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Musculoskeletal disorder and pain associated with smartphone use: A systematic review of biomechanical evidence

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The number of smartphone users is growing dramatically. Using the smartphone frequently forces the users to adopt an awkward posture leading to an increased risk of musculoskeletal disorders and pain. The objective of this study is to conduct a systematic review of studies that assess the effect of smartphone use on musculoskeletal disorders and pain. A systematic literature search of AMED, CINAHL, PubMed, Proquest, ScienceDirect using specific keywords relating to smartphone, musculoskeletal disorders and pain was conducted. Reference lists of related papers were searched for additional studies. Methodological quality was assessed by two independent reviewers using the modified Downs and Black checklist. From 639 reports identified from electronic databases, 11 were eligible to include in the review. One paper was found from the list of references and added to the review. The quality scores were rated as moderate. The results show that muscle activity of upper trapezius, erector spinae and the neck extensor muscles are increased as well as head flexion angle, head

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tilt angle and forward head shifting which increased during the smartphone use. Also, smartphone use in a sitting position seems to cause more shift in head–neck angle than in a standing position. Smartphone usage may contribute to musculoskeletal disorders. The findings of the included papers should be interpreted carefully in light of the issues highlighted by the moderate-quality assessment scores.

Keywords: Smartphone; musculoskeletal disorders; pain.

Introduction

Smartphones now have a significant role in people's everyday lives as they are being used for communication, internet browsing and gaming. In the past decade, the rate of smartphone usage, hours and frequency of use, has been increased.[1,2] A study in 2012 revealed that there were more than six billion smartphone users worldwide.[3] Additionally, research reported that over 65% of the owners in the USA spent at least 1 h per day on their phone.[4] A survey supported this trend by reporting that users spend more than 20 h weekly on texting, emailing, and using social network, representing the significant dependence on smartphones for connecting and communicating with others.[5] Consequently, the heavy reliance on the smartphone may contribute to musculoskeletal injuries in the users. Therefore, health professionals should be aware of the effect of smartphone use on physical health problems. Generally, the typical posture when using smartphones (or other touchscreen handheld devices) involves holding the tool with one or two hands below the eye level, looking down at the device and using the thumb to touch the screen.[6] This pattern of use forces the user to adopt an awkward posture such as forward neck flexion which is often maintained for long periods.[6–9] The prolonged and frequent use of smartphones, as well as the repeated movement of the upper extremities in an awkward posture, have been shown to be the main contributing factors to the incidence of musculoskeletal symptoms.[7–9] Musculoskeletal symptoms, such as discomfort and pain, in smartphone users not only occur in the neck but also in other areas of the body including shoulders, elbows, arms, wrists, hands, thumbs and fingers.[1,6,10–14]

While some research has been conducted to study the effect of smartphone use on the musculoskeletal symptoms of the neck and upper extremity, there has not been a systematic review evaluating this research. The purpose of this study is to systematically review the evidence from experimental studies and may draw a definite conclusion regarding the research that focuses on the changes in musculoskeletal symptoms caused by smartphone usage.

Methods

A search of the Cochrane Library and the databases included in this review revealed no equivalent systematic review. This systematic review was planned and accomplished based on the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) statement for reporting systematic review.[15]

Literature Search

A comprehensive search was performed in May 2016 by two independent researchers (AE and SV) of the following databases: AMED, CINAHL, PubMed, ProQuest and ScienceDirect. There was no date restriction. The combination of terms and keywords used were (smartphone OR mobile phone OR texting OR typing) AND (musculoskeletal disorder OR pain) AND (ergonomic OR human factor). Handsearching of the reference lists of all relevant papers was performed. Only papers written in English were included. The inclusion criteria were the following: (1) the studies must be laboratory experimental studies (pre-post, quasi-experimental, or cross-sectional study) so that the actual data relating to the change in different musculoskeletal symptoms due to the use of smartphone could be tracked in an objective way; (2) the outcome must contain at least one of the following aspects: pain, postural analysis or muscle activity; (3) the assessments of the subjects must focus on the upper extremities including neck, shoulder, elbow, wrist, hand, thumb, fingers, and upper back; and (4) the effects of smartphone use must be the main focus in the research. Studies were excluded if (1) the research recruited subjects aged under 18; (2) the studies focused on the use of a tablet, computer, and other visual display units; and (3) the primary outcome of the research was from survey or qualitative methods.

In addition to the recruiting criteria, there is no clear and well-accepted diagnostic criteria for the term of "musculoskeletal disorders and pain". Therefore, this review was specifically designed to include the relevant papers where the participants were recruited based on one of the following indications: the participants identified themselves as having musculoskeletal disorders and pain, having participant screening processes that were able to identify those people who were symptomatic with musculoskeletal disorders and pain, having objective measurements that included but were not limited to electromyography (EMG), muscle strength or cross-sectional area of muscles that could detect change in musculoskeletal functions (either in comparison to base-line measurement or while performing the assigned task).

Data Extraction and Management

The papers were initially screened and analyzed on titles and abstracts by independent reviewers (AE and SV). Where there was any doubt, the full text was read to determine if inclusion criteria were met. Studies that failed to meet the selection criteria were excluded. The data extraction form was applied from the PECO questions on population, exposure, comparison, and outcomes.[16]

Methodological Quality

There appears no validated checklist or scale available to assess the methodological quality of the cross-sectional experimental laboratory studies in the literature.[17] Therefore, the Downs and Black checklist[18] was modified based on the previous studies[19,20] and used to assess methodological quality of the included studies. The modified Downs and Black checklist was developed that all items were scored 0 to 1, except the item number 5 with a score 0 to 2 and the item number 27 that the score was changed from a scale of 0 to 5 (unclear wording and difficult to score) to a scale of 0 to 1 (where 1 was scored if a power calculation or sample size calculation was present while 0 was scored if there was no power calculation, sample size calculation or explanation whether the number of subjects was appropriate).

Two reviewers (AE and SV) independently scored the quality of each study. Disagreements were resolved by consensus or by a third reviewer (LR). The possible range of reporting quality summary scores was 0 to 28. There is no formal cut-off point to separate the level of quality scores in the modified Downs and Black checklist. Therefore, as recommended by the previous reviews,[20] Quality scores above 19 were considered as "good," between 11 and 19 as "moderate," and below 11 as "poor".

Results

Selection of the study

The flowchart in Fig. 1 illustrates the selection process of the included studies. 639 reports were identified from the electronic databases (AMED = 64, CINAHL = 265, PubMed = 153, ProQuest = 70 and ScienceDirect = 87). Of these publications, 609 were excluded due to an irrelevant title and abstract. Duplications were also excluded, leaving 28 studies. The selection criteria of this systematic review were then applied and 17 more studies were excluded.[6,12,15,21–34] Following this selection process, 11 papers were eligible to be included in the review.[35–45] Additionally, a reference search was conducted using the reference lists of relevant papers to retrieve any missing references. Consequently, a paper written by Akkaya *et al.*[46] was added to the review. Therefore, the total number of studies included in the review was 12.[35–46]

Study characteristics

The main characteristics of the 12 studies are presented in Table 1.[35–46] All the included studies were cross-sectional experimental laboratory studies, which provided data collected form a total of 755 subjects. When considering the inclusion criteria for the studies, four papers used the term "university students," ($n = 406$),[35,37,39,42] three papers used the term "healthy (normal) adult" ($n = 214$),[36,44,46] four papers used the term "young adult" ($n = 125$)[38,40,41,45] and one paper specifically included only right-handed female subjects in their study ($n = 10$).[43]

Considering the inclusion criteria quoted in the papers, seven studies failed to provide a clear list of inclusion criteria.[35–38,43,44,46] Whereas, three

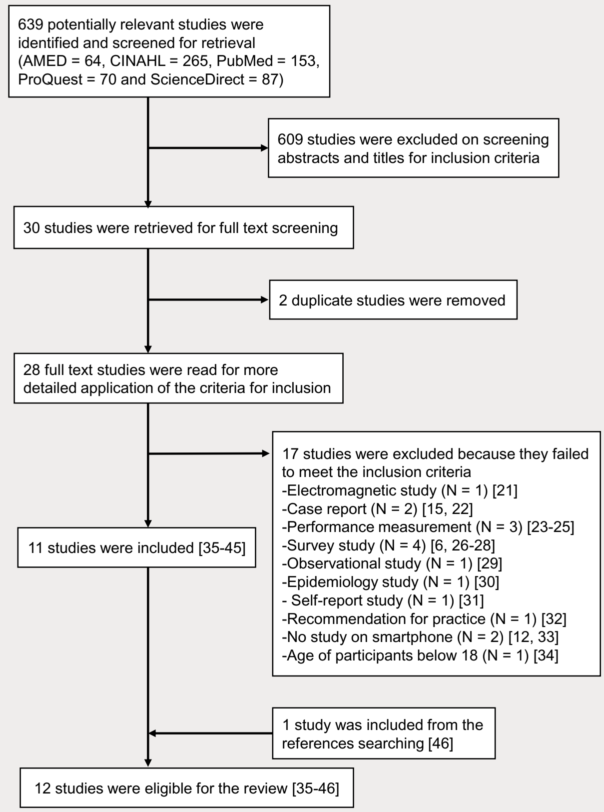

Fig. 1. Flowchart for the selection of studies.

studies indicated the amount of experience with a touch screen smartphone,[40,41,45] one study specifically included only participants aged between 18 to 29 years,[39] one study used the term "use mobile phone regularly" as an inclusion criteria.[42] Only one study by Xie *et al.*[45] demonstrated well-constructed inclusion criteria with an intention to recruit participants with similar characteristics. For the exclusion criteria, 10 studies excluded participants with experience of injury, trauma, deformity, surgery and/or any neurological condition that affected head, neck, and upper limbs.[36–39,41–46] However, participants who had any physical difficulty were excluded in Lee *et al.*,[40] but this term was not defined. There was one study which did not indicate any exclusion criteria.[35]

Regarding the study intervention, six studies had no comparison group.[35,36,39,40,42,43] Of these, two studies focused on the thumb area.[35,39] Xiong and Murasaki[35] used EMG to assess thumb performance and muscular activity of the thumb (AdP: adductor pollicis, FPB: flexor pollicis brevis, APB: abductor pollicis brevis, APL: abductor pollicis longus, FDI: first dorsal interosseous, and ED: extensor digitorum) while Eapen *et al.*[39] used ultrasound to evaluate the diameter of the thumb tendons (APL, EPB: extensor pollicis brevis, EPL: extensor pollisis longus, and FPL: flexor pollicis longus). Three studies focused on the effect of head and neck positioning during smartphone use in different positions; sitting position (lap and desk posture)[36]; standing position (using and without using smartphone)[42]; and sitting versus standing posture while using smartphone.[40] Another study used EMG to assess the neck (UT: upper trapezius) and thumb muscle (EPL and AbP: abductor pollicis) activity in sitting to compare the muscle activity between one and two hands smartphone use.[43] Four studies had a comparison group and of these; two studies compared the range of motion (ROM)[41] and muscular activity[45] in neck pain and non-pain groups; the other two studies compared the ROM between frequent and infrequent smartphone users.[44,46] The study by Inal *et al.*[37] had three groups for comparison (non, low, and high smartphone user) and used the ultrasonographic assessment of the FPL muscle and the median nerve. Another study with three-group comparison compared pain threshold and the muscle activity during smartphone use, computer use and in a control group.[38]

Table 1. Characteristic of the methodology, outcome measurement and finding included in the review.

References	PECO				Recruitment criteria	Reported finding
	Participants (n)	Exposure	Comparison	Outcome		
Akkaya *et al.* (2015)[46]	Healthy adults (149; 36 male and 86 female)	Using VAS to measure thumb pain during texting and using ROM to measure MCP joint and IP joint of thumb, grip strength, pinch strength, and ultrasonographic evaluation of FPL tendon in different groups.	Frequent users versus infrequent users	VAS, pinch strength, grip strength, ROM, and ultrasonographic evaluation of FPL tendon	I: N/A E: Experience of injury of fracture to nerve, vessel and tendon and rheumatic disease.	FPL tendons were larger and had more pain on the texting side in frequent texter group.
Eapen C *et al.* (2014)[39]	Students (98)	Using ultrasound evaluation on APL, EPB, EPL, FPL and Thenar eminence.	N/A	Finklestein test, pinch strength and APL, EPB, EPL, FPL, and Thenar eminence diameter	I: Age 18 to 29 years E: Past experience of inflamative and degenerative of neuromuscular conditions of thumb, hand, and UE due to other activity instead of smartphone use.	Participants express musculoskeletal-related symptoms such as tenderness on extensor compartments, positive Finklestein test, pain on abduction and extension of thumb and increased fluid around dorsal compartment.
Guan X *et al.* (2015)[42]	University students (186; 105 male and 81 female)	Using photographic analysis to measure sagittal posture of head tilt angle, neck tilt angle, forward head shift, and gaze angle during smartphone use in different standing conditions.	Standing while using smartphone versus standing while not using smartphone	Head tilt angle, neck tilt angle, forward head shift, and gaze angle	I: Using smartphone regularly. E: Experience of craniofacial, cervical, shoulder, thoracic, and spine pain.	Head tilt angle and forward head posture were significantly increased during mobile phone use whereas neck tilt angle was decreased.
iNAL EE *et al.* (2015)[37]	University students (102; 30 male and 72 female)	Using self-report hand function questionnaire, clinical evaluation, and ultrasonographic assessment to measure hand performances in different groups.	Non-users versus low-users versus high-users	VAS, grip strength, pinch strength, median nerve ration, and FPL ratio	I: N/A E: Experience of neuropathy, radiculopathy, previous contracture, and lateral or medial epicondylitis.	High smartphone users had significantly larger median nerve CSA, less pinch strength, and hand function in dominant hand.

Table 1. (*Continued*)

References	PECO				Recruitment criteria	Reported finding
	Participants (n)	Exposure	Comparison	Outcome		
Jung SI *et al.* (2016)[44]	Healthy adults (50)	Using craniovertebral angle, scapular index, and respiratory function assessment to measure body functions in different groups.	Frequent users versus infrequent users	Craniovertebral angle, scapular index, FVC, FEV1, ratio of FEV1/FVC, and peak expiratory flow	I: N/A E: Past experience of pain, trauma, fracture or surgery to cervical, thoracic, and abdominal area, neurological disorders, lung function restriction, unstable cardiac conditions, recently smoking or smoker free within five years.	Long duration of smartphone use negatively affected the posture and respiratory function, especially peak expiratory flow.
Kim GY *et al.* (2012)[38]	Young adults (40; 17 male and 23 female)	Using pain pressure threshold and EMG to measure dominant UT, brachioradialis, FCU, and APB in different groups.	Smartphone users versus computer users versus control	Pressure pain threshold and EMG	I: N/A E: Past experience of injury, surgery or deformity of spine and UE, visual problems, dizziness, vertigo, neurological disorders and using sedative drug within 48 h.	Smartphone users showed statistically significant different in brachioradialis muscle fatigue while computer user shows statistically significant different in UT muscle fatigue. Both experimental groups showed significant reduction in pressure pain threshold of UT muscle.
Kim MS (2015)[41]	Young adults (27; 12 male and 15 female)	Using ROM to measure cervical angle during two-hand texting in sitting position.	Pain versus control	Upper and lower cervical ROM	I: At least one year experience of using smartphone. E: Past experience of neck pain, spinal trauma, cervical surgery, fibromyalgia, and systematic or connective tissue disorder.	Neck flexion angle was increased with time during smartphone use both on upper and lower cervical spines. Neck pain group was found to have greater angle.
Lee M *et al.* (2015)[43]	Right-handed female (10)	Using EMG and dolorimeter to measure muscle activity and tenderness in UT, EPL, and AbP during different conditions of smartphone use on thigh in sitting position.	One-handed smartphone use versus two-handed smartphone use	EMG and pressure pain threshold	I: N/A E: Past experience of UE ROM limitation and orthopedic problems.	One-handed smartphone use showed higher muscular activity in UT, AbP, and EPL.

Table 1. (*Continued*)

References	PECO				Recruitment criteria	Reported finding
	Participants (n)	Exposure	Comparison	Outcome		
Lee S *et al.* (2015)[40]	Young adults (18; 9 male and 9 female)	Using ROM to measure head flexion angle during text messaging, web browsing, and video watching in different position.	Sitting position versus standing position	Head flexion angle	I: At least one year experience of using smartphone. E: Physical difficulties of using smartphone.	Head flexion angle was the highest during text messaging in sitting.
Shin H & Kim K (2014)[36]	Healthy adults (15)	Using VAS, EMG, and ROM to measure cervical erector spinae during smartphone use in different posture.	Desk posture versus lap posture	Flexion relaxation ratio, ROM, and VAS	I: N/A E: Past experience of neck pain, spinal trauma, and cervical surgery.	Sustained smartphone use in lap posture could influence neck pain.
Xie Y *et al.* (2016)[45]	Young adults (40; 16 male and 24 female)	Using EMG, discomfort score, and borg scale to measure on cervical erector spinae, UT, LT, ECR, ED, FDS, and APB during smartphone and computer use in different groups.	Pain versus non-pain	EMG, discomfort score, and rate of perceived exertion	I: Right-handed users with similar texting speed who spent at least 2 h daily using smartphone for the last six months. E: Past experience of pain, trauma, fracture or surgery to cervical and UE, neurological and systematic disorders.	Participants with neck–shoulder pain showed higher muscle activity in cervical erector spinae and UT muscle during texting and typing tasks. Unilateral texting showed higher muscle loading in forearm muscles when compared to bilateral texting.
Xiong J & Murasaki S (2014)[35]	Right-handed university students (20; 10 male and 10 female)	Using pressure sensor and EMG to measure thumb performance and muscular activity during smartphone use in different button size and speed.	Small button versus large button	Thumb performance, iEMG, contraction time and iEMG/s	I: N/A E: N/A	Smaller button negatively affects thumb performance.

Notes: APB: abductor pollicis brevis; APL: abductor pollicis longus; ECR: extensor carpi radialis; ED: extensor digitorum; EMG: electromyography; EPB: extensor pollicis brevis; EPL: extensor pollicis longus; FCU: flexor carpi ulnaris; FDS: flexor digitorum superficialis; FEV1: force expiratory volume at 1 s; FPL: flexor pollicis longus; FVC: force vital capacity; iEMG: integrated electromyography; LT: lower trapezius; N/A: non-applicable; n: number; ROM: range of motion; SAS: smartphone addiction scale; UT: upper trapezius; VAS: visual analog scale.

In this systematic review, it is not possible to perform a meta-analysis due to the heterogeneity of the study designs and outcome measures.

Methodological Quality

Table 2 presents the methodological quality results from the modified Downs and Black checklist. All studies[35–46] included in this review were rated as "moderate" (ranged from 11 to 18). All studies[35–46] failed to provide information about representativeness of the population and the intervention as well as adverse events, subjects recruiting periods, blinding (both subjects and assessors) and randomization (allocation and concealment). The study by Xiong and Murasaki[35] did not provide information about the participants' characteristics. Six studies[37,38,41,44–46] partially reported information regarding principal confounders. One study[40] failed to report the descriptive statistics from the raw data percentiles was reported but not the mean and standard deviation of the measured variable and also their main confounders were not investigated. The actual p-value of the main outcomes (0.05 rather than < 0.05) was reported in eight studies.[35–39,42,45,46] Six studies[36–38,40,43,46] had no information about source of population and their recruitment processes. Compliance with the intervention was not mentioned in six studies.[35,36,39,40,42,43] Only a study by Akkaya[46] provided a statement of recruitment period. All studies with the exception of one[39] failed to conduct a power calculation.

Findings

The outcome of the studies can be divided into seven categories: EMG, ROM, Pain, finger and hand performance, tendon diameter, and subjective measures of discomfort and exertion.

Electromyography

Four studies used EMG to assess muscular activity.[35,38,43,45] Comparing between smaller buttons and larger buttons, Xiong and Muraki[35] found that using smaller buttons significantly increased the muscle activity of the FDI muscle ($p < 0.01$) and significantly decreased the muscle activity of the APB muscle ($p < 0.01$). Kim *et al.*[38] found that after a smartphone typing task, when compared to the control group, there was a statistically significant decrease in the median frequencies of the brachioradialis muscle ($p < 0.05$). Lee *et al.*[43] discovered that the muscular activity of the UT, ELP and AbP muscle was significantly higher when using the smartphone in one hand than in two hands ($p < 0.05$). Xie *et al.*[45] found that participants with neck and shoulder pain had significantly higher muscular activity in the cervical erector spinae and UT muscles than non-symptomatic participants when performing a texting and typing task. Xie *et al.*[45] also found that one-hand texting produced significantly more muscle activity of the forearm muscles than two-hand texting.

Range of motion

Five studies used ROM of the head and neck or the thumb and hand as an assessment to evaluate the change in posture during and after the smartphone use.[36,40–42,44] Shin and Kim[36] found an average change of $44 \pm 4.31°$ in ROM of cervical flexion in the lap posture when compared to the baseline measurements. Lee *et al.*[40] concluded that the cervical flexion angle was significantly larger when text messaging than when carrying out the other tasks (web browsing and video watching) ($p < 0.05$) and significantly larger in sitting than in standing ($p < 0.05$). When using the smartphone in a sitting position, one study[41] discovered that the upper and lower cervical flexion angles were significantly higher in the neck pain group than in the control group ($p < 0.05$). In addition, another study[42] compared the head and neck posture in standing with and without looking at the smartphone. They found that participants who were standing and looking at the smartphone had significantly increased the head tilt angle and forward head shift ($p < 0.05$) while significantly decreased the neck tilt angle ($p < 0.05$). Jung *et al.*[44] also found that frequent smartphone users have higher scapular index and craniovertebral angle ($p < 0.05$) compared to infrequent smartphone users.

Pain

Measures of pain were presented in five studies.[36–38,43,46] Shin and Kim[36] presented the change of mean value measured using a visual analog scale (VAS) after using a smartphone in a desk and lap posture from 0 (baseline measurement) to 1.7 and

Table 2. An assessment of methodological quality of studies assessed by modified Downs & Black checklist.

	Check list																											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	
References	Study aim	Main outcome	Subject characteristics	Description of intervention	Principal confounders	Outcome data	Range of results	Adverse events	Lost to follow-up	Probability value (exact)	Source population	Representative of population	Staff, place, facility	Subjects blind to intervention	Blind assessors	Data dredging	Same length of follow-up	Appropriate statistical tests	Compliance with the intervention	Accurate outcome measure	Control recruited same	Recruitment at same time	Randomized allocation	Concealed randomization	Adjustment for confounders	Subjects lost to follow-up	Power	Total
Akkaya *et al.* (2015)[46]	Y	Y	Y	Y	P	Y	Y	N	Y	Y	N	N	N	N	N	Y	Y	Y	Y	Y	N	Y	N	N	Y	Y	0	17/28
Eapen C *et al.* (2014)[39]	Y	Y	Y	Y	N	Y	Y	N	Y	Y	Y	N	N	N	N	Y	Y	Y	N	Y	Y	N	N	N	Y	Y	1	17/28
Guan X *et al.* (2015)[42]	Y	Y	Y	Y	N	Y	Y	N	Y	Y	Y	N	N	N	N	Y	Y	Y	N	Y	Y	N	N	N	Y	Y	0	16/28
iNAL EE *et al.* (2015)[37]	Y	Y	Y	Y	P	Y	Y	N	Y	Y	N	N	N	N	N	Y	Y	Y	Y	Y	Y	N	N	N	Y	Y	0	17/28
Jung SI *et al.* (2016)[44]	Y	Y	Y	Y	P	Y	Y	N	Y	N	Y	N	N	N	N	Y	Y	Y	Y	Y	Y	N	N	N	Y	Y	0	17/28
Kim GY *et al.* (2012)[38]	Y	Y	Y	Y	P	Y	Y	N	Y	Y	N	N	N	N	N	Y	Y	Y	Y	Y	N	N	N	N	Y	Y	0	16/28
Kim MS (2015)[41]	Y	Y	Y	Y	P	Y	Y	N	Y	N	Y	N	N	N	N	Y	Y	Y	Y	Y	Y	N	N	N	Y	Y	0	17/28
Lee M *et al.* (2015)[43]	Y	Y	Y	Y	N	Y	Y	N	Y	N	N	N	N	N	N	Y	Y	Y	N	Y	N	N	N	N	Y	Y	0	13/28
Lee S *et al.* (2015)[40]	Y	Y	Y	Y	N	Y	N	N	Y	N	N	N	N	N	N	Y	Y	Y	N	Y	N	N	N	N	N	Y	0	11/28
Shin H & Kim K (2014)[36]	Y	Y	Y	Y	N	Y	Y	N	Y	Y	N	N	N	N	N	Y	Y	Y	N	Y	N	N	N	N	Y	Y	0	14/28
Xie Y *et al.* (2016)[45]	Y	Y	Y	Y	P	Y	Y	N	Y	Y	Y	N	N	N	N	Y	Y	Y	Y	Y	Y	N	N	N	Y	Y	0	18/28
Xiong J & Murasaki S (2014)[35]	Y	Y	N	Y	N	Y	Y	N	Y	Y	Y	N	N	N	N	Y	Y	Y	N	Y	Y	N	N	N	Y	Y	0	15/28

Notes: *Items 1 to 27 of the modified Downs & Black checklist. "Y": the answer is yes; "N": the answer is no; "U": the answer is unable to determine; "P": the answer is partial. The question number 5 will assign a score of "0" if the answer is "No", "1" if the answer is "Partial", and "2" if the answer is "Yes". The question number 27 will assign a score of "0" if no power calculation is provided, and "1" if a power calculation is provided. All the questions except the question numbers 5 and 27 will assign a score of "0" if the answer is "No" or "Unable to determine", and "1" if the answer is "Yes". Total quality scores of studies: Less than 11 = poor 11–19 = moderate; Higher than 19 = good.

5.2, respectively. Inal *et al.*[37] found that frequent smartphone users had significantly higher VAS scores than the infrequent and non-user groups ($p < 0.05$) but found no difference between non-users and infrequent users. Two studies[38,43] concluded that the pain threshold of the UT muscle decreased significantly after smartphone use ($p < 0.01$). Lee *et al.*[43] also found that one-hand smartphone use significantly increased muscle tenderness compared to two-hand use ($p < 0.01$). Akkaya *et al.*[46] showed a statistically significant difference ($p = 0.005$) in the VAS scores between the texting side (0.3 ± 0.9) and the contralateral side (0.01 ± 0.1) in a frequent texter group.

Thumb–finger–hand performance

Four studies assessed the performance of the thumb, finger, and hand.[35,37,39,45] Xiong and Muraki[35] indicated that using a small button leads to significant shorter fatigue times than when using a large button ($p < 0.01$) in a tapping task, while the tapping speed found to be significantly slower in flexion–extension than in abduction–adduction of the thumb during a moving task ($p < 0.01$). Inal *et al.*[36] presented a correlation between pinch strength and smartphone addition scale (SAS) ($p = 0.022$, $r = -0.281$; negatively weak correlation), pinch strength and duration of smartphone use ($p = 0.288$, $r = 0.133$; weak correlation), and pinch strength with Duruoz hand index score ($p = 0.014$, $r = -0.242$; negatively weak correlation). Eapen *et al.*[39] reported the significant reduction in tip ($p = 0.002$) and lateral ($p = 0.02$) pinch grip strength in patients with thumb pain while text messaging when compared to the control group.

Tendon–nerve diameter

Three studies evaluated the thickness of the tendon and nerve in symptomatic[39] and non-symptomatic smartphone users.[37,46] Eapen *et al.*[39] applied ultrasound evaluation to the thumb area of the symptomatic subjects and found fluid around the thumb tendons at the wrist level (19%) and in the flexor muscles of the thumb (2%). Two studies[37,46] discovered that the frequent smartphone users had significantly larger FPL tendons ($p = 0.001$)[46] and median nerves ($p < 0.001$)[37] than the infrequent smartphone users.

Discomfort and exertion level

Only two studies investigated the discomfort and exertion level.[35,45] One reported[45] a significant change in the discomfort scores ($p = 0.008$) as well as the rate of perceived exertion ($p < 0.001$) after performing the texting task. This effect was greater in the symptomatic group than in the control group. Another study[35] reported that smaller button size leads to a significantly higher rating of perceived exertion (using the Borg scale) of the FDI muscle in the tapping task. Moreover, they found a significant decrease of perceived exertion score of the APB and APL muscles and a significant increase of perceived exertion score of the FDI muscle in the moving task.

Discussion

This systematic review has provided information about the change[37–39,46] and associations with musculoskeletal symptoms[35,36,40–45] in the neck, the shoulder, the upper limb, the hands and the thumb associated with smartphone use. The findings of all studies emphasized that the use of smartphone may contribute to the musculoskeletal symptoms.

Methodological Quality of Studies

The methodological quality of the studies included in this review was scored as moderate. This may be due to the nature of cross-sectional experimental laboratory studies where blinding and randomization are hard to implement.[47] In addition, more than half of the included studies[35–39,41–46] simulated the smartphone use conditions for participants to perform in the laboratory setting. Accordingly, these data may not represent the actual smartphone use in real life and therefore the studies have low external validity.[48] Half of the studies[35,36,39,40,42,43] were lacking information regarding confounding variables, source of population and how they were recruited which, therefore, exposing to high risk of selection bias (low internal validity). The presence of low internal and external validity resulted in some concerns about the applicability of the study results.[48] Moreover, half of the studies included in this review[35,36,39,40,42,43] did not provide sufficient information in order to effectively assess the comparability of the intervention and comparison groups. This notion made it difficult to analyze whether the change and associations with musculoskeletal symptoms found in the study groups really originated from smartphone use, or from other factors. Moreover, almost all studies included in this review did not attempt to address potential sources of bias.[35–38,40–46] Finally, only one study[39] mentioned that their sample size was based on data from the pilot study while the rest of the studies[35–38,40–46] did not mention a power calculation.

Consequently, the study quality scores were moderate. However, the issues identified above must be taken into account when interpreting the results of the studies included in this review.

Overall Findings

The studies included in this review[35–46] reported their finding in three specific body regions: the head–neck, shoulder–arm, and hand–thumb.

The findings of this review suggest that using smartphone may induce musculoskeletal symptoms in the neck.[36,40–42,44,45] During smartphone use, the muscle activity of UT, erector spinae and the neck extensor muscles are increased,[43,45] especially for those who already have pain in the neck region.[45] Moreover, many studies found that neck flexion angle, head tilt angle and forward head shifting were increased during the smartphone use[36,40–42,44] and also increased with the duration of smartphone use.[40,41] Many studies suggested that people with pain in the neck region tended to adopt a more flexed posture than those who have no pain[41,44,45] which negatively affected the neck posture.[44] This could be explained by the theory that the motor control of the neck muscles was altered by prolonged poor neck posture during the use of smartphones.[49,50] In addition, the variation of the head–neck angle could possibly depend on the task, the posture and the way of holding the smartphone.[6,40] The recent review concluded that smartphone use in a sitting position seems to cause more shift in head–neck angle than in a standing position.[36,40] A possible explanation is that postural stability is associated with the head position and movement in standing, since neck flexion or extension in an upright posture in standing can alter the postural stability.[51] Therefore, when the smartphone is used in a standing position, the user tends to minimize the alternations in neck posture to avoid postural instability.[40]

For the shoulder–arm region, muscle activity increased and the pain pressure threshold decreased in the shoulder and forearm area when using a smartphone.[38,43,45] This is because the increase in muscle activity is associated directly with the rise of muscle fatigue[52,53] and the reduction of pain pressure threshold.[54,55] The repeated upper limb movements during smartphone use activate a continuous muscle contraction which may cause microscopic damage to the muscle which is the risk factor for musculoskeletal disorders.[38,43,56]

For the hand–thumb region, this review also found that one-handed smartphone use may cause more musculoskeletal symptoms in the shoulder–arm and the hand–thumb areas than using two hands to operate a smartphone.[43–45] The reason is that two-handed smartphone use allowed more effective cooperation between holding and conducting the smartphone tasks which resulted in improving the task performance and variation in movements.[25,55] Thus, less muscle activity was found in two-hand smartphone use when compare to one-hand smartphone use (less stereotypical and repetitive movements).[25,43–45] Consequently, to reduce the risk of musculoskeletal problems, using two hands to operate a smartphone is recommended.[25,43]

Furthermore, this review also revealed that the frequent smartphone users had reduced thumb performance when compared to the infrequent users,[37,39] especially, when performing sensitive tasks or tapping on a small button.[35] Additionally, this study detected changes in the tendon, nerve and space between muscular tissue in frequent smart phone users.[37,39] Practically, smartphone users naturally adjust their hand and thumb postures to fit with the phone layout which may alter their efficiency of smartphone use. The prolonged altered static posture and repetitive use of the wrist and thumb during smartphone operation may negatively impact the muscular and nervous tissue in the hand.[57] Excessive repetitive or static use of wrist and thumb movements during the smartphone use can increase the load on the joints,[1,6,57] increase carpal tunnel pressure,[58] and decrease the space available for the median nerve to move.[59] Thus, leading to the acute trauma and causing the enlargement of the median nerve[59–62] and muscular tendon (e.g., FPL tendon).[46] Accordingly, the structural changes from frequent smartphone usage may aggravate pain[36,37,43,46] which was also reported more frequently in the group of frequent smartphone users than the group of infrequent smartphone users.

Limitations of the Review

This review was based on a comprehensive search of all the evidence that relates to the research question and adheres to the inclusion and exclusion criteria set. However, there were some limitations to the data found.

This review only included publications that were published in English, leading to missing evidence that has been published in other languages. There may be some possibility of publication bias because all reports presented more positive outcomes on musculoskeletal change than null results which may indicate overestimation of the positive outcomes. In addition, the power calculations were not reported and the research design and outcome measures were different between studies. There are some issues that lower the quality of the included studies. Most studies were done on university students or young healthy adults. Consequently, the research cannot be generalized to people of all ages. Furthermore, inclusion and exclusion criteria were not explicit enough to recruit participants with similar characteristics and did not mention existing poor postures or personal habits that might affect the association between the use of smartphone and measured parameters. Additionally, the gender issue has not been addressed. The intervention and task simulations designed may not represent the use of smartphones in real life as it appears that short duration tasks and standardized posture were used in the laboratory setting. The model of smartphones used in each study were different and, moreover, the role of examiners in all studies was not clearly described and intra- and inter-rater reliability were not reported.

Implication for Further Research

Future primary research should use publication guidelines, for example, CONSORT or STROBE, to improve the reporting quality and study design. Research planning should focus initially on the issue of study quality and study validity. More clinical trials with comparison groups are needed to further improve the strength of the evidence and to identify the most suitable method of assessing the musculoskeletal changes due to the use of smartphones.

Conclusion

This systematic review revealed that the use of smartphones may contribute to the occurrence of clinical and subclinical musculoskeletal changes as well as associated factors in the head–neck, shoulder–arm, and hand–thumb areas. While there is a strong case presented in the findings of all the studies reported in this review, the evidence must be considered in the light of the moderate scores from the modified Downs and Black checklist.

Conflict of Interest

All authors declare that they have no conflict of interest.

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Author Contributions

AE is the leading reviewer who contributed to the conception and design of the study. AE and SV contributed to the development of the search strategy, conducted the systematic search, extracted the data, and performed the data analysis. All authors assisted with the interpretation, prepared the manuscript, drafted and revised the final paper. LR contributed to the proof reading of the whole manuscript. All authors approved the final submitted version of the manuscript.

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