ISSN: 2572-3243

Young et al. J Musculoskelet Disord Treat 2022, 8:114
DOI: 10.23937/2572-3243.1510114
Volume 8 | Issue 2
Open Access

Journal of
Musculoskeletal Disorders and Treatment

SYSTEMATIC REVIEW

Effects of Electronic Usage on the Musculoskeletal System in Adolescents and Young Adults: A Systematic Review

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Abstract

Background: Rapid developments in technology demand the use of various electronic devices in daily life. Adolescents and younger adults are reported to consume more technology compared to other age groups. Examining the health implications of device use may assist with population level prevention and wellness strategies and stakeholder education.

Objective: To systematically examine the literature regarding the effects of electronic device usage on the musculoskeletal system in adolescents and young adults.

Method: Four electronic databases (OVID Medline, PubMed, EBSCOhost, and Scopus) were searched for peer-reviewed articles published in English between 2011 and 2021. All selected articles were critically appraised and examined for risk of bias. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were used to report data.

Result: Sixteen articles met the inclusion criteria. The evidence synthesis revealed an association between electronic device use and musculoskeletal impairments. Notably, excessive use and non-neutral postures during the use contributed to musculoskeletal discomfort and disorders. Neck, upper and lower back, and upper extremities were the most affected body regions.

Conclusion: Prolonged use of electronic devices and maladaptive postures while using may contribute to musculoskeletal impairments in adolescents and young adults.

Keywords

Occupational therapy, Posture, Upper extremity, Pain, Electronics

Introduction

Technology has become an integral part of our lives. To access technology, people use electronic gadgets. During recent years, touchscreen smartphone devices have become increasingly accessible to all ages and budgets and therefore, are often commonly used on a daily basis [1]. Approximately 61% of the global population use the internet, 67% use a mobile device, and 56.8% actively use social media. Additionally, social media usage has increased by 13.1% in the past 12 months [2]. Due to the greater accessibility of and higher demand for technology, a resulting dependency has developed in educational and employment settings. Further, the recent pandemic has caused a shift toward and surge in the electronic device usage for work and educational purposes.

The use of electronic devices, including mobile computers, leads to frequent deviation from neutral body positioning, such as non-neutral posture, sustained posture, repetitive motions, and awkward movements that causes stress to musculoskeletal system. This can

Citation: Young JL, Snell MG, Robles O, Kelso JE, Kammitsis AM, et al. (2022) Effects of Electronic Usage on the Musculoskeletal System in Adolescents and Young Adults: A Systematic Review. J Musculoskelet Disord Treat 8:114. doi.org/10.23937/2572-3243.1510114

Accepted: June 28, 2022: **Published:** June 30, 2022

result in ergonomic difficulties which may contribute to development of musculoskeletal disorders (MSDs) [3]. MSDs are defined as injuries and/or disorders of the muscles, tendons, cartilage, joints, and spinal discs [4].

Literature reveals a strong association between device use and musculoskeletal issues. Xie, et al. explored the physical demands imposed on muscles and joints in different body regions through the use of electronic devices and found that typing on the computer placed higher demand on the neck and back muscles (upper and lower trapezius) and hand muscles (wrist and finger extensors) compared to touchscreen typing [5]. They also found that greater demand was placed on the neck extensors and thumb muscles during texting on touchscreen smartphones. Kaya Aytutuldu, et al. also found a strong association between symptoms in the upper extremity and those who regularly used computers at work [6]. Yu, et al. reported that head and neck issues were associated with poor placement of the screen in mobile computer users (laptop/tablet) [7].

The positioning of devices in relation to the users was found to be a contributor to the risk of back pain and the symptom severity is influenced by factors such as posture, devices used, duration of use, and gender [8,9]. Yoakum, et al. examined the influence of anthropometric factors such as height, weight, and sex of individuals on neck positions when using devices. They attributed the degree of impact of neck flexion to sex and height characteristics, and posited that females experience more mandibular protrusion with device use than males [10].

Evidence indicates that smartphone usage may also lead to musculoskeletal impairments related to the hand, such as pain near the base of the thumb, De Quervain's tenosynovitis, and osteoarthritis of the first carpometacarpal joint [11-13].

MSDs have huge economic implications for society. The costs related to MSDs include, but are not limited to medical expenses, disability, and lost income. The direct and indirect costs related to MSDs, from 2004-2006, were estimated to be $576 billion and $373 billion respectively [14]. Individuals with MSDs may experience disability and reduced quality of life, which in turn may affect their participation in daily occupations, including education and work, leading to income loss. Employers may incur costs related to decreased productivity and increased absenteeism of their workforce. In 2012, 29% of days off from work were attributed to MSDs [14].

Device usage is popular among youth. The prevalence of device usage was found to be high among young adults and adolescents [15]. Many young adults and adolescents own and use gadgets like cell phones, tablets, and laptops. They use devices to communicate, learn, play, and pursue hobbies. The literature is limited in identifying the effects and long-term implications of device usage among young adults and adolescents.

As prolonged electronic device usage is generally believed to be associated with MSDs, it is possible that the prevalence of MSDs will increase alongside the rise in technology consumption. Given the prevalence and high economic implications of MSDs, it is essential to examine the contributing factors to develop effective

Table 1: Search strategies and databases.

Data Base	Search Terms	Limitations	Articles
Ovid	(“Musculoskeletal disease”) AND (“smartphone” OR “cellphone”)	Limit to English Limit to publications 2011 - 2021 Limit to adolescents and young adults Exclusion: Musculoskeletal treatments using electronics	3
PubMed (3 Search Strings)	(1.) “musculoskeletal condition” AND “tablet use” (2.) “electronic use” AND “effect” AND “musculoskeletal” AND “phones” (3.) “electronic use” AND “effect” AND “musculoskeletal” AND “videogames”	(1.) Publication date: last 10 years (2.) Filters applied: in the last 10 years, Humans, Young Adult: 19-24 years (3.) Filters applied: 10 years, Humans, Young Adult: 19-24 years	(1.) 4 (2.) 2 (3.) 1
EBSCOhost	(“musculoskeletal diseases” OR “diagnosis, musculoskeletal”) AND (“smart phone” OR “cellular phone” OR “tablets” or “digitizers”)	Limit to English Limit to publications 2011-2021	4
SCOPUS	“tablet” AND “use” AND “musculoskeletal” AND “pain”	Limit to health professions	2

prevention and stakeholder education strategies. Hence, this systematic review attempts to examine the current evidence on the effect of electronic device usage on the musculoskeletal system in young adults and adolescents.

Methods

Search strategies and databases

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines served as the model for this systematic review [16]. The first six authors determined the search terms with guidance from the institution's librarian (Table 1). To determine initial eligibility, authors reviewed article titles and abstracts from the following databases: Scopus, Ovid, PubMed, and EBSCOhost. Two additional sources were located from reviewing the search results' reference lists. Risk of bias and level of evidence were determined for each reference extracted, based on the guidelines recommended by the American Occupational Therapy Association (AOTA) [17-19]. To determine the reliability of the evidence, bias was graded as low, moderate, or high. The authors used the following inclusion and exclusion criteria to select articles for the review. Disagreements in article selection were resolved through discussion and consensus. A summary of article exclusions with reasoning is presented in the PRISMA diagram (Figure 1).

Inclusion criteria

We used the following inclusion criteria to identify

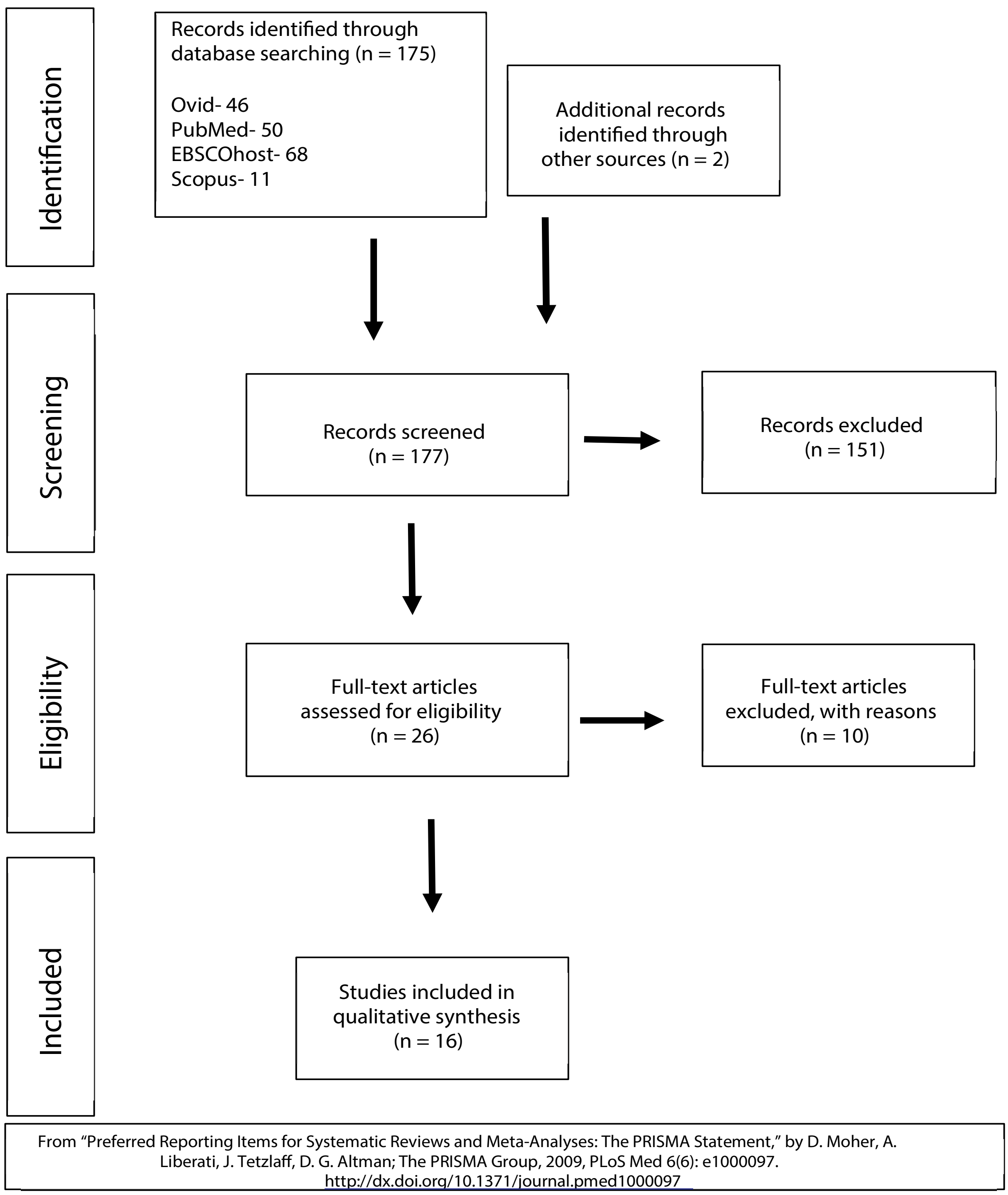

Figure 1: PRISMA Diagram

Table 2: Risk of bias.

Citation	Study Question or Objective Clear	Eligibility or Selection Criteria Clearly Described	Participants Representative of Real World Patients	All Eligible Participants Enrolled	Sample Size Appropriate for Confidence in Findings	Intervention Clearly Described and Delivered Consistently	Outcome Measures Prespecified, Defined, Valid/ Reliable, and Assessed Consistently	Assessors Blinded to Participant Exposure to Intervention	Loss to Follow Up after Baseline 20% or Less	Statistical Methods Examine Changes in Outcome Measures from Before to after Intervention	Outcome Measures were Collected Multiple Times before and after Intervention	Overall Risk of Bias Assessment (Low, Moderate, High Risk)
Betsch, et al. [30]	Y	Y	N	Y	N	Y	Y	N	NA	NA	NA	Low
Choi, et al. [31]	Y	Y	N	Y	N	Y	Y	N	NA	NA	NA	Low
Douglas & Gallagher [22]	Y	Y	N	Y	N	Y	Y	N	NA	NA	NA	Low
Elserty, et al. [23]	Y	Y	N	Y	Y	Y	Y	N	NA	NA	NA	Low
Emodi-Perlman, et al. [32]	N	Y	N	Y	N	Y	Y	N	NA	NA	NA	Moderate
Gustafsson, et al. [24]	Y	Y	Y	Y	Y	NA	Y	NA	N	NA	NA	Low
Korpinen & Pääkkönen [33]	Y	Y	Y	Y	Y	NA	Y	NA	NA	NA	NA	Low
Lin, et al. [25]	Y	Y	N	Y	N	Y	Y	NA	NA	NA	NA	Low
Pais, et al. [34]	Y	Y	Y	Y	N	Y	Y	N	NA	NA	NA	Low
Queiroz, et al. [35]	Y	Y	N	Y	Y	Y	Y	NA	NA	NA	NA	Low
Short, et al. [36]	Y	Y	N	Y	N	Y	Y	NA	NA	NA	NA	Low
Silva, et al. [26]	Y	Y	Y	Y	Y	NA	Y	NA	NA	NA	NA	Low
Szucs, et al. [27]	Y	Y	Y	Y	N	Y	Y	N	NA	NA	NA	Low
Tapanya, et al. [28]	Y	Y	Y	Y	Y	Y	Y	N	NA	NA	NA	Low
Toh, et al. [29]	Y	Y	N	Y	Y	Y	Y	N	N	NA	Y	Low
Young, et al. [37]	Y	Y	N	Y	N	Y	Y	N	NA	NA	NA	Low

Note: Y: Yes; N: No; NR: Not Reported; NA: Not Applicable; Scoring for overall risk of bias assessment is as follows: 0-3 N, Low risk of bias (L); 4-8 N, Moderate risk of bias (M); 9-11 N, High risk of bias (H).

Citation: Table format adapted from National Heart Lung and Blood Institute [18].

articles for this review: (i) Articles published in peer-reviewed journals between 2011 and 2021; (ii) Articles published in English; (iii) Articles that included human participants aged between 10-35 years; (iv) Articles that met a minimum evidence level of 3B as per the evidence table recommended by the AOTA [17]; and (v) Articles that focused on musculoskeletal issues associated with electronic usage. For this review, we considered the use of smartphones, handheld gaming devices, tablets, laptops, and computer devices as electronic usage.

Exclusion criteria

We excluded articles that used electronics as a form of treatment for musculoskeletal diseases and studies that focused on additional factors for effects on the musculoskeletal system other than electronic usage. We also excluded articles that had participants with pre-existing mental or musculoskeletal disorders which could potentially be confounding factors. Two studies were excluded after initial review due to having a low level of evidence, and participants outside the criteria age, respectively [20,21].

Results

Of the 16 articles that met the inclusion criteria, eight were identified as level 2B evidence [22-29] and eight were level 3B evidence [30-37]. The authors examined all 16 articles for risk of bias using the NIH Quality Assessment Tool for Before-After (Pre-Post Studies) with No Control Group (Table 2) [18]. Fifteen articles were determined to have low risk of bias [22-31; 33-37] and one was determined to have moderate risk of bias [32]. In seven studies, [23,24,26,29,32,33,35] the authors utilized a self-report survey or questionnaire as the outcome measure collecting data related to pain level, location, and type, presence of numbness/tingling, presence of bruxism (teeth grinding), and diagnosis of temporomandibular disorder. In eight studies [22,27,28,30,31,34,36,37], the authors reported using quantitative assessment measures to collect data related to posture, spinal kinematics, joint positioning and angles, and pain. In one study [25], authors examined the results using both types of outcome measures (a self-report questionnaire on perceived musculoskeletal discomfort and quantitative assessment measures of posture and upper extremity positioning).

The selected studies examined electronic usage pertaining to general amount/duration of use, age at start of use, frequency of use, time of use per week, positioning during usage, purpose associated with use, and types of electronic devices used. Electronic devices used included cellphones/smartphones/mobile phones, tablets, desktop computers, laptop computers, and gaming devices.

Table 3 presents the evidence synthesis. To determine the effect of electronic usage on various body segments, the following analysis groups the articles by the regions of the body reported to be affected (head and neck, upper and lower back, and upper extremity).

Head & neck

Twelve studies provided evidence of the effects of electronic usage on the cervical spine. From these studies, 12,253 participants were investigated for the effects of electronic devices on the musculoskeletal system.

Elserty et al. [23] found that the most common area for discomfort was the neck region. Korpinen & Pääkkönen [33] and Queiroz et al. [35]. reported that about half of their study participants experienced neck related symptoms. Most of the neck problems appear to be related to increased neck flexion. Tapanya, et al. found that greater neck flexion during smartphone use showed increased biomechanical burden on the cervical spine, resulting in more musculoskeletal discomfort and risk of injury to the area [28]. Short, et al. found a trend that cervical neck flexion during smart phone use could contribute to deformity over time [36]. Similarly, Szucs, et al. found that using a tablet, whether supported on a table or held in the hands, produced the greatest amount of forward head shift and neck flexion [27].

The duration of device usage was reported to contribute to neck related symptoms. Gustafsson, et al. explored the relationship between number of texts sent per day and physical symptoms and found that a higher number of texts sent was associated with neck pain [24]. Lin, et al. found an association between duration of electronic use and posture, with the neck being one of the body regions showing a 13-38% joint movement increase from the middle to end of a typing session [25]. Pais, et al. also assessed long term device usage on neck flexion. The findings indicated a negative association between the duration of digital device use and neck flexion ability [34]. Silva, et al. found that an average electronic device use of 583 minutes per week was associated with pain in the cervical region [26].

Non-neutral postures and patterns of device use were also reported to contribute to musculoskeletal symptoms around the neck region. Douglas and Gallagher used x-rays to examine the effect of trunk position on various intervertebral joints in the cervical spine, including sitting in a reclined, semi-reclined, or upright posture and reported increased demand on the neck in each position when compared to neutral [22]. Toh, et al.'s study revealed a prospective association between the patterns of mobile touch screen device use and musculoskeletal symptoms in adolescents [29].

Aside from the musculoskeletal symptoms related to the cervical spine, one study [32] revealed symptoms related to the temporomandibular joint. In this cross-sectional study, the authors surveyed 578 young adult participants (18 to 35 years of age) on the effects of modern cellular technology on various aspects of life

DOI: 10.23937/2572-3243.1510114 ISSN: 2572-3243

Table 3: Evidence table.

Author/Year	**Level of Evidence** **Study Design** **Risk of Bias**	**Participants** **Inclusion Criteria** **Study Setting**	**Intervention** **Control Groups**	**Outcome Measures**	**Results**	**Strengths** **Weaknesses**
Betsch, et al. [30]	Level 3B Cross Sectional Cohort Study *Risk of Bias* Low	*Participants* N = 50 participants for standing measures (24F/26M) (Mean age = 25.3) 34 Participants for dynamic measures (16F/18M) (Mean age = 25.4) *Inclusion Criteria* - Volunteers from the university community - Aged 18-50-years-old - more than one year experience using a touch smartphone - daily smartphone usage > 60 minutes. *Study Setting* Simulation in a laboratory	*Intervention* - Each participant conducted a one-handed and two-handed texting task while standing and while walking on a treadmill. - Participants simulated a phone call with the smartphone to their ear while standing and walking on a treadmill. - As a control, participants were standing in a neutral standing position, and while walking on a treadmill without a smartphone. - Participants completed the smartphone addiction scale and SF-36 health questionnaire.	*Outcome Measures* - Spinal posture and pelvic position during standing and while walking on a treadmill was measured using a surface topography system. - Self-report smartphone addiction scale (SAS) *Devices Tested* - Smartphone	*Significant Findings* - All smartphone tasks lead to a significant increase in thoracic kyphosis and trunk inclination during standing and while walking. - A significantly increased lumbar lordosis was also found. - Texting with one or two hands correlated with increased surface rotation. - No associations between smartphone addiction and changes in spinal posture were reported.	*Strengths* - Reliable system used to measure spinal posture and pelvis position. - Extensive statistical analysis. - Control measurements recorded prior to testing. *Weaknesses* - Study design does not allow us to draw conclusions about changes in spinal posture over time with smartphone use. - Size of sample. - Some participants did not want to undergo dynamic measurements as it meant revealing their trunk.

Choi, et al. [31]	Level 3B Cohort Study *Risk of Bias* Low	*Participants* 20 subjects (11M/9F) (Mean age = 21.5) *Inclusion Criteria* - No previous or current musculoskeletal disorders. - Have owned a touch-smartphone for more than three years. - No difficulty in using a smartphone while walking. *Study Setting* Simulation in a laboratory	*Intervention* Walking on a treadmill in five different conditions: - normal walking without using a phone, - conducting one-handed browsing while walking, - two-handed texting while walking, - walking with one arm bound, - walking with both arms bound.	*Outcome Measurements* - Spine kinematics variables and the myoelectric activity levels of the lumbar erector spinae muscles were quantified and compared between the five walking conditions *Devices Tested* - Smartphone	*Significant Findings* - Thoracic kyphosis and lumbar lordosis was more significant when using a phone ($P < 0.05$). - The median level of muscle activity was 16.5% (browsing) to 31.8% (texting) greater than walking without a smartphone, with the differences being significant ($P < 0.05$). - No significant difference in muscle activity found between the two bound walking conditions.	*Strengths* - Data collected and quantified by reliable systems. - A reference posture was recorded before the experiment for each participant. *Weaknesses* - Examination of muscle activity and spine kinematics observed only for 5 minutes. - Simulation of walking in a laboratory may not represent real usage environments of smartphone use on the street. - Potential effects of environmental factors were not considered.

Douglas & Gallagher [22]	Level 2B Prospective cohort study *Risk of Bias* Low	*Participants* N= 22 young adults (11M/11F) 20-23 yrs old. *Inclusion Criteria* - No previous neck or spine injury - No chronic headaches - No allergies to rubbing alcohol - No exposure to lumbar spine x-ray, GI tract x-ray, barium enema x-ray, or CT scans within the past two years. - Women- no chance of pregnancy *Study Setting* University of Arkansas- Walker Health Center	*Intervention* - X-rays taken while participants were seated in 5 different postures (neutral, max neck flexion, upright seated, semi-reclined, reclined) with biomarkers placed on 4 different part of their body	*Relevant Measures taken* - Participant were instructed to read/look at a tablet without using the arm rests - Measures taken were centroid cervical lordosis (CCL), skull angle relative to the horizontal, gravitational moment arm (GMA), And intervertebral Joint angles between skull-C1, C1 -C2, C2-C3. *Devices Tested* -Tablet	*SignificantFindings* - CCL was more flexed in each position compared to neutral. - There was a significant effect of trunk position for the moment arm. GMA of the head was smallest when reading a tablet with a recline trunk vs. semi-reclined and upright. Upright position was not significantly different. - Trunk position also had a significant effect on skull angle. Skull angle was less flexed in neutral compared to the 3 reading postures. Of the 3 reading postures, there was less skull flexion in the reclined position vs. semi and upright; however there was no difference between semi vs. upright. - There was a significant main effect of trunk position for skull-C1, C1-C2, and C2-C3. Skull-C-1 Full flexion was significantly more flexed vs. other four positions. C1-C2 was more extended in neutral and reclined vs. upright position, but was not different compared to semi reclined and upright positions. C2-C3 was more flexed in reclined compared to neutral.	*Strengths* - Multiple (5) angles were measured. *Weaknesses* - The study only examined a short duration, simulated reading tablet task. - Hip and trunk angle were not specifically measured within the seat the participant was in other than cueing them to sit as far back as possible. Hip angle was not directly controlled for and could have been responsible for some variations in intervertebral joint angles. - The study did not assess thoracic angle or intervertebral joints below C7, and upper thoracic kyphosis could be a further risk of semi-recline or reclined positions. - Small sample size and were all university students.

DOI: 10.23937/2572-3243.1510114 ISSN: 2572-3243

Elserty, et al. [23]	Level 2B Cross-sectional survey study *Risk of Bias* Low	*Participants* N = 420 Physical Therapy students (133M/280F) mean age of 18-21 yrs *Inclusion Criteria* - Having smartphone to access survey - Being able to ready and understand survey in English - Being an undergraduate university student of physical therapy. - Using a smartphone for 2+hr on a typical day. *Study Setting* - Egypt - Online	*Intervention* - Online questionnaire administered at one point in time.	*Demographic data* - Prevalence of smartphone use *Relevant measures taken* - Different sites of discomfort (shoulder, arm, neck, eye, back, hand/finger, wrist, leg/feet. -Types of discomfort (stiffness, tingling/numbness, aching/pain, cramping, soreness) - Common positions during usage of smartphone (standing, sitting on floor, sitting in chair/couch, laying on side/side lying, lying on stomach/prone, lying on back/supine) *Devices Tested* - Smartphone	*Significant Findings* - 62.4% of participants reported smartphone addiction, which what higher in females (68%) than males (52%) - There was a significant difference between males and females feeling pain in wrist and back and neck. - The most common discomfort was felt at the neck region. - There was a significant difference between males and females regarding pain in shoulders, hands, and fingers. - There was a significance between duration of smartphone use over 6hrs per day and feeling discomfort with a specific body part.	*Strengths* - Several body positions were included - Several locations for discomfort were included with the different types of discomfort *Weaknesses* - Only one point in time was measured - The study was limited to only physical therapy students and not the general public - The sample size was small and there was no follow up questionnaire

Emodi-Perlman, et al. [32]	Level 3B Cohort Study *Risk of Bias* Moderate	*Participants* 3 groups of young aged adults (18-35 years-old). Group 1 included ultra-Orthodox subjects. Group 2 included Orthodox subjects. Group 3 included secular subjects *Inclusion Criteria* - Young adults - Good health, - Using a phone for remote communication. *Study Setting* Questionnaire completed in person at participants schooling institution or place of work	*Intervention* - Questionnaires on demographic variables, mobile phone use characteristics, anxiety, depression, daytime sleepiness, bruxism, and diagnosis of temporomandibular disorders	*Outcome Measures* Self-Report Questionnaire *Device Tested* Smartphones	*Significant Findings* - Various aspects of smartphone use, including being awakened at night, stress caused by information delivered by phone, and stress from phone overuse increased the risk of daytime sleepiness, temporomandibular disorders, and bruxism.	*Strengths* - Questionnaire was filled out on the spot so any questions could be asked while completing the questionnaire *Weaknesses* - Participants are not necessarily representative samples of their sectors. Several additional demographic, cultural, and lifestyle differences might have affected the results

DOI: 10.23937/2572-3243.1510114 ISSN: 2572-3243

Gustafsson, et al. [24]	Level 2B Longitudinal Cohort Study *Risk of Bias* Low	*Participants* N = 7092 Young Adults (2759M/4333F) aged 20-24 years old *Inclusion Criteria* - Responds to at least one question about SMS texting *Study Setting* - Sweden - Web-based questionnaire	*Intervention* - Survey administered at baseline, one year, and five years	*Text Messaging* - Number of texts sent in last 30 days *Musculoskeletal Symptoms* - Pain in upper back/neck - Pain in shoulders, arms, wrists, hands - Numbness/tingling in hands and fingers	*Significant Findings* - For those with no symptoms at baseline, prospective associations were found between high reports of text messaging and numbness and tingling in the hands at one year follow-up. -For those with symptoms at baseline, associations were found between text messaging and reported pain in neck/upper back and in shoulder/upper extremities. *Nonsignificant Findings* - At five year follow-up, reports were of pain in the shoulder/upper extremities, but no association was found between text-messaging and reported symptoms.	*Strengths* - Large study group, population-based, longitudinal design, control for confounding variables. *Weaknesses* - Self-report data tends toward potential bias, limited information on length of text messages or use of phone for other purposes, limited information on the nature of work or study occupations, only data from 3 points in time.

Korpinen & Pääkkönen [33]	Level 3B Cohort Study *Risk of Bias* Low	*Participants* N = 1563 Young Adults (604M/956W) (30-years-old and younger) (Mean = 24.1 +/- 3.6 years) *Inclusion Criteria* - Under 30-years-old *Study Setting* - Finland - Web-based questionnaire	*Intervention* - Self-Report questionnaire	*Use of Technology* - Type of electronics used (Desktop Computers, Portable Computers & Mobile Phones) - Amount of use *Musculoskeletal Symptoms* - Aches, pains, or numbness in various body segments	*Significant Findings* - 65% of women experienced pain, numbness, or aches in the neck pretty often, compared to 34.5% of males. - Overall, 53.3% of young adults experienced symptoms in the neck and 32.2% in the hip and lower back. - Associations were found between use of desktop versus portable computers at leisure and symptoms in various body segments. -Exhaustion also had an association with some symptoms.	*Strengths* - High response rate. *Weaknesses* - Inability to differentiate between "home work" and "students" - Participants may have different interpretations of the symptoms. - Self-report tends towards a response bias. - Confounding variables may contribute to symptoms, such as stress.

Lin, et al. [25]	Level 2B Cohort Study: 3x3 mixed factorial design *Risk of Bias* Low	*Participants* N = 18 adults - (9M/9F) - (Age 20-31 years) *Inclusion Criteria* - Right hand dominant - No known musculoskeletal disorders in neck, back, buttocks, or extremities - No non-specific pain in areas stated above within past 6 months - Can touch type on electronic keyboard at least 35 words/min - No lifting of objects over 5 kg in week before study *Study Setting* - Simulated setting in laboratory	*Intervention* - Random assignment to desk, lap, or bed for usage position - 60 minute typing on Apple ipad, with keyboard being manipulated (STD, Wide, and Split) over 6 non-consecutive days *Control* - Although participants were assigned randomly to 3 different conditions, there was no control group tested for reference	*Joint Position* - Wrist, elbow, and neck joint angles measured by flexible electro-goniometry system - Wrist extension, flexion, and radial and ulnar deviation also measured by bi-axial electrogoniometers *Musculoskeletal Discomfort* - 0-10 body discomfort scale *Electronic Use* - System-usability scale questionnaire *Devices Used* - Apple i-pad (tablet)	*Significant Findings* - Difference in joint angles of upper limb and neck with different positions and type of keyboard used - Range of joint movement significantly increased with electronic usage time - Position of tablet and keyboard design affecting wrist extension (with bed being most, lap being next, and then table) - Self-perceived discomfort in UE increased with electronic use duration *Non-significant Findings* - Lap position had highest self-perceived discomfort, and desk had lowest - Tablet use in bed showed more wrist extension but a more neutral elbow compared to tablet use at a desk. - The keyboard option with the least ulnar deviation was the angled split keyboard. - The wrists, elbows, and neck showed a 13-38% increase in joint movement from the middle of the typing session compared to the end.	*Strengths* - Random assignment to testing groups *Weaknesses* - Did not look at non-typing tasks - Posture not observed in a natural setting during this simulated task -Objective task performance was not analyzed - Data collected from myoelectrical signals from active muscles during task not analyzed - Contact pressure tablet can cause on users was not evaluated

Pais, et al. [34]	Level 3B Cross-sectional cohort *Risk of Bias* Low	*Participants* - 88 participants total. 42 males and 46 females. Students and staff of a university. - Ages 18-25 *Inclusion Criteria* - Participants use digital devices 6 + months for a minimum 5 days/week - No previous trauma to cervical spine or any deformities *Study Setting* - Not specified. Performed with university students and staff.	*Intervention* - 4 groups separated individuals based on duration of usage of devices (1hr/day; 1-2 hr/day; 2-4 hr/day; 4+ hr/day) *Control* - No reported control groups	*Outcome Measures* - Measurements taken for cervical ROM. ROM tested 3 times with 1 minute intervals and average was recorded. - Images also taken for measuring craniovertebral angle *Devices used* - Mobile phones	*Significant Findings* - Reported statistical significance in flexion variable between the four groups - No difference noted in extension variables - Additionally, no difference in the CVA variable.	*Strengths* - No reported conflict of interest; statistically significant differences *Weaknesses* - Small sample size; participants dominantly used smartphones; no educational interventions to observe outcome variables

Queiroz, et al. [35]	Level 3B Cross-Sectional Cohort Study *Risk of Bias* Low	*Participants* N = 299 adolescents (10-19 years old) *Inclusion Criteria* - No musculoskeletal pain secondary to infections, rheumatic, oncologic, genetics, DM, or thyroid diseases - No reports of recent trauma - Must have informed consent from legal guardian *Study Setting* - Classroom within private school in São Paulo, Brazil	*Intervention* - Self-report questionnaire reporting demographic data, physical activities, musculoskeletal pain symptoms, and the use of television/ digital media (including computer, internet, electronic games, and cell phones).	*7 Musculoskeletal pain syndromes were evaluated*: - Juvenile fibromyalgia - Benign joint hypermobility syndrome - Myofascial syndrome - Tendinitis - Bursitis - Epicondylitis - Complex regional pain syndrome *Devices used*: - Computer - Mobile handheld devices - Nintendo DS - Gameboy - Wii - Playstation - Xbox	*Findings* - 61% reported musculoskeletal pain with 66% being in the back, 49% in the neck, 41% in the lower limbs, 31% in the shoulder/arms, and 19% in the wrist and hands. - Electronic game use was reported by 70% of adolescents. - At least 1 musculoskeletal pain syndrome was observed in 33% of the adolescents. - Overall, the study presented a high frequency of musculoskeletal pain in adolescents, most commonly 15 year olds who use at least 2 electronic devices.	*Strengths* - The use of a questionnaire with excellent test–retest reliability...reducing the effect of memory bias (change to Excellent test-retest reliability shown by Kappa index of 0.83, which reduced effect of memory bias) - Utilization of a systematic musculoskeletal physical examination of adolescents who complained of musculoskeletal pain, using established criteria for musculoskeletal pain syndromes. *Weaknesses* - The population only includes upper and upper/middle socio-economic classes with low frequency of work activities - meaning work may increase pain tolerance from low-demand use. - Other issues were not studied such as emotional disorders and other risk behaviors - Self-report of electronic use presents potential bias

DOI: 10.23937/2572-3243.1510114 ISSN: 2572-3243

Short, et al. [36]	Level 3B Cross-Sectional Cohort Study *Risk of Bias* Low	*Participants* N = 46 Adults - (44F/2M) - (Age 20-40 years) *Inclusion Criteria* - Use of smartphone - No known musculoskeletal conditions impacting posture - Graduate students in doctor of occupational therapy (OTD) program at Huntington University *Study Setting* - Laboratory setting at Huntington University	*Intervention* - Smart phone used to either search the internet or text while seated in a chair. *Control* - No control group, with all participants experiencing the same condition of being seated in a chair and performing the same task.	*Joint Position and Posture* - Goniometer measurements including joint position and degree of motion of the digits, scapula, spine, shoulder, elbow, forearm, and wrist *Self Report Questionnaire and Apple Reported "Screen Time"* - Data collection on how frequently phone is used (hours/day) *Devices Used:* - Smartphone	*Findings* - Screen time showed an average of 143 minutes per day within mobile phone use - Results showed cervical spine flexion, scapular protraction, elbow flexion, and wrist ulnar deviation with thumb flexion during smart phone use that could contribute to deformity over time.	*Strengths* - Extensive goniometric measurements of different joint positions in the upper extremity with experienced certified hand therapist (CHT) *Weaknesses* - Goniometer measurements were not taken in a position besides seated - The size of smartphones was not a controlled factor, which could affect body strain and positioning - Study sample was mostly females and included only OT graduate students, which makes it harder to generalize findings. - Goniometer measurement can be subjective - Technique used to measure scapular protraction has not been empirically tested

Silva, et al. [26]	Level 2B Cross Sectional Cohort Study *Risk of Bias* Low	*Participants* N = 961 Adolescents (14-19 years old) *Inclusion Criteria* - Must complete questionnaire - Must agree to assessment measures - Must not have musculoskeletal pain or injuries due to pregnancy, infectious, genetic, or traumatic disorders. *Study Setting* - Brazil - Public Schools - Self-report questionnaire	*Intervention* - Self-report questionnaire asking about electronic use and symptoms over past 6 months	*Electronic Use* - Computers and electronic games - Age at start of use - Frequency of use -Weekly frequency of use - Weekly time of use -Time of use *Musculoskeletal Pain*	*Significant Findings* - 65.1% of adolescents reported some musculoskeletal pain, most commonly in thoracolumbar spine (46.9%) and upper limbs (20%). - Use of electronic devices averaged 583 minutes per week and was associated with pain in the cervical region and low back. - Symptoms were reported to interfere with performing activities of daily living including study tasks and sports. - Female gender was also found to be associated with pain in all assessed body regions.	*Strengths* - Considers the unique impact of technological advancement in public schools and the effect of increased electronic use with musculoskeletal pain in adolescents. *Weaknesses* - Poor generalizability to other populations. - Self-report bias possible.

Szucs, et al. [27]	Level 2B Cohort Study *Risk of Bias* Low	*Participants* N = 21 college students (18 females, 3 males) (21.1 ± 1.5-years-old) *Inclusion Criteria* - Ability to achieve full cervical ROM - A BMI less than or equal to 25 *Study Setting* - Lab setting	*Intervention* - Participants completed a five-minute questionnaire to better understand their daily technology usage. - Pictures of participants were taken in a neutral posture and as they performed standard tasks with 3 devices (mobile phone, tablet, laptop). - A mobile application calculated sagittal and coronal plane posture variables, which were compared between device conditions.	*Postural Assessment* - Angular and translational postural variables in the coronal and sagittal planes were calculated using digitized landmarks on pictures taken with a device camera *Devices Used*: - Desktop computer - Laptop computer - Tablet - Cellphone	*Significant Findings* - Using a tablet, whether supported on a table or held in the hands, produced the greatest amount of forward head shift and neck flexion - Tablet use produced postures that were statistically different than many other devices and technology - regular use of this device may produce greater deleterious effects than regular use of other handheld devices/ technology	*Strengths* - Reliability and validity of The PostureScreen Mobile® Application with good outcomes *Weaknesses* - Activities were being done in a lab with standardized methods - Collected data not long after they began completing the task - Investigators provided the laptop and tablet - Did not compare postures during technology use with posture during reading a typical book or completing a pencil and paper writing task - Participants were all right-hand dominant and healthy college students

Tapanya, et al. [28]	Level 2B Non Randomized (Quasi-Experimental) *Risk of Bias* Low	*Participants* N = 32 young adults (16 males, 16 females) (18-25 years of age) *Inclusion Criteria* - Participants had at least 6 months of smartphone use and used their smartphone daily for at least two hours per day *Study Setting* - Physical Therapy Laboratory - Faculty of Associated Medical Sciences - KhonKaen University, Thailand.	*Intervention* - Participants were randomly put into 4 different neck postures, including 0, 15, 30, and 45 neck flexion angles with elector - Participants were instructed to stand with feet shoulder-width apart - Participants were instructed to text for 3 minutes	*Pain Assessment* - Participants were asked to rate their neck discomfort score on a visual analogue scale before and after all assessments were completed in each condition. *Relevant measures taken:* - Electromyography of 4 neck muscle groups (left cervical erector spinae, right cervical erector spinae, left upper trapezius, right upper trapezius) -Neck kinematics directly observed via 2-dimensional video recording *Devices Used*: - Smartphone	*Significant Findings* - Using a smartphone in a greater flexed neck posture results in a larger biomechanical burden on kinematics, gravitational moment and neck muscle loading which may increase the risk of neck musculoskeletal discomfort and injuries. - An appropriate neck posture for operating a smartphone while standing is represented by 0 neck flexion. - To use a smartphone with a 0 neck flexion, the appropriate phone tilt and gaze angles were considered to be 76 ± 5 and 14 ± 5, respectively	*Strengths* - A sample size power level calculated to be 90% *Weaknesses* - Only a static posture was measured. - Unable to identify the most appropriate shoulder angle for smartphone use. - Smartphone texting tasks were relatively short.

Toh, et al. [29]	Level 2B Longitudinal Study *Risk of Bias* Low	*Participants* N = 1691 adolescents (829M/862F) Age- 10-19 years *Inclusion Criteria* - Use of MTSD - Enrolled in primary or secondary schools - parent/guardian consent *Study Setting* - Singapore - Web-based questionnaire at school	*Intervention* - Response to survey at baseline and at one year follow-up.	*Relevant Measures Taken* - Prevalence of MTSD use at baseline - Length of MTSD use - Activities using MTSD - Location of musculoskeletal pain (Neck/shoulder, upper back, lower back, arms. wrist/hand) *Devices Tested* -Mobile Touch Screen Devices (smartphone, tablet)	*Significant findings* - Baseline to one year follow-up 74% of participants reported neck/shoulder symptoms - Baseline prevalence of phone use associated with neck/shoulder and low back symptoms - Baseline tablet use associated with neck/shoulder, low back, and arm symptoms at follow-up - Bout length >1 hr of smartphone at baseline associated with neck/shoulder and upper back symptoms at follow up, while >1hr of tablet use at baseline associated with low back symptoms. - Participation in certain activities (social, games, watching videos, general use) on MTSD at baseline associated with musculoskeletal symptoms at follow-up - Multitasking on smartphones at baseline associated with neck/shoulder and arm symptoms have follow-up. - No relationship between MTSD use duration (hrs/day) per activity and musculoskeletal systems. - Changes in MTSD use between Baseline and follow up not associated with severity of symptoms.	*Strengths* - First longitudinal study on associations between MTSD use and musculoskeletal symptoms and visual health outcomes among adolescents. - Large sample with high follow up. - Detailed measures across a whole week including obtaining use during weekdays and weekend days. - Adjustments for known confounding factors. *Weaknesses* - Self-report measures may introduce recall bias and inaccuracy. - Lack of multiple time point measures of symptoms. - Prior use or lifetime exposure to MTSD was not measured, and cumulative exposure may increase risk for symptoms. - Some adolescents dropped out and those who were lost to the follow up have significantly higher smartphone use duration and prevalence of musculoskeletal symptoms; their omission likely made findings more conservative.

Young, et al. [37]	Level 3B Cohort Study *Risk of Bias* Low	*Participants* N = 15 Adults - (7M/8F) - (Mean age = 29) *Inclusion Criteria* - Experience with tablet/ computer - No previous or current musculoskeletal conditions of head, neck, back, or UE *Study Setting* - Simulated in lab	*Intervention* 2 different tablets (either ipad or Xoom) with configurations in: - support of tablet - location (lap vs table) - software task (web browsing, email, games) - Hand use (dominant vs. non-dominant) *Control* - This study had no control group, with all participants experiencing the intervention to see significant differences in use.	*Posture and Muscle Activity* - Posture of shoulder (3-D kinematics) - Posture of trunk (infrared 3-D motion analysis system) - Wrist (bi-axial goniometer) - Muscle activity (EMG) *Devices Used:* - Xoom Tablet - ipad Tablet	*Significant Findings* - Mean wrist posture, wrist angle accelerations, and muscle activity varied significantly across configurations and dominant vs. nondominant hand - Significantly more ulnar deviation noted in wrist during software task of emailing email *Non-significant Findings* - No significant difference between the 2 different tablets and the participant's posture - Wrist radial deviation when holding tablet - Higher values of wrist extension noted when using tablet	*Strengths* - Extensive statistical analysis *Weaknesses* - Simulated nature of environment and tasks may change natural behavior - Measurements taken over one time frame for each intervention and did not note extended use.

Key: M: Male; F: Female; OT: Occupational Therapy; OTD: Doctorate of Occupational Therapy; UE: Upper Extremity; MTSD: Mobile Touch Screen Devices; DM: Diabetes Mellitus; GMA: Gravitational Moment Arm; CCL: Centroid Cervical Lordosis.

Citation: Table format adapted from American Occupational Therapy Association [17].

using a self-report questionnaire. The findings indicated that the stress associated with information received by cellular technology and the stress of overuse increased the risk of temporomandibular disorder and bruxism. The study also revealed additional negative consequences including chronic orofacial pain and irreversible damage to hard dental tissue structures.

Upper & lower back

Eight studies found effects of electronic usage on the upper and lower back. In total, 11,691 participants were identified and studied for the impacts on the upper and lower back.

The back appears to be the region most impacted by device use. Back pain after prolonged device use was reported by nearly two thirds of participants in several studies [26,35]. The factors reported to contribute to neck symptoms also contributed to upper and lower back symptoms. For instance, the duration of device usage [24,26,29] and non-neutral postures [30,31] contributed to musculoskeletal discomfort in the upper and lower back.

The pattern of and posture during use may also contribute to back problems. For instance, walking while using a handheld device was shown to have an impact on spinal positioning, including increase in thoracic kyphosis, lumbar lordosis, and trunk inclination [30,31].

Upper extremity

Eight studies focused on the effect of electronic use on the upper extremity in 10,143 participants through quantitative measures and self-report questionnaires and surveys. Overall, the evidence illustrated that electronic use did impact upper extremity positioning in various joints.

Two studies revealed increased wrist ulnar deviation during gadget (smartphone, tablet, etc.) use [36,37]. One of these studies also noted increased radial deviation at the wrist while holding a tablet [37]. Two studies noted higher wrist extension measurements during tablet use [25,37]. Lin, et al. further specified the postures that cause extreme wrist flexion while typing on a tablet and reported that lying in bed has extreme values compared to having the tablet on lap or desk [25].

Device use also affected the positioning of proximal upper extremity joints. Short, et al. highlighted the general trend of flexed elbows and thumb flexion during smartphone use [36]. Szucs, et al. found significant anterior shift and flexion in the shoulders when tablets were supported by a table during the use [27].

Several studies revealed the association between device use and pain in their upper extremities. Silva, et al. reported that 20% of the study participants reported pain in the upper limbs after electronic usage [26]. Toh, et al. stated that device use at baseline was associated with shoulder pain at one year follow-up [29]. In Queiroz, et al.'s study, close to half of the participants reported symptoms in upper extremity joints [35]. Younger (15-year-olds) participants who used at least two electronic devices reported more symptoms.

Lin, et al. found a positive association between the duration of electronic use and musculoskeletal symptoms of pain and discomfort in the upper extremity [25]. Gustafsson, et al. reported an association between upper extremity symptoms such as shoulder pain, numbness/tingling in the hand, etc. and the number of texts sent per day at a one-year follow-up [24].

Discussion

This systematic review examined the impacts of electronic device use on the musculoskeletal system in adolescents and young adults. A majority of the studies explored the impact of using various electronic devices on multiple body regions. Of the 16 studies evaluated, eight were level 2B and eight were level 3B evidence; thus, the level of evidence for the effect of technology use on the presence of musculoskeletal symptoms is of moderate strength [17]. Overall, the findings suggest that the musculoskeletal system is almost always affected by maladaptive postures and positioning associated with device use and the duration of device use and long-term effects are expected. The following paragraphs discuss each of these findings and offer some general insights on handling these issues.

Maladaptive posture & positioning

Non-neutral and maladaptive positions were seen to increase the prevalence of musculoskeletal symptoms in the neck and upper extremities. This could be due to the type of gadgets used (handheld devices), usage pattern and behavior (prolonged use, holding them in hands while using, walking while using smartphones, etc.), and the environment (high or low surface in relation to the user) in which the devices are used. Ergonomic solutions may help mitigate the issue [21].

When considering ergonomic solutions, it is important to understand that ergonomics is about the fit between the user, device, and environment. The usage environment of gadgets needs careful attention as it may contribute to non-neutral or maladaptive posturing. For instance, using gadgets while lying or sitting on a bed may contribute to maladaptive posture of neck and upper body. Gadget use in a sitting posture with a neutral back is generally considered a safe position. To optimize device usage in sitting, mounting devices may be considered. For handheld devices (tablets and smart phones, etc.), mounting devices such as tablet cases, mounting stands, tablet cradles, etc. may be considered. For users who input data through tablets, a keyboard case may be considered. For adolescents accessing gaming technology through gadgets, head mounted virtual reality technology may be considered to encourage neutral posture. Traditional office computer work ergonomic solutions such as adjustable table, office chair with adjustable components, keyboard tray, etc. may help desktop and laptop users.

The users must be encouraged to reflect on their usage pattern and behavior periodically. To promote such reflection, several smart gadgets offer usage data that may provide insight into the duration of use. Additionally, educating users about potential issues may help them appreciate how much they may compromise their health for convenience in usage of electronic gadgets.

Aside from the external modifications and changes in usage pattern and behavior, engaging in stretching and strengthening exercises may help gadget users avoid musculoskeletal issues.

Duration of device use & other predictors

The findings of this review also showed that the prolonged use of electronic devices has an increased negative effect on the body. Aside from the actual device usage, other related variables such as sex [23,26,33,34], presence of a paid job, excess weight [26], and level of exhaustion [32,33], were reported to predict the musculoskeletal symptoms.

Stakeholder education on these predictive factors is the key to mitigate the musculoskeletal issues among young gadget users. Several software ergonomic applications are available in the market that alert the users periodically regarding the duration of usage. For instance, a user may set a timer to go off when it is two hours. The users may be encouraged to download and use these applications on their devices. Measures that promote healthy lifestyle, effective stress management, and work-life balance may also help mitigate musculoskeletal issues in young workers.

Strengths and limitations

The strengths of this systematic review include the examination of the impact of electronic device usage on all body regions, inclusion of studies with moderately large sample sizes, and the consideration of all technological devices that are being utilized on a daily basis. The limitations include the lack of higher-level evidence (level I) and longitudinal studies to examine long-term effects. Also, some studies included in this review were conducted in a laboratory setting rather than natural settings.

Implications for practice

The findings have implications for multiple stakeholders, such as healthcare professionals (physicians, occupational therapists, ergonomic consultants, etc.), device manufacturers, teachers, and employers.

- Healthcare professionals may begin to assess and document device usage behavior during annual physical examinations and/or preventive visits to generate data and educate the public on the potential impact of device overuse on the musculoskeletal system.
- Rehabilitation professionals, such as occupational therapists, when providing care to adolescent or young adult patients with musculoskeletal issues, should assess the patient's device use behavior as part of their evaluation. Further, they should educate the individuals who are at risk for developing MSDs on proper body mechanics, ergonomic principles, and environmental modifications associated with device use.
- Electronic device manufacturers may be more competitive if they are more mindful of the musculoskeletal issues associated with device use when designing and manufacturing the device and should include information related to the safe usage of their products inside the product package and on their websites.
- Teachers should ensure that adolescents are using devices and gadgets in moderation to complete educational activities.
- Employers need to ensure that their young workers have proper work/office environment to optimally position and safely use electronic devices to complete work responsibilities.

Recommendations for future research

The emergence of the modern technology era and increased dependency on electronic devices over the last two decades may continue to increase the prevalence of musculoskeletal conditions. Hence, it is essential for the healthcare community to be cognizant of the impacts of device usage on body systems and ways to effectively manage them, through high-quality rigorous research. Longitudinal studies may help identify the long-term impact of device usage on the musculoskeletal system. Further, studies spanning across age groups, gender, population with different anthropometrics, bodily regions, devices used, etc. may reveal additional insights. Furthermore, studies exploring the effectiveness of ergonomic interventions in managing the musculoskeletal symptoms secondary to device usage may yield valuable insights with practice implications.

Conclusion

The use of various electronic devices is associated with musculoskeletal symptoms in multiple regions of the body, specifically the head and neck, upper and lower back, and upper extremity in adolescents and young adults. Maladaptive postures and prolonged device use contribute to the musculoskeletal symptoms. Future research examining the effect of usage of specific devices, such as a smart phone, gaming device, etc. on bodily systems may further our understanding of the human-device interaction and yield valuable insights for stakeholders. Longitudinal studies examining the long-term impact of device usage may help validate and generalize these preliminary findings and provide additional insights.

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