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THE IMPACT OF SCREEN TIME, POSTURAL BEHAVIOR, AND PHYSICAL ACTIVITY ON THE MUSCULOSKELETAL SYSTEM OF HIGH SCHOOL STUDENTS

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ABSTRACT
The prevalence of musculoskeletal disorders among adolescents reaches 45-70%, with mobile device use in non-physiological postures considered a key modifiable risk factor. However, for the North Caucasus population, systematic studies linking behavioral patterns with objective orthopedic examination data are lacking. The aim of this study was to assess the prevalence of musculoskeletal disorders among high school students in Makhachkala and to identify behavioral risk factors associated with gadget use, learning posture, and physical activity. A cross-sectional study involving 840 adolescents aged 15-18 years undergoing routine preventive examination was conducted. All participants completed an anonymous questionnaire assessing screen time, predominant learning posture, and regularity of sports activities. Orthopedic examination included visual posture assessment, scoliometry, and forward head posture registration. Statistical analysis was performed using binary logistic regression with adjusted odds ratios. Musculoskeletal disorders were identified in 468 adolescents (55.7%). The strongest risk factor was studying in a lying position (aOR=4.92; 95% CI: 3.15-7.69), whereas regular sports activities acted as a protective factor (aOR=0.31; 95% CI: 0.22-0.44). High screen time (>6 h/day) increased the risk 2.68-fold compared with low screen time (<4 h/day); each additional hour increased the risk by 29%. The combination of sports absence and lying posture produced a synergistic effect: the risk rose to 7.84 (95% CI: 4.79-12.84), with musculoskeletal disorders in this subgroup reaching 80.3%. These findings substantiate the need for comprehensive preventive programs including postural behavior correction, screen time limitation, and mandatory promotion of regular physical activity.

KEYWORDS: musculoskeletal system, adolescents, screen time, postural behavior, physical activity, Makhachkala.

INTRODUCTION

Adolescence is a critical period of ontogenesis, when bone tissue has not yet completed mineralization, the muscular corset is actively forming, and the spine remains highly sensitive to prolonged static loads. It is at this age that postural habits are established, which either maintain the physiological axis of the body or reinforce a pathological motor stereotype [1-3]. Preventive examinations in Russian schools reveal postural abnormalities in 52% of children by the end of the first grade, and by high school this figure, according to various data, reaches 45-70%, with a considerable proportion of changes attributed to functional disorders and scoliotic posture – conditions that are potentially reversible with timely correction but capable of transforming into persistent deformities if left unaddressed [4-7].

Modern adolescents spend 6 to 9 hours daily in front of screens, and most of this time involves a static posture with a forward-tilted head and flexed spine. The key biomechanical phenomenon linking gadget use with musculoskeletal pathology is forward head posture [8,9]. In a neutral stance, the head, weighing 4-6 kg, is balanced by the neck muscles and exerts minimal load on the cervical spine; however, at a 30° tilt, this load increases to 18 kg, at 45° to 22-27 kg, and at 60° reaches 30 kg. Prolonged maintenance of this position triggers a cascade of pathophysiological changes: overstretching and weakening of the deep cervical flexors, compensatory shortening of the posterior muscle group, impaired proprioception, and the formation of a vicious postural cycle, into which the thoracic and lumbar regions are gradually drawn, leading to slouched posture, shoulder and scapular asymmetry, and altered pelvic biomechanics [10-12].

Over the past five years, a number of studies have confirmed the association between screen time and postural disorders in children. One study demonstrated that even 30 minutes of smartphone use with a head tilt of approximately 30° induces significant subjective discomfort in the cervicothoracic region [13]. Another investigation compared cervical spine kinematics during smartphone versus desktop computer use: the neck flexion angle reached 38.9° in the former case and remained nearly neutral at 0.2° in the latter, explaining why mobile devices, rather than stationary computers, become the primary trigger of postural disturbances [14,15].

Despite the strength of these findings, substantial gaps remain. The vast majority of studies have been conducted in Western Europe, the United States, and East Asia; many rely exclusively on questionnaires without objective orthopedic examination; and such behavioral patterns as learning posture (sitting at a desk, on a sofa, or lying down) and regularity of sports activities, as well as their combination, which may produce a synergistic effect substantially exceeding the risk of each factor individually, have remained beyond the scope of analysis [16-18].
The Republic of Dagestan is no exception to the global trend: high school students in Makhachkala and other cities of the region use gadgets just as intensively and think about proper posture just as rarely. However, no systematic data on the prevalence of musculoskeletal disorders among Dagestani adolescents are available in the accessible literature. The few studies addressing the health of schoolchildren in the North Caucasus deal primarily with somatic and infectious morbidity, leaving the medico-social aspects of the digital era outside the focus. The absence of local epidemiological data prevents the development of targeted preventive programs, forcing physicians to rely on nationwide or foreign protocols that are not always adapted to the real lifestyle of adolescents in the region [19,20].
The aim of the present study, conducted at the Dagestan State Medical University, was to assess the prevalence of musculoskeletal disorders among high school students aged 15-18 years undergoing preventive examinations in clinical centers of Makhachkala and to establish the association of the identified disorders with the volume and structure of screen time, preferred learning posture, and physical activity level. We hypothesized that prolonged smartphone use and the habit of studying in a lying position would be associated with a significantly higher risk of orthopedic pathology, that regular sports activities and sitting at a desk would act as protective factors, and that the combination of unfavorable patterns would produce a synergistic effect exceeding the sum of individual risks.

MATERIALS AND METHODS

A cross-sectional study was conducted at clinical centers in Makhachkala. The program included 9th-11th grade students aged 15-18 years undergoing routine preventive examination. Inclusion criteria were the presence of informed consent from the participant and their parents, as well as the absence of acute illness at the time of examination. Adolescents with congenital spinal pathology, severe trauma history, neuromuscular diseases, and those who completed less than 80% of the questionnaire were excluded from the analysis. The final sample comprised 840 participants.
An anonymous questionnaire completed immediately before the examination was used to assess behavioral risk factors. Participants reported the duration of smartphone, computer, and tablet use during a typical school day; total screen time was categorized as low (<4 h), moderate (4-6 h), and high (>6 h). In the postural behavior section, adolescents selected their predominant posture during learning and gadget use – sitting at a desk, sitting on an armchair or sofa without a desk, or lying down. Physical activity was assessed using the short version of the International Physical Activity Questionnaire for Adolescents (IPAQ-A); regular sports participation was defined as high or moderate activity at least twice a week with a total duration of 90 minutes or more. Age, sex, height, and body weight were extracted from medical records and direct measurement, with body mass index calculated according to WHO centile tables.
Orthopedic examination was performed by two practicing physicians who underwent preliminary calibration (agreement coefficient $\kappa \geq 0.85$). The examination in a standing position without shoes included visual postural assessment in three projections with registration of forward head posture, shoulder and scapular asymmetry (significance threshold >1 cm), waist triangle symmetry, thoracic kyphosis and lumbar lordosis shape, as well as scoliometry with measurement of the trunk rotation angle during the Adam's forward bend test (threshold for scoliotic deformity ≥5°). Based on the examination, each participant was assigned to one of four categories: "normal" (no visible abnormalities, rotation angle <5°), "postural disorder" (asymmetry or altered curvatures without fixed deformity), "scoliotic posture" (persistent asymmetry with rotation angle 5-7°), and "grade I-II scoliosis" (radiologically confirmed deformity with Cobb angle 10-35° according to medical records). For primary statistical comparisons, all three types of abnormalities were combined into a binary variable "pathology"; the "normal" category served as the reference. The validity of this pooling was verified by sensitivity analysis: when the 44 cases of structural scoliosis were excluded from the model, the odds ratio estimates for the main risk factors changed by less than 12%, confirming the robustness of the conclusions.
Quantitative variables were tested for normality using the Kolmogorov-Smirnov test with Lilliefors correction; normally distributed data were described as mean and standard deviation, otherwise as median and interquartile range. Groups were compared using Student's t-test or the Mann-Whitney U-test for quantitative variables, and Pearson's chi-squared test or Fisher's exact test for categorical variables. The contribution of behavioral factors to the risk of musculoskeletal disorders was assessed using binary logistic regression with calculation of adjusted odds ratios (aOR) and 95% confidence intervals; the model included screen time, posture, and regularity of sports activities with adjustment for age, sex, and BMI. The synergistic effect of the "lying posture × sports absence" combination was evaluated through statistical interaction in the multiplicative model. The dose-response relationship of screen time was tested using the Cochran-Armitage linear trend test. Differences were considered significant at $p<0.05$. An a priori power calculation showed that 378 participants were sufficient to detect an odds ratio of approximately 2.0 with a pathology prevalence of 40%; the sample of 840 participants provided a reliable margin for stratified analysis.

RESULTS

The study included 840 high school students (grades 9-11) aged 15 to 18 years (mean age 16.3±0.9 years). The sex distribution was balanced: 408 males (48.6%) and 432 females (51.4%). The majority of participants had a normal body mass index (n=602; 71.7%), while overweight was recorded in 126 individuals (15.0%) and underweight in 112 (13.3%). Detailed characteristics of the sample are presented in Table 1.

Table 1. Socio-demographic and anthropometric characteristics of participants (n=840)

Parameter	Value
Age, years (M±SD)	16.3 ± 0.9
Sex, n (%):	
Males	408 (48.6)
Females	432 (51.4)
Grade, n (%):	
9th	294 (35.0)
10th	280 (33.3)
11th	266 (31.7)
Body mass index, n (%):	
Normal	602 (71.7)
Overweight	126 (15.0)
Underweight	112 (13.3)

Orthopedic examination revealed musculoskeletal disorders in 468 adolescents (55.7% of the sample). Functional postural disorders predominated in the pathology structure (36.3%), scoliotic posture was recorded in 14.2%, and grade I-II scoliosis in 5.2%. No abnormalities were found in 372 participants (44.3%). Forward head posture was registered in 301 adolescents (35.8%), reaching 58.3% in the group with musculoskeletal disorders. Females had a slightly higher frequency of disorders compared with males (59.0% vs. 52.2%; p=0.041); however, after adjustment for multiple comparisons, the difference did not reach a high level of significance. The distribution of musculoskeletal system status categories in the total sample is shown in Figure 1.

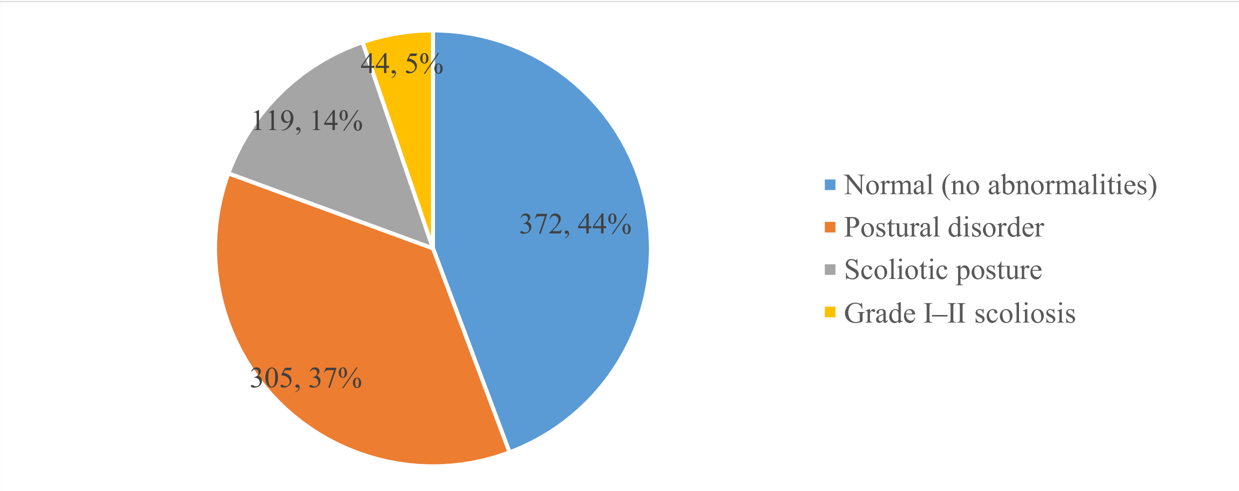

Figure 1. Distribution of musculoskeletal system status categories among 840 high school students (absolute numbers and percentages of the sample)

Mean total screen time on a school day was 6.8±2.4 h (smartphone – 4.5±1.9 h, computer equipment – 2.3±1.3 h). Only 15.8% of adolescents stayed within 4 hours or less, 38.5% fell within the 4-6 hour range, and 45.7% exceeded 6 hours. The predominant learning posture was sitting on an armchair or sofa without a desk (43.1%), while 31.9% studied at a desk and 25.0% studied lying down. Of the 210 adolescents with the habit of studying in a lying position, 83.8% preferred the prone or lateral position and only 16.2% lay on their back. Regular sports activities were reported by 52.9% of participants; 14.8% of the entire sample indicated a complete absence of physical activity outside school lessons. Mean daily sitting time was 8.7±2.1 h on school days and 7.4±2.4 h on weekends. Comparison of the "MSD pathology" (n=468) and "normal" (n=372) groups revealed statistically significant differences across all studied behavioral parameters (Table 2).

Table 2. Comparison of behavioral characteristics in groups with and without musculoskeletal disorders (M±SD or n/%)

Parameter	MSD pathology group (n=468)	Normal group (n=372)	p (χ^2/t)

Total screen time (h/day)	7.6 ± 2.2	5.7 ± 2.1	<0.001
Smartphone time (h/day)	5.2 ± 1.8	3.5 ± 1.5	<0.001
PC/laptop time (h/day)	2.4 ± 1.3	2.2 ± 1.2	0.024
Proportion with high screen time (>6 h/day), %	58.1%	29.8%	<0.001
Predominant posture, n (%):			
Sitting at a desk	97 (20.7%)	171 (46.0%)	<0.001
Sitting on an armchair/sofa	205 (43.8%)	157 (42.2%)	0.639
Lying down	166 (35.5%)	44 (11.8%)	<0.001
Regular sports (≥2 times/week), n (%)	181 (38.7%)	263 (70.7%)	<0.001
Forward head posture, n (%)	273 (58.3%)	28 (7.5%)	<0.001
Mean sitting time (h/day)	9.4 ± 2.0	7.9 ± 1.9	<0.001

The most pronounced differences were observed for the lying posture: among adolescents with MSD pathology, this habit was three times more frequent (35.5% vs. 11.8%), whereas regular sports activities were more than one and a half times more prevalent in the normal group (70.7% vs. 38.7%). Forward head posture proved to be virtually a marker of pathological status (58.3% vs. 7.5%). To quantify the contribution of each factor to the development of musculoskeletal disorders, a binary logistic regression model was constructed (Table 3), with "MSD pathology" status as the dependent variable.

Table 3. Factors associated with the presence of musculoskeletal disorders: logistic regression results

Factor	Unadjusted OR (95% CI)	p	Adjusted OR[1] (95% CI)	p
Total screen time (per 1 h/day)	1.38 (1.28-1.49)	<0.001	1.29 (1.18-1.41)	<0.001
Screen time >6 h/day (reference: <4 h)	3.02 (2.08-4.38)	<0.001	2.68 (1.79-4.02)	<0.001
Lying posture (reference: sitting at a desk)	5.31 (3.53-8.00)	<0.001	4.92 (3.15-7.69)	<0.001
Sitting on an armchair/sofa (reference: sitting at a desk)	1.57 (1.15-2.14)	0.004	1.41 (0.98-2.03)	0.063
Regular sports (yes vs. no)	0.26 (0.19-0.34)	<0.001	0.31 (0.22-0.44)	<0.001
Sex (females vs. males)	1.32 (1.01-1.72)	0.042	1.48 (1.07-2.05)	0.018

[1] – model adjusted for age, sex, BMI, and simultaneous inclusion of all listed factors

The strongest risk factor was the habit of studying in a lying position: the adjusted odds ratio was 4.92 (95% CI: 3.15-7.69) compared with sitting at a desk. The "sitting on an armchair or sofa" posture lost significance after adjustment (aOR=1.41; p=0.063), indicating its intermediate nature. High screen time (>6 h/day) increased the risk 2.68-fold compared with low screen time (<4 h), with each additional hour increasing the risk by 29% (aOR=1.29; 95% CI: 1.18-1.41). Regular sports activities proved to be a strong protective factor (aOR=0.31; 95% CI: 0.22-0.44). The risk was 48% higher in females (aOR=1.48; 95% CI: 1.07-2.05). The results of the analysis of the combination of two unfavorable patterns (the habit of studying lying down and sports absence) are presented in Figure 2 and Table 4.

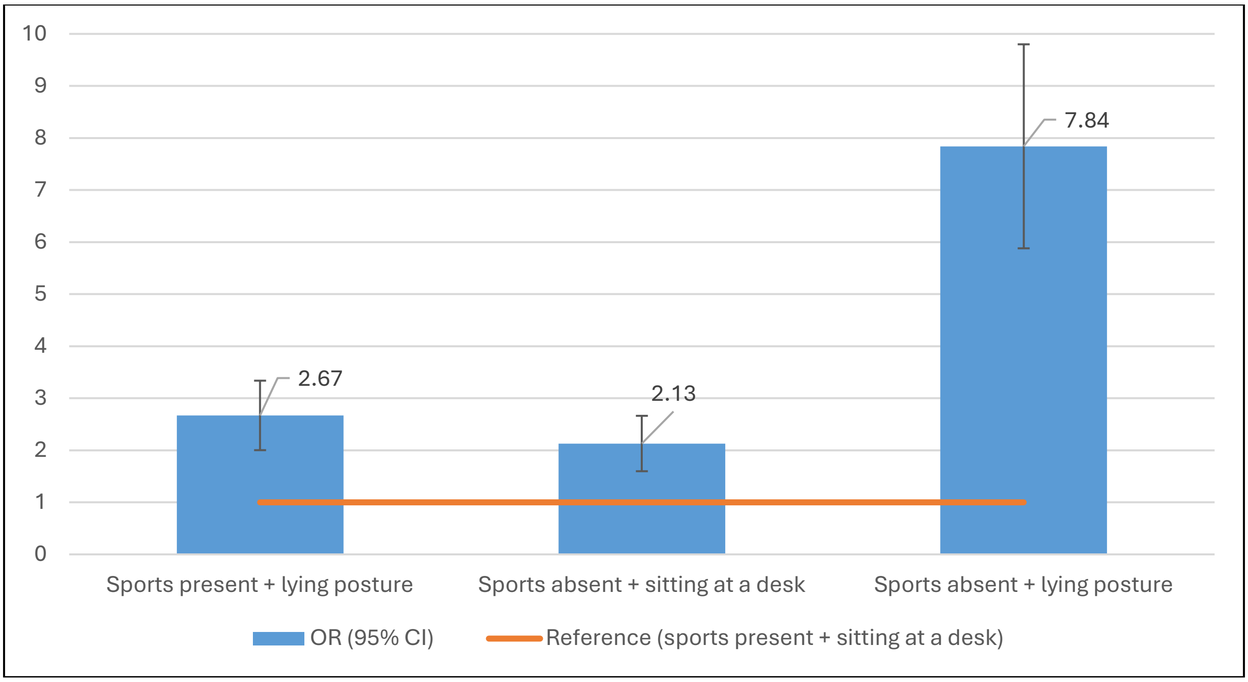

Figure 2. Odds ratios (OR) for different combinations of behavioral risk factors (reference group: "sports present + sitting at a desk")

Table 4. Prevalence of musculoskeletal disorders depending on the combination of factors ("lying posture" and "sports absence") and synergistic effect

Combination	n in group	Proportion with MSD pathology, %	OR (95% CI)*	p
Sports present + sitting at a desk	142	24.6%	1.00	–
Sports present + lying posture	68	48.5%	2.67 (1.65-4.32)	<0.001
Sports absent + sitting at a desk	126	56.3%	2.13 (1.34-3.38)	0.001
Sports absent + lying posture	142	80.3%	7.84 (4.79-12.84)	<0.001

- reference group: "sports present + sitting at a desk"

The combination of "sports absent + lying posture" produced a supra-additive effect: the observed odds ratio (7.84) exceeded that expected under additive action of the factors (2.13 × 2.67 ≈ 5.68). The relative excess risk due to interaction was 2.73 (95% CI: 1.21-4.25; p=0.008). Stratified analysis by screen time categories revealed a clear gradient: the proportion of musculoskeletal disorders increased with the number of hours spent in front of screens (32.3% at <4 h/day, 48.9% at 4-6 h/day, and 69.5% at >6 h/day; linear trend p<0.001). In the group with low screen time (<4 h), the frequency of musculoskeletal disorders remained relatively high (32.3%), indicating the contribution of posture and physical activity. With screen time exceeding 6 hours, the proportion of pathology reached nearly 70%, underscoring the critical role of digital overload as a modifiable risk factor. Thus, the prevalence of musculoskeletal disorders among high school students in Makhachkala was 55.7%, with functional postural disorders predominating (36.3%). The strongest risk factor was the habit of studying in a lying position (aOR=4.92), whereas regular sports reduced the risk more than threefold (aOR=0.31). High screen time increased the risk 2.68-fold with a clear dose-response effect, and the combination of sports absence and lying posture produced a synergistic effect, increasing the risk 7.84-fold compared with the reference group.

DISCUSSION

In this study conducted on a representative sample, the prevalence of musculoskeletal disorders among high school students in Makhachkala was 55.7%, which is consistent with nationwide data reporting MSD pathology detection in 45-70% of schoolchildren. The strongest behavioral risk factor was the habit of studying in a lying position (aOR=4.92), whereas regular sports activities acted as a powerful protective factor (aOR=0.31) [21,22]. For the first time in this population, a synergistic effect of the combination of sports absence and lying posture was demonstrated, increasing the risk nearly eightfold compared with the reference group.

The association between the lying posture and MSD pathology deserves particular attention. Adolescents who prefer doing homework and using gadgets while lying down have an almost fivefold risk of disorders compared with those who study at a desk [23,24]. This result substantially exceeds the values previously reported for screen time-related factors. Earlier published studies demonstrated the development of subjective discomfort after as little as 30 minutes of smartphone use and documented a difference in cervical spine kinematics of approximately 30° between smartphone and desktop computer use; however, they did not translate these observations into odds ratios or assess the association with chronic disorders [25-27]. Our data complement these findings by showing that it is not so much the screen time itself as the posture in which it is spent that constitutes the critical factor [28]. The "sitting on an armchair or sofa without a desk" posture lost significance after adjustment (aOR=1.41; p=0.063), occupying an intermediate position between ergonomically correct and overtly harmful [29]. The protective effect of sports (aOR=0.31) is expected and consistent with the extensive literature on the role of the muscular corset in compensating for static loads. Notably, even with low screen time (<4 h), the proportion of MSD disorders remained relatively high (32.3%), suggesting that posture and physical activity may be more important than absolute time spent in front of screens [30].

The most important finding is the supra-additive interaction between sports absence and the habit of studying while lying down. In the group of adolescents with both risk factors, the proportion of disorders reached 80.3% (aOR=7.84), whereas with only one factor present the risk increased 2-2.7-fold. The RERI calculation confirmed the presence of positive synergism (2.73; 95% CI: 1.21-4.25) [31,32]. This means that preventive interventions targeting only one factor will be less effective than comprehensive programs addressing both ergonomics and physical activity simultaneously [33,34].

Females had a higher risk of MSD disorders even after adjustment for other factors (aOR=1.48; 95% CI: 1.07-2.05), which is consistent with data on the higher prevalence of scoliotic deformities among adolescent girls and may be explained by both hormonal and behavioral characteristics [35]. The clear dose-response effect of screen time (linear trend p<0.001; each additional hour increased the risk by 29%) supports a probable causal relationship, although the cross-sectional design limits the definitiveness of this conclusion [36,37]. The absence of a significant difference in PC and laptop use time between the groups with and without pathology is explained biomechanically: when working at a desktop computer, the screen is at eye level and the neck flexion angle is close to neutral, whereas a smartphone provokes a head tilt of 30-45°. It is mobile devices, not computer equipment, that constitute the primary source of the problem [38,39]. Time spent with paper books and notebooks also did not correlate with the risk of disorders (p=0.12), since traditional reading and writing typically occur in an organized posture at a desk. Therefore, the problem lies not in the learning process itself but in the way it is organized in the digital era [40-42].

The practical significance of the obtained results lies in the fact that just three screening questions (about the habit of studying lying down, regularity of sports, and smartphone use time) can identify with high probability an adolescent requiring an in-depth orthopedic examination. For parents, the key message is the priority of posture and physical activity over strict screen time restrictions: organizing an ergonomic workspace and encouraging sports may be more effective than prohibitions [43-45]. Schools should include behavioral risk factor screening in preventive examinations and conduct educational sessions emphasizing specific rules for working with gadgets – not lying down with a phone, taking breaks every 30-40 minutes, and using stands that raise the screen to eye level [46-48].

The study limitations include the cross-sectional design, which does not allow establishing causal relationships and does not exclude reverse causality (adolescents with existing postural disorders may choose a lying posture that is more comfortable for them) [49-51]. The questionnaire relied on subjective assessments, creating a risk of socially desirable responses. Diagnosis was performed without universal radiological confirmation, although sensitivity analysis showed that excluding cases of structural scoliosis did not change the assessment of the contribution of behavioral factors. The study was conducted in a single city, which limits geographical generalization; however, the consistency of the obtained data with international studies indicates the universal nature of the identified patterns. The strengths of the study include the large sample size, the combination of objective examination with questionnaires, and the analysis of synergistic interaction between risk factors. Further research should include prospective cohort observation, randomized trials of ergonomic interventions, and replication of similar studies in other regions of Russia to develop regionally adapted preventive programs.

CONCLUSION

This study, conducted on a sample of 840 high school students in Makhachkala, revealed musculoskeletal disorders in 55.7% of adolescents, with functional postural disorders predominating (36.3%). The strongest risk factor was the habit of studying in a lying position (aOR=4.92), whereas regular sports activities reduced the risk more than threefold (aOR=0.31). High screen time (>6 h) increased the risk 2.68-fold with a clear dose-response effect, with mobile devices, rather than desktop computers, making the primary contribution. The combination of sports absence and lying posture produced a synergistic effect, increasing the risk to 7.84, with the proportion of disorders in this subgroup reaching 80.3%. Practical recommendations include three-question screening during preventive examinations, organization of an ergonomic workspace, educational sessions in schools, and the introduction of posture change reminders in applications. Limitations are associated with the cross-sectional design and the subjectivity of questionnaire data; prospects lie in prospective cohort and interventional studies. The key message: an adolescent who prefers studying while lying down and does not engage in sports has an almost eightfold risk of musculoskeletal pathology, making prevention at this age an investment in spinal health for decades to come.

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Authors' contribution: All authors contributed equally to the study design, data collection, statistical analysis, and manuscript preparation.

Conflict of interest: The authors declare no conflict of interest.

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Ethics statement: The study was conducted in accordance with the ethical standards of the institutional research committee of Dagestan State Medical University (Makhachkala, Russia) and with the principles of the Declaration of Helsinki (2013 revision). Written informed consent was obtained from all participants and their legal representatives prior to enrollment. All questionnaire data were collected anonymously. Orthopedic examination findings and anthropometric measurements were coded and stored on a secure computing environment in compliance with applicable data protection regulations. Patient confidentiality was maintained throughout the study by removing all personal identifiers prior to analysis and publication.

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