parameters for evaluating MSD consequences among computer-based workers and smartphone-addicted users.

Discussion

This research revealed a strong link between excessive smartphone usage and neck discomfort, physical limitations, hand ailments, and signs of obesity in nearly two-thirds of the participants. The data also indicated that a higher proportion of female participants were more prone to addiction and related issues than their male counterparts, with the figures being 62.5% for women and 37.5% for men. Overall, prolonged use of smartphones was found to be positively associated with increased body fat, Neck Disability Index, Cornell Hand Discomfort Questionnaire (CHDQ) scores, and visual

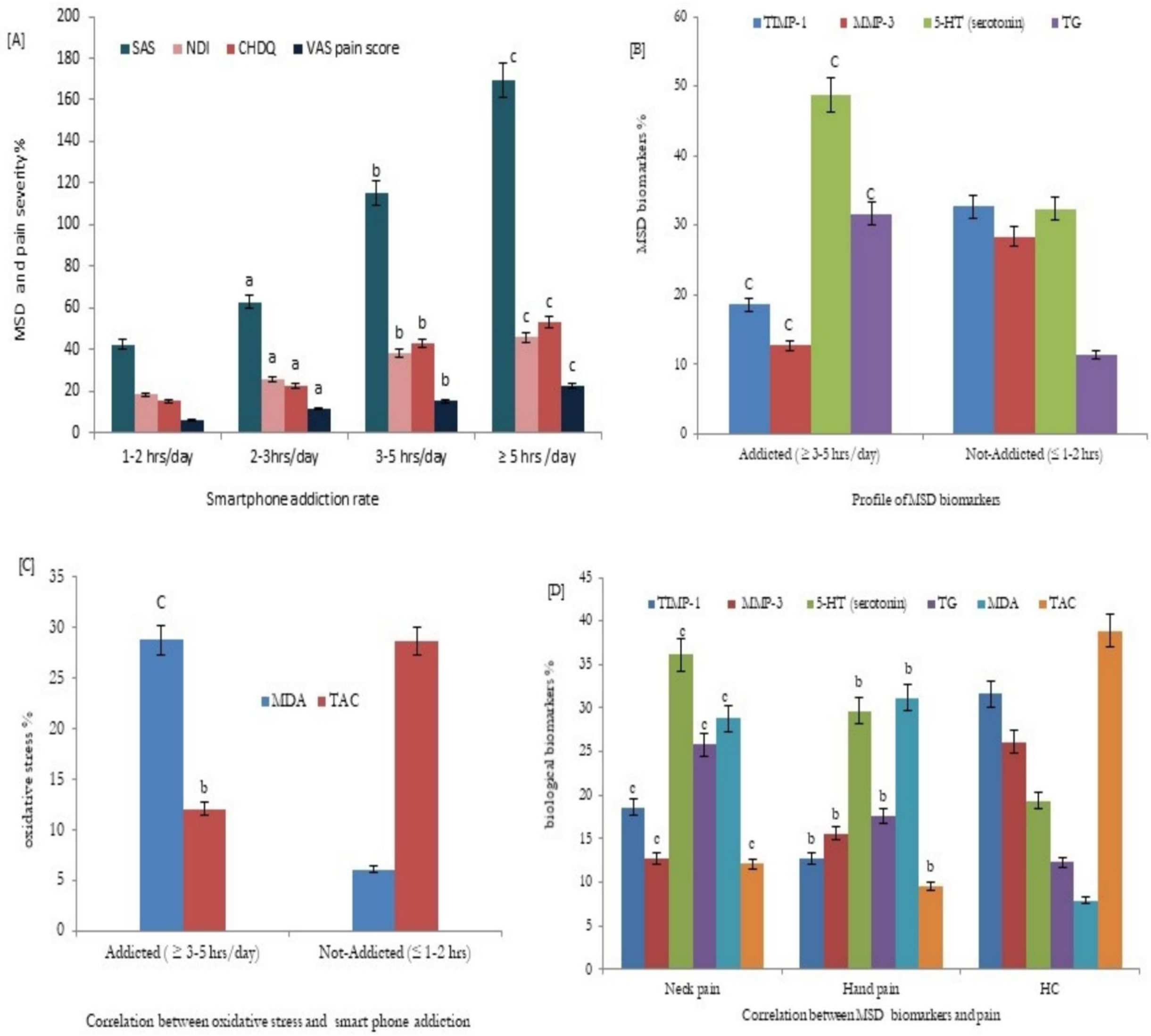

Fig. 2 A-D Association between smartphone use among university students based upon hours of phone use/day (M ± SD) (**A**), biological change in MSD biomarkers (**B**), oxidative stress (**C**), and correlation of MSD markers with neck and hand pain in addicted and healthy control participants (**D**). SAS: Smartphone Addiction Scale; NDI: Neck Disability Index; CHDQ: Cornell Hand Discomfort Questionnaire; VAS: Visual Analogue Scale; TIMP-1/TIMP-2: metallopeptidase inhibitor 1/2 (a tissue inhibitor of metalloproteinase); MDA: malondialdehyde; TAC: total antioxidant capacity; TG: triglycerides. 5-HT: 5-hydroxytryptamine (serotonin). $^{a}p < 0.05$, $^{b}p < 0.01$, $^{c}p < 0.001$

analog scale measurements for pain. Also, TIMP-1, TIMP-2, 5-HT, TG, MDA, and TAC biomarkers showed a significant correlation with the severity of MSD in the neck and hands of smartphone-addicted students and could be useful as biological bio-predictive parameters for evaluating MSD consequences among computer-based workers and smartphone-addicted users.

Lately, a significant portion of individuals aged 18–44, exceeding 79%, are found to predominantly use their smartphones throughout the day, experiencing intense pain in musculoskeletal areas, particularly around the neck and shoulders [1, 2]. Earlier studies indicated a notable addiction to smartphones, approximately 36 percentages in medical students studying in Saudi Arabia, closely tied to extended durations of smartphone usage [48]. The high incidence of such addiction, as observed in this research and others, might be attributed to the ease with which smartphones, compared to other touchscreen devices, provide access to extensive educational content online [1, 2, 58–64].

In this particular study, about 70% of the participants who frequently utilized smartphone apps were

Table 2 Correlations between musculoskeletal symptoms, MSD predictive biological markers, and smartphone addiction scores in university students

Parameters	Not addicted (36%; *n* = 90) SAS (18.6–36.1; 1–3 h./day)		Addicted (64%; *n* = 160) SAS (158.8–175.4; ≥ 3 h./day)	
	OR_{crude} (95% CI)*	$OR_{adjusted}$ (95% CI)#	OR_{crude} (95% CI)*	$OR_{adjusted}$ (95% CI)#
BMI	0.123 (0.10–0.156)[a]	0.13 (0.12–0.164)[a]	0.245 (0.196–0.350)[b]	0.250 (0.210–0.358)[b]
NDI score	0.214 (0.153–0.315)[a]	0.218 (0.165–0.320)[a]	0.316 (0.182–0.464)[c]	0.320 (0.197–0.480)[c]
CHDQ score	0.238 (0.213–0.321)[a]	0.245 (0.221–0.365)[a]	0.259 (0.152–0.364)[c]	0.265 (0.158–0.390)[c]
VAS pain score	0.234 (0.211–0.290)[a]	0.240 (0.235–0.310)[a]	0.357(0.312–0.420)[c]	0.365 (0.320–0.470)[c]
TIMP-1 (ng/mL)	0.231 (0.193–0.285)[a]	0.239 (0.198–0.289)[a]	0.258 (0.212–0.324)[c]	0.285 (0.225–0.332)[c]
TIMP-2 (ng/mL)	0.123 (0.108–0.215)[a]	0.135 (0.120–0.230)[a]	0.458 (0.312–0.584)[c]	0.462 (0.321–0.595)[c]
5-HT (serotonin; ng/ml)	0.223 (0.213–0.392)[a]	0.250 (0.236–0.410)[a]	0.289 (0.242–0.364)[c]	0.292 (0.252–0.386)[c]
TG	0.145 (0.123–0.165)[a]	0.152 (0.135–0.172)[a]	0.147 (0.132–0.215)[c]	0.155 (0.138–0.235)[c]
MDA (µ mole/L)	0.378 (0.351–0.475)[a]	0.395 (0.354–0.512)[a]	0.365 (0.295–0.450)[c]	0.375 (0.310–0.462)[c]
TAC	0.148 (0.125–0.215)[a]	0.155 (0.137–0.238)[a]	0.315 (0.250–0.415)[c]	0.321 (0.262–0.425)[c]

BMI: body mass index; MSD: musculoskeletal disorders; SAS: Smartphone addiction scale; NDI: Neck Disability Index; CHDQ: Cornell Hand Discomfort Questionnaire; VAS: Visual Analogue Scale; TIMP-1/TIMP-2: metallopeptidase inhibitor 1/2 (a tissue inhibitor of metalloproteinase); MDA: malondialdehyde; TAC: total antioxidant capacity; TG: triglycerides. 5-HT: 5-hydroxytryptamine (serotonin)

[a] $p < 0.05$

[b] $p < 0.01$

[c] $p < 0.001$

[*] Significant at the level 0.05 as analyzed by χ2 test

[#] adjusted for all variables in table as measured by multiple logistic regression

observed to be obese, with female participants displaying higher scores in the Neck Disability Index, Carpal Hand Discomfort Questionnaire, and Visual Analog Scale for pain, compared to their male counterparts. Recent findings also reported a link between smartphone addiction to diminished energy, disrupted sleep patterns, altered eating habits, changes in body weight, reduced physical activity, and academic performance, particularly in younger individuals [10]. The prevalence of smartphone addiction has pointed out in students who exhibit low physical activity and heightened levels of stress [65]. Consequently, the students participating in this study are likely to be less physically active due to obesity, which might contribute to their increased dependence on mobile phones. Moreover, conforming results were recently showed that the increase in the duration of social media use, significantly increases the sedentary behaviors of individuals and the risk of eating disorders among university students between the ages of 18–29. Consequently, it suggested to prevent unconscious social media use and proposed health risks among younger adults, education/seminars should be given to different age groups, including appropriate body image, healthy nutrition, and physical activity recommendations [66].

Also, recent results approved that there was a correlation between internet addiction (IA) with eating disorders and musculoskeletal health problems among university students. It was reported that participants who uses internet for longer periods had statistically significantly more back pain with a higher risk of eating disorders, compared to non-adducted smartphone users [67, 68].

Furthermore, this study advocated that the SAS scores were elevated, particularly among female students who engaged in prolonged smartphone use, suggesting a trend toward addiction. This addiction in our student sample positively correlated with NDI and CHDQ scores, indicative of average neck and shoulder pain and discomfort [12]. Such musculoskeletal issues could stem from the continuous and repetitive excursion of the head and neck towards the smartphone screen, a factor that may contribute to chronic neck pain and elucidate the robust link between SAS and NDI scores found in this study [69].

Moreover, existing studies have established that extensive texting on smartphones can detrimentally impact the musculoskeletal structure of the hand. This encompasses different pathologies, including the extensor pollicis longus tendinitis and myofascial pain in the thinner muscles, and risks of neck, shoulder, and LBP [70–72].

Additionally, previous research has underscored the role of biochemical changes in the development of certain MSD in both human and animal models [73, 74].

This study estimated TIMP-1, TIMP-2, 5-HT, TG, MDA, and TAC biomarkers in the serum samples of all smartphone-addicted and non-addicted students. The

Table 3 Correlations between musculoskeletal symptoms with MSD predictive biological markers in smartphone-addicted university students

Parameters	Not addicted (36%; *n* = 90) SAS (18.6–36.1; 1–3 h./day)			Addicted (64%; *n* = 160) SAS (158.8–175.4; ≥ 3 h./day)		
	MSD score			MSD score		
	NDI score	CHDQ score	VAS score	NDI score	CHDQ score	VAS score
TIMP-1 (ng/mL)						
OR_{crude} (95% CI)*	0.214 (0.178–0.298)[a]	0.211 (0.150–0.241)[b]	0.245 (0.210–0.381)[c]	0.325 (0.250–0.486)[c]	0.356 (0.310–0.485)[c]	0.296 (0.225–0.350)[c]
$OR_{adjusted}$ (95% CI)#	0.221 (0.198–0.312)[a]	0.225 (0.154–0.258)[b]	0.50 (0.254–0.441)[c]	0.345(0.290–0.510)[c]	0.360 (0.345–0.524)[c]	0.312 (0.235–0.380)[c]
TIMP-2 (ng/mL)						
OR_{crude} (95% CI)*	0.234 (0.148–0.311)[a]	0.155 (0.98–0.212)[b]	0.321 (0.152–0.425)[c]	0.285 (0.210–0.380)[c]	0.528 (0.290–0.612)[c]	0.296 (0.158–0.350)[c]
$OR_{adjusted}$ (95% CI)#	0.236(0.160–0.342)[a]	0.160(0.120–0.275)[b]	0.332(0.165–0.498)[c]	0.290 (0.230–0.415) [c]	0.532(0.320–0.645) [c]	0.315 (0.165–0.370)[c]
5-HT (serotonin; ng/ml)						
OR_{crude} (95% CI)*	0.127 (0.80–0.230)[a]	0.361 (0.160–0.442)[b]	0.412 (0.230–0.560)[c]	0.368 (0.152–0.442)[c]	0.325 (0.135–0.422)[c]	0.314 (0.115–0.385)[c]
$OR_{adjusted}$ (95% CI)#	0.135 (0.95–0.252)[a]	0.370 (0.168–0.455)[b]	0.420 (0.255–0.580)[c]	0.375 (0.160–0.450)[c]	0.330 (0.145–0.450)[c]	0.325 (0.125–0.395)[c]
TG						
OR_{crude} (95% CI)*	0.356 (0.280–0.430)[a]	0.145 (0.80–0.230)[b]	0.213 (0.180–0.330)[c]	0.125 (0.70–0.230)[c]	0.231 (0.120–0.312)[c]	0.298 (0.175–0.415)[c]
$OR_{adjusted}$ (95% CI)#	0.360 (0.290–0.480)[a]	0.150 (0.90–0.240)[b]	0.220 (0.210–0.360)[c]	0.130 (0.80–0.324)[c]	0.238 (0.160–0.330)[c]	0.315 (0.185–0.435)[c]
MDA (μ mole/L)						
OR_{crude} (95% CI)*	0.125 (0.79–0.200)[a]	0.378 (0.185–0.430)[b]	0.218 (0.180–0.350)[c]	0.235 (0.150–0.345)[c]	0.275 (0.120–0.377)[c]	0.432 (0.180–0.530)[c]
$OR_{adjusted}$ (95% CI)#	0.140 (0.80–0.230)[a]	0.385 (0.190–0.490)[b]	0.228 (0.195–0.370)[c]	0.240 (0.160–0.390)[c]	0.290 (0.145–0.412)[c]	0.450 (0.198–0.590)[c]
TAC						
OR_{crude} (95% CI)*	0.324 (0.115–0.490)[a]	0.148 (0.76–0.280)[b]	0.185 (0.60–0.215)[c]	0.256 (0.140–0.350)[c]	0.219 (0.70–0.310)[c]	0.318 (0.115–0.430)[c]
$OR_{adjusted}$ (95% CI)#	0.345 (0.130–0.530)[a]	0.155 (0.86–0.330)[b]	0.195 (0.80–0.230)[c]	0.265 (0.165–0.413)[c]	0.230 (0.80–0.350)[c]	0.328 (0.125–0.470)[c]

MSD: musculoskeletal disorders; SAS: Smartphone Addiction Scale; NDI: Neck Disability Index; CHDQ: Cornell Hand Discomfort Questionnaire; VAS: Visual Analogue Scale; TIMP-1/TIMP-2: metallopeptidase inhibitor 1/2 (a tissue inhibitor of metalloproteinase); MDA: malondialdehyde; TAC: total antioxidant capacity; TG: triglycerides. 5-HT: 5-hydroxytryptamine (serotonin)

[a] $p < 0.05$

[b] $p < 0.01$

[c] $p < 0.001$

[*] Significant at the level 0.05 as analyzed by χ2 test

[#] adjusted for all variables in table as measured by multiple logistic regression

data showed that TIMP-1, TIMP-2, 5-HT, TG, MDA, and TAC significantly changed in smartphone-addicted MSD students compared to healthy controls. The expressions of these markers are significantly linked with the severity of MSD in the neck and hands of smartphone-addicted students. In MSD cases, higher levels of markers indicating collagen breakdown were observed compared to control groups. Notably, there was a notable rise in matrix metalloproteinases (MMPs) in the synovial fluid and tissue samples from patients suffering from torn tendons in the rotator cuff and palmar fascia [75, 76].

The proposed mechanisms of the influence of the studied MSD parameters with the prolonged use of smartphones that for example, imbalances in the TIMP-1/TMP-2 ratio can lead to abnormal tissue remodeling and have been implicated in various pathological conditions, including musculoskeletal disorders. Also, prolonged smartphone use may contribute to oxidative stress due to factors such as increased screen time, sedentary behavior, and exposure to blue light. Elevated oxidative stress has been associated with various health conditions, including musculoskeletal disorders. Moreover, serotonin is a neurotransmitter that plays a crucial role in the regulation of mood, sleep, and pain perception which increases with the use of smartphones for longer periods. Elevated serotonin levels may be indirectly associated with chronic pain conditions and musculoskeletal disorders in smartphone users for a longer time as a result of the disorder in mood, sleep, and perception.

Our study had several limitations. Although our study with this small sample size generally showed the importance of studying the influence of prolonged use of smartphones on MSD among university students and or other smartphone users, and their association with biological changes in the levels of some biomarkers such as TIMP-1, TIMP-2, 5-HT, TG, MDA, and TAC, the lack of both larger sample size as well as long-term follow-up leads to a difficulty in seeing long-lasting changes in biomarker marker of MSD with considerable validity and reliability. The studied biomarkers were significantly achieved in many studies with such validity and reliability, and their roles in the development of certain MSD in both human and animal models were identified [71–76], however, their validity and reliability in the diagnosis of the impact of smartphone addiction for a long time on MSD is rare and larger cohort samples.

Our results can be interpreted as preliminary findings. Thus, further studies based on large sample sizes with long follow-ups are recommended to understand the potential association of these biological parameters with diagnosing the impact of smartphone addiction for long time of MSD among students and to establish a future model of biological diagnosis of the severity of smartphone addiction for a long time. In addition, the specific link between, TIMP-1, TMP-2, serotonin, and oxidative stress as markers of MSD in university students with smartphone addiction is not well-established and needs further investigation.

In summary, the present study found a relatively significant influence of smartphone addiction among university students, whereas the prevalence of upper body musculoskeletal symptoms is relatively high. Biological results of MSD biomarkers also indicate that smartphone addiction associated with musculoskeletal symptoms for university students when adjusted at relative significant values [ORadjusted (95% CI)] for each respective biomarker as mentioned in Tables 1 and 2, respectively. Altogether, this study provides information on risk and bio factors to alleviate the symptoms of musculoskeletal damage due to the use of smartphones in the future. In terms of health care, students with age range of 17–30 yrs addicted to smartphones may have a higher probability of developing upper body musculoskeletal symptoms.

Conclusion

The outcome of this current study reported that smartphone addiction for longer periods negatively impacted the pain in the muscles of the neck and the hands of university students. Prolonged smartphone use has shown a positive association with musculoskeletal pain in the muscles of the neck and the hand. In addition, TIMP-1, TIMP-2, 5-HT, TG, MDA, and TAC as predictive biomarkers for MSD were significantly correlated with the severity of neck pain and hand discomfort among students with Smartphone use addiction. Thus, for clinical importance, these markers could be useful as biological bio-predictive parameters for evaluating MSD consequences among computer-based workers and smartphone-addicted users. However, their validity and reliability in the diagnosis of the impact of smartphone addiction for a long time on MSD is required and needs future research using larger cohort samples. Caution should be taken towards the safe implementation of smartphone use and new public health education initiatives should to initiated among students about the physical health risks linked to the excessive usage of smartphones.

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Author contributions

A.H.A. S.A.G. A.A.R. and A.I. proposed the study conception and design. S.A.G. T.A. F.A. and A.A.R. completed the practical work. S.A.G. A.A.R. T.A. and F.A. collected data. A.I. contributed to the data analysis. A.H.A. S.A.G. T.A. F.A. and A.I. contributed to data interpretation. S.A.G. A.A.R. A.H.A. T.A. F.A. and A.I. prepared the manuscript's initial draft. A.H.A. S.A.G. A.A.R. T.A. F.A. and A.I. critically reviewed and edited the manuscript's intellectual content. All authors read and approved the manuscript's final version to be submitted or published and took responsibility for the intellectual content of the same manuscript.

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Availability of data and materials

All data generated or analyzed during this study will be available upon a reasonable request from the corresponding.

Declarations

Ethics statement and consent to participate

The study was performed between January and June 2022. The study protocol conformed to the ethical guidelines of the 1975 Declaration of Helsinki and was reviewed and approved by the Ethics Sub-Committee of King Saud University, Kingdom of Saudi Arabia, under file number ID: RRC-2022-028; dated: 15 January 2022. The study's objectives and intent were elucidated, and participants were provided with clear explanations. Subsequently, informed verbal consent was obtained from all the individuals involved.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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