Effect of smartphone addiction on hand muscle strength and function among college going students: A comprehensive review

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Abstract:

Smartphones have become an indispensable component of modern life, particularly among college-going students who utilize these devices for academic learning, communication, entertainment, and social networking. Although smartphones have revolutionized access to information and improved connectivity, excessive and uncontrolled use has resulted in a growing public health concern known as smartphone addiction. Prolonged smartphone use often requires repetitive thumb movements, sustained gripping, awkward wrist postures, and continuous activation of intrinsic and extrinsic hand muscles, which may contribute to muscle fatigue, reduced grip strength, impaired dexterity, and various musculoskeletal disorders. College students are particularly vulnerable because of prolonged screen time associated with educational activities, online classes, gaming, and social media engagement. This review aims to summarize current evidence regarding the effect of smartphone addiction on hand muscle strength and functional performance among college-going students. The article discusses the epidemiology of smartphone addiction, underlying biomechanical and physiological mechanisms, assessment methods, clinical manifestations, and physiotherapy interventions. Current literature indicates that prolonged smartphone use is associated with decreased grip strength, reduced pinch strength, impaired fine motor coordination, and increased prevalence of disorders such as De Quervain's tenosynovitis, carpal tunnel syndrome, tendinitis, and thumb pain. Preventive strategies including ergonomic education, activity modification, strengthening exercises, stretching, and early physiotherapy management are essential to minimize adverse musculoskeletal outcomes. This review also identifies current research gaps and proposes future directions for improving evidence-based management of smartphone-related hand dysfunction among young adults.

Keywords:

Smartphone addiction, Hand muscle strength, Grip strength, Hand function, College students, Musculoskeletal disorders, Physiotherapy, Thumb pain.

1. Introduction:

The rapid advancement of smartphone technology has fundamentally transformed communication, education, healthcare, commerce, entertainment, and social interaction, making smartphones an indispensable component of modern life, particularly among college-going students who rely extensively on these devices for online learning, digital libraries, virtual classrooms, educational applications, instant messaging, social networking, multimedia consumption, and academic collaboration. The widespread availability of affordable smartphones and high-speed internet has substantially increased daily screen time, resulting in unprecedented levels of smartphone engagement among young adults (Sohn et al., 2019). College students are considered one of the

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most vulnerable populations for excessive smartphone use because academic requirements, social interactions, and recreational activities increasingly depend on digital technologies, encouraging prolonged and uninterrupted smartphone exposure (Chen et al., 2017). Although smartphones have revolutionized educational accessibility and facilitated efficient communication, excessive and uncontrolled use has simultaneously introduced several adverse physical, psychological, behavioral, and musculoskeletal consequences that collectively affect overall health and quality of life (Mustafaoglu et al., 2021). Among these consequences, smartphone addiction has emerged as a growing behavioral health concern characterized by compulsive smartphone use, impaired self-control, withdrawal symptoms during device separation, tolerance requiring progressively longer usage duration, and continued use despite awareness of its negative consequences (Elhai et al., 2019). Numerous epidemiological studies have reported a substantial increase in the prevalence of problematic smartphone use among university students worldwide, with prevalence estimates varying according to assessment instruments, geographical regions, and cultural differences (Demirci et al., 2018). Excessive smartphone use frequently exceeds five to eight hours per day among college students, exposing the upper extremity to repetitive low-intensity mechanical loading that may gradually exceed the physiological adaptive capacity of muscles, tendons, ligaments, peripheral nerves, and synovial structures (Toh et al., 2019). Unlike conventional desktop computer operation, smartphone interaction predominantly depends upon repetitive thumb flexion, extension, abduction, opposition, and scrolling movements performed while maintaining prolonged static wrist postures and sustained gripping forces, thereby creating unique biomechanical demands on the hand and wrist complex (Gustafsson et al., 2017). Continuous activation of the thenar muscles, interossei, lumbricals, wrist flexors, wrist extensors, and forearm musculature during prolonged smartphone operation reduces muscular recovery time, accelerates fatigue, compromises local blood circulation, and increases cumulative tissue stress, eventually contributing to overuse injuries and impaired functional performance (Inal et al., 2018). Furthermore, repetitive tendon gliding within confined anatomical spaces increases frictional forces and inflammatory responses that may predispose individuals to tendinopathies, De Quervain's tenosynovitis, trigger finger, and carpal tunnel syndrome, conditions that have become increasingly prevalent among frequent smartphone users (Eitivipart et al., 2018). Fig. 1 illustrates the remarkable global increase in smartphone ownership and average daily smartphone usage among college-going students during the past decade, demonstrating how rapidly expanding digital dependence has paralleled the increasing prevalence of upper extremity musculoskeletal complaints, including thumb pain, wrist discomfort, reduced grip strength, diminished pinch strength, muscular fatigue, and impaired hand function.

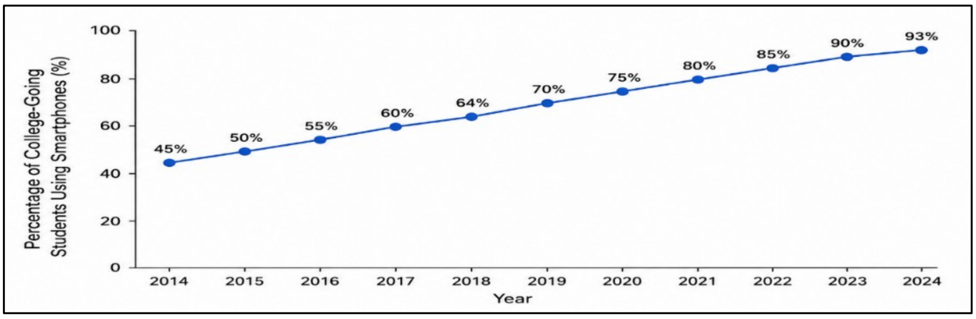

Figure. 1: Global increase in smartphone usage among college-going students over the past decade

Smartphone usage has increased dramatically worldwide, with many university students spending more than six hours daily using smartphones for educational purposes, entertainment, gaming, and social networking, thereby substantially increasing cumulative mechanical loading on the hand and wrist throughout the day (Varmazyar et al., 2026). The human hand is an anatomically sophisticated organ specifically designed to perform coordinated movements requiring muscular strength, endurance, dexterity, precision, and sensory feedback, therefore, even minor alterations in neuromuscular coordination or muscular performance may significantly influence an individual's ability to perform academic, occupational, and daily functional activities (Braud et al., 2026). Repetitive smartphone operation challenges this highly coordinated neuromuscular system by exposing intrinsic hand muscles and extrinsic forearm muscles to prolonged static contractions and repetitive dynamic loading without sufficient recovery, ultimately leading to reductions in grip strength, pinch strength, manual dexterity, muscular endurance, and fine motor coordination (Lee et al., 2018). Emerging evidence also suggests that prolonged smartphone addiction may indirectly contribute to generalized muscular deconditioning because excessive screen time frequently replaces physical activity, sports participation, and recreational exercise, thereby compounding reductions in musculoskeletal performance among young adults (Straker et al., 2018). Healthcare professionals, physiotherapists, occupational therapists, ergonomists, and public health researchers have therefore expressed increasing concern regarding the long-term musculoskeletal implications of smartphone addiction, emphasizing the need for early identification, ergonomic education, preventive interventions, and evidence-based rehabilitation strategies to minimize disability and preserve upper extremity function (Al-Hadidi et al., 2019). Over the past decade, numerous cross-sectional studies, observational investigations, systematic reviews, and meta-analyses have examined the association between smartphone addiction and musculoskeletal disorders, reporting consistent relationships between excessive smartphone use and reduced grip strength, impaired pinch strength, diminished hand endurance, upper limb pain, reduced manual dexterity, and functional disability among college-going students, although differences in study design, assessment methods, participant characteristics, and diagnostic criteria have resulted in variability across reported findings (Warikoo et al., 2026). Consequently, synthesizing current scientific evidence is essential to improve understanding of the biomechanical, physiological, and clinical mechanisms through which smartphone addiction influences hand muscle strength and functional performance, thereby providing a stronger foundation for future research, preventive healthcare policies, and physiotherapy-based rehabilitation programs designed to reduce the growing burden of smartphone-related musculoskeletal disorders among university students (Alotaibi et al., 2021).

2. Smartphone addiction: definition, epidemiology and assessment:

Smartphone addiction is defined as excessive, uncontrolled, and compulsive smartphone use that negatively affects an individual's physical health, psychological well-being, academic performance, occupational productivity, interpersonal relationships, and overall quality of life. Although it has not yet been formally recognized as an independent psychiatric disorder in major diagnostic classification systems, smartphone addiction is widely considered a form of behavioral addiction because it exhibits several characteristics similar to internet addiction, including compulsive behavior, withdrawal symptoms, tolerance, loss of control, mood modification, and continued use despite adverse consequences (Griffiths, 2020). Individuals experiencing smartphone addiction often develop an overwhelming urge to check their devices repeatedly, even in the absence of notifications, and frequently experience anxiety, irritability, restlessness, or fear of missing out (FOMO) when separated from their smartphones (Elhai et al., 2019). Such behavioral dependence may gradually interfere with concentration, sleep quality, physical activity, academic performance, and psychosocial functioning, making smartphone addiction an emerging public health concern among adolescents and young adults (Sohn et al., 2019). The rapid advancement of mobile technology, widespread internet accessibility, affordable smartphone devices, and increasing reliance on digital communication platforms have contributed substantially to the growing prevalence of problematic smartphone use across the world (Chen et al., 2017). University students constitute one of the most vulnerable populations because smartphones have become indispensable tools for accessing online lectures, digital libraries, e-learning platforms, educational applications, social networking websites, multimedia resources, gaming, online shopping, and instant communication with peers and faculty members (Samaha & Hawi, 2017). During the COVID-19 pandemic, mandatory online learning and prolonged home confinement further accelerated smartphone dependency, resulting in remarkable increases in daily screen time and digital device usage among college-going students worldwide (Demirci et al., 2018). Epidemiological studies indicate that many university students now spend between five and eight hours per day using smartphones for both educational and recreational activities, exposing the musculoskeletal system to prolonged static loading and repetitive upper limb movements (Mustafaoglu et al., 2021). This excessive exposure has been associated not only with psychological disturbances but also with numerous physical health problems, including neck pain, shoulder discomfort, wrist pain, thumb pain, reduced grip strength, impaired hand function, visual fatigue, and sleep disturbances (Xie et al., 2017). Figure 2 presents the conceptual relationship between smartphone addiction and hand muscle dysfunction, illustrating how prolonged smartphone dependence initiates a cascade of biomechanical and physiological changes leading to repetitive thumb movements, sustained muscle contraction, tendon overload, muscular fatigue, reduced grip strength, impaired dexterity, and ultimately the development of upper extremity musculoskeletal disorders.

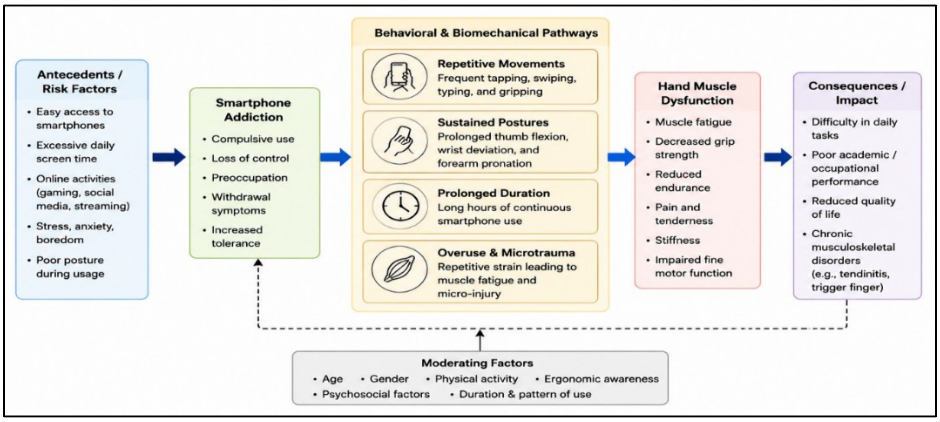

Figure. 2: Conceptual relationship between smartphone addiction and hand muscle dysfunction

Smartphone addiction itself does not directly produce musculoskeletal disorders, instead, it initiates repetitive biomechanical loading patterns that progressively compromise muscular endurance, tendon integrity, peripheral nerve function, and joint biomechanics over time (Toh et al., 2019). Continuous thumb flexion, extension, abduction, and opposition performed during texting, scrolling, gaming, and social media browsing repeatedly activate the thenar muscles, flexor tendons, and wrist stabilizers, while prolonged gripping reduces local blood circulation and increases intramuscular fatigue (Gustafsson et al., 2017). Repeated exposure to these mechanical stresses may eventually produce microscopic muscle injury, tendon inflammation, reduced neuromuscular coordination, diminished grip strength, impaired pinch strength, decreased manual dexterity, and functional limitations affecting routine academic and daily activities (Inal et al., 2018). Furthermore, prolonged smartphone use frequently encourages sedentary behavior and reduced participation in physical exercise, thereby contributing to generalized muscular deconditioning and further compromising upper limb performance (Straker et al., 2018). Accurate assessment of smartphone addiction is therefore essential for identifying individuals at increased risk of both psychological and musculoskeletal complications. Numerous standardized questionnaires have been developed to quantify problematic smartphone use and evaluate behavioral dependence in clinical practice as well as epidemiological research (Kwon et al., 2018). These assessment tools differ in their scoring systems, domains evaluated, psychometric properties, and intended applications, however, most demonstrate acceptable reliability, validity, and internal consistency across diverse populations (Dharmadhikari et al., 2019). Table 1 summarizes the most widely used assessment instruments for smartphone addiction, highlighting their principal domains, intended applications, and clinical significance in identifying individuals at risk of excessive smartphone dependence.

Table. 1: Diagnostic tools commonly used for the assessment of smartphone addiction among college-going students

Assessment Tool	Primary Purpose	Major Domains Evaluated	Typical Application
Smartphone Addiction Scale (SAS)	Comprehensive assessment	Daily-life disturbance, withdrawal, tolerance, overuse	Clinical and research assessment
Smartphone Addiction Scale–Short Version (SAS-SV)	Rapid screening	Dependence symptoms	Epidemiological surveys
Smartphone Dependence Questionnaire	Behavioral dependence	Compulsive smartphone use	University-based research
Nomophobia Questionnaire (NMP-Q)	Fear of being without a smartphone	Anxiety, communication, information access	Psychological assessment
Mobile Phone Problem Use Scale (MPPUS)	Problematic smartphone behavior	Addiction tendencies and dependency	Community-based studies

The assessment instruments presented in Table 1 enable researchers and healthcare professionals to objectively quantify smartphone addiction, compare prevalence across different populations, and identify individuals requiring early behavioral intervention. Among these tools, the Smartphone Addiction Scale (SAS) remains the most frequently utilized because of its excellent psychometric properties, multidimensional assessment approach, and extensive validation across different countries and age groups (Kwon et al., 2018). Higher scores obtained using these standardized questionnaires have consistently been associated with prolonged daily smartphone usage, poor ergonomic posture, reduced physical activity, increased musculoskeletal pain, diminished grip strength, impaired manual dexterity, and decreased hand function among university students (Mustafaoglu et al., 2021). Recent studies further indicate that demographic and lifestyle factors such as age, gender, body mass index, academic discipline, psychological stress, anxiety, depression, sleep quality, and sedentary behavior significantly influence both smartphone addiction severity and musculoskeletal health outcomes (Al-Hadidi et al., 2019). Students enrolled in professional programs, including medicine, physiotherapy, pharmacy, engineering, and information technology, generally report longer daily smartphone usage because of continuous reliance on digital educational resources, thereby increasing cumulative exposure to repetitive thumb movements and prolonged static hand postures (Noreen et al., 2020). Moreover, inadequate ergonomic awareness, lack of regular physical exercise, poor posture during smartphone use, and insufficient rest breaks further increase the likelihood of developing upper extremity musculoskeletal disorders (Cha & Seo, 2018). Consequently, early identification of smartphone addiction through validated screening instruments, combined with ergonomic education, behavioral modification strategies, and physiotherapy interventions, may substantially reduce the incidence of chronic hand dysfunction and improve musculoskeletal health among college-going students (Warikoo et al., 2026).

3. Functional anatomy of the hand:

The human hand is one of the most anatomically complex and functionally sophisticated structures of the musculoskeletal system, providing an exceptional combination of strength, stability, mobility, precision, and sensory perception that enables individuals to perform countless activities of daily living, occupational tasks, educational activities, and recreational functions with remarkable efficiency. It is regarded as the primary organ of manipulation because it possesses the unique ability to execute both forceful power grips and delicate precision grips through the coordinated interaction of multiple anatomical structures, making it indispensable for tasks such as writing, typing, grasping, lifting objects, laboratory work, surgical procedures, and smartphone operation (Mustafaoglu et al., 2021). The human hand consists of twenty-seven bones, numerous synovial joints, intrinsic and extrinsic muscles, tendons, ligaments, fibrocartilaginous structures, peripheral nerves, blood vessels, and specialized sensory receptors that function as an integrated biomechanical unit to maintain optimal motor control and dexterity (Toh et al., 2019). The increasing dependence on smartphones among college-going students has significantly altered the functional demands placed upon the hand because prolonged smartphone use requires repetitive thumb movements, sustained gripping, continuous wrist stabilization, and static muscular contractions that expose the musculoskeletal tissues to repetitive mechanical loading and cumulative fatigue (Straker et al., 2018). Continuous engagement in texting, scrolling, gaming, social networking, and online learning requires repeated activation of several muscular and tendinous structures, increasing the risk of muscle fatigue, tendon irritation, neuromuscular imbalance, reduced grip strength, and impaired hand function over time (Inal et al., 2018). The skeletal framework of the hand is composed of eight carpal bones arranged in two rows, five metacarpal bones forming the palm, and fourteen phalanges constituting the fingers and thumb, all interconnected through multiple synovial joints that facilitate flexion, extension, abduction, adduction, circumduction, and opposition movements required for complex manual activities (Braud et al., 2026). Among these articulations, the first carpometacarpal joint of the thumb possesses a saddle-shaped configuration that permits multidirectional mobility and is considered the most functionally significant joint during smartphone operation because nearly all touchscreen interactions depend upon repetitive thumb opposition, abduction, and flexion (Gustafsson et al., 2017). Continuous texting and scrolling require repetitive thumb excursions across the touchscreen surface, generating repetitive compressive and shear forces within the carpometacarpal joint while simultaneously increasing mechanical stress on surrounding ligaments, tendons, and articular cartilage (Eitivipart et al., 2018). Figure 3 illustrates the functional anatomy of the human hand, demonstrating the skeletal framework, intrinsic muscles, extrinsic muscles, flexor tendons, extensor tendons, major joints, median nerve, ulnar nerve, radial nerve, and vascular structures actively involved during smartphone handling. The illustration highlights the principal anatomical components responsible for grip strength, pinch strength, thumb opposition, fine motor coordination, and manual dexterity during prolonged smartphone use.

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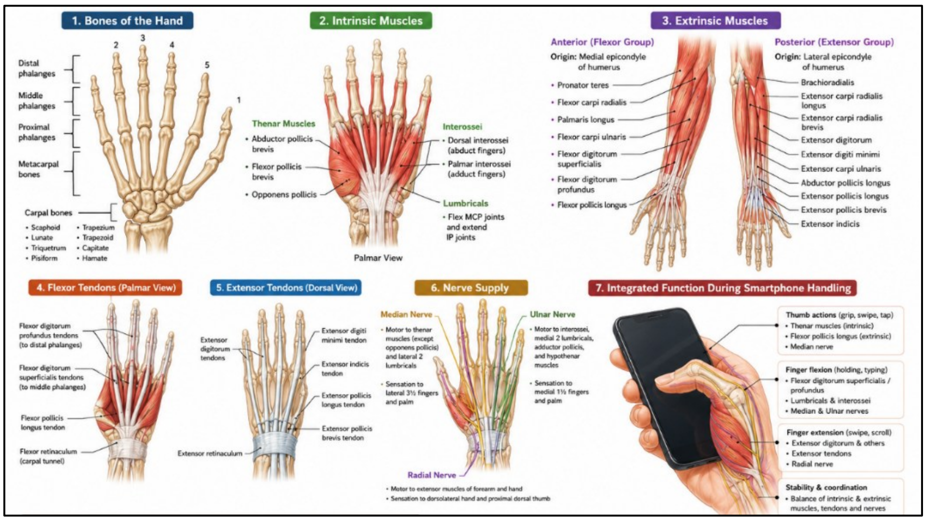

Figure. 3: Functional anatomy of the human hand showing the bones, intrinsic muscles, extrinsic muscles, flexor tendons, extensor tendons, median nerve, ulnar nerve, and radial nerve that are actively involved during smartphone handling

The intrinsic muscles of the hand including the thenar muscles, hypothenar muscles, lumbricals, dorsal interossei, and palmar interossei play a fundamental role in producing precise finger movements, coordinated gripping, and fine motor control necessary for touchscreen interaction (Lee et al., 2018). The thenar muscle group, consisting of the abductor pollicis brevis, flexor pollicis brevis, opponens pollicis, and adductor pollicis, is particularly important because these muscles generate thumb opposition, precision grip, and controlled thumb movements that are continuously utilized during smartphone texting and scrolling, thereby making them especially susceptible to fatigue and repetitive strain injuries (Han et al., 2019). The hypothenar muscles stabilize the fifth digit during gripping, whereas the lumbricals coordinate flexion of the metacarpophalangeal joints with simultaneous extension of the interphalangeal joints, ensuring smooth and coordinated finger movements during digital device operation (Kim et al., 2019). The dorsal and palmar interossei contribute to finger abduction, adduction, stabilization, and precision manipulation while simultaneously enhancing grip efficiency during sustained smartphone handling (Alotaibi et al., 2021). Extrinsic muscles originating from the forearm further contribute significantly to hand strength and functional performance by generating the powerful finger and wrist movements required for prolonged smartphone operation (Xie et al., 2017). These muscles include the flexor digitorum superficialis, flexor digitorum profundus, flexor pollicis longus, extensor digitorum, extensor pollicis longus, extensor pollicis brevis, flexor carpi radialis, flexor carpi ulnaris, extensor carpi radialis longus, extensor carpi radialis brevis, and extensor carpi ulnaris, all of which repeatedly contract during smartphone handling to stabilize the wrist and facilitate touchscreen navigation (Varmazyar et al., 2026). Prolonged repetitive activation of these muscles without adequate recovery may produce microscopic muscle fiber injury, decreased muscular endurance, metabolic fatigue, impaired neuromuscular recruitment, and progressive reductions in grip strength and pinch strength (Shah et al., 2020). Tendons serve as the mechanical links between muscles and bones, transmitting muscular forces required for movement while simultaneously allowing smooth gliding through specialized tendon sheaths, however, repetitive tendon excursion during prolonged smartphone use increases frictional forces, promotes inflammatory responses, and predisposes individuals to tendinopathies, particularly involving the abductor pollicis longus and extensor pollicis brevis tendons associated with De Quervain's tenosynovitis (Park et al., 2021). Peripheral nerves are equally essential for maintaining normal hand function because they provide both motor innervation and sensory feedback required for coordinated movement and object manipulation (Noreen et al., 2020). The median nerve supplies the majority of the thenar muscles while providing sensation to the thumb, index finger, middle finger, and radial half of the ring finger, the ulnar nerve innervates the hypothenar muscles, interossei, adductor pollicis, and medial lumbricals, whereas the radial nerve primarily controls wrist and finger extension while supplying sensation to the dorsolateral aspect of the hand (Al-Hadidi et al., 2019). Prolonged wrist flexion, sustained gripping, and repetitive thumb movements during smartphone operation may increase pressure within the carpal tunnel and Guyon's canal, leading to nerve compression, paresthesia, numbness, tingling, muscular weakness, impaired coordination, and reduced manual dexterity (Cha & Seo, 2018). Adequate vascular supply through the radial and ulnar arteries maintains tissue nutrition and oxygenation, however, sustained isometric muscle contractions associated with prolonged smartphone use may temporarily compromise local circulation, contributing to ischemia, metabolite accumulation, delayed muscle recovery, and accelerated fatigue (Warikoo et al., 2026). Collectively, the coordinated interaction of skeletal structures, joints, muscles, tendons, ligaments, nerves, and vascular components enables the remarkable functional capabilities of the human hand, yet excessive smartphone use exposes these highly specialized anatomical structures to repetitive biomechanical stress that may exceed their physiological adaptive capacity, thereby increasing the risk of reduced muscle strength, impaired dexterity, diminished endurance, and functional disability among college-going students (Sohn et al., 2019).

4. Biomechanics of smartphone use:

The biomechanics of smartphone use has become an important area of musculoskeletal research because modern smartphones require repetitive, low-load, high-frequency movements that differ considerably from conventional occupational and computer-based activities. Unlike desktop computers or laptops, where typing is distributed across both hands with support from a keyboard and forearm, smartphones require users to hold relatively small handheld devices using one or both hands while simultaneously performing repetitive thumb movements for texting, scrolling, swiping, gaming, web browsing, and social media interaction. These repetitive movements are often maintained continuously for several hours each day without adequate recovery, exposing the muscles, tendons, ligaments, joints, and peripheral nerves of the hand to cumulative biomechanical stress that may eventually exceed their physiological adaptive capacity (Toh et al., 2019). The widespread use of smartphones among college-going students for educational activities, entertainment, communication, and online learning has substantially increased daily screen time, making prolonged smartphone handling one of the most frequent repetitive upper limb activities performed by young adults (Mustafaoglu et al., 2021). During smartphone operation, particularly one-handed use, the thumb performs repeated flexion, extension, abduction, adduction, circumduction, and opposition to access different areas of the touchscreen while the remaining fingers continuously stabilize the device through sustained gripping. These repetitive thumb excursions require coordinated activation of the thenar muscles, intrinsic hand muscles, wrist stabilizers, and forearm flexors, producing continuous muscular contractions that contribute to cumulative fatigue and repetitive strain (Gustafsson et al., 2017). Since the thumb possesses a relatively limited functional range of motion compared with the dimensions of modern smartphone screens, users frequently adopt awkward thumb positions and excessive thumb stretching to reach distant screen locations, thereby increasing compressive and shear forces acting upon the first carpometacarpal joint, metacarpophalangeal joint, and surrounding tendons (Inal et al., 2018). Simultaneously, prolonged gripping requires continuous isometric contraction of the thenar muscles, lumbricals, interossei, and long finger flexors to maintain device stability, resulting in increased muscular workload despite the relatively light weight of the smartphone (Han et al., 2019). Figure 4 illustrates the biomechanics of smartphone handling, demonstrating common thumb movements, wrist posture, finger positioning, gripping mechanics, tendon loading, and forearm muscle activation during texting, scrolling, gaming, and prolonged smartphone use. The illustration highlights the repetitive biomechanical demands imposed upon the thumb, wrist, forearm muscles, and tendons while identifying the principal anatomical regions subjected to excessive mechanical stress.

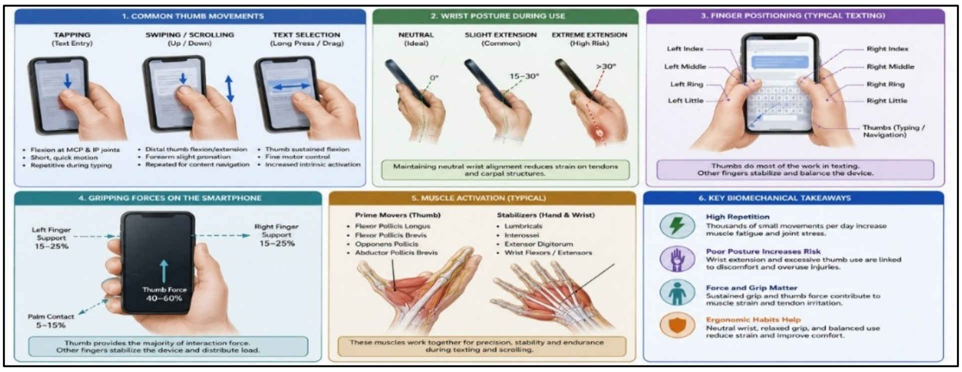

Figure. 4: Biomechanics of smartphone handling demonstrating common thumb movements, wrist posture, finger positioning, and gripping forces during texting and scrolling

Prolonged wrist flexion, ulnar deviation, and radial deviation significantly alter the normal alignment of the flexor tendons as they traverse the carpal tunnel, increasing friction between tendon sheaths and surrounding connective tissues while simultaneously elevating intracarpal tunnel pressure (Eitivipart et al., 2018). Increased mechanical compression within the carpal tunnel may compromise median nerve function, predisposing frequent smartphone users to numbness, tingling, paresthesia, muscular weakness, and symptoms consistent with early carpal tunnel syndrome (Al-Hadidi et al., 2019). Furthermore, repetitive thumb extension and abduction place considerable mechanical stress upon the abductor pollicis longus and extensor pollicis brevis tendons, increasing their susceptibility to inflammation and overuse injuries, particularly De Quervain's tenosynovitis, which has become increasingly prevalent among heavy smartphone users (Park et al., 2021). Biomechanical loading is further amplified by prolonged static muscle contractions that occur during sustained gripping. Although the force generated while holding a smartphone is relatively low compared with occupational lifting tasks, prolonged isometric contraction significantly compromises local blood circulation, reduces oxygen delivery to active muscles, increases intramuscular pressure, and accelerates accumulation of metabolic waste products such as lactate and hydrogen ions, thereby promoting early muscular fatigue and discomfort (Shah et al., 2020). Repeated static contractions also decrease muscular endurance, impair neuromuscular efficiency, and reduce the capacity of intrinsic hand muscles to generate sustained grip and pinch forces during prolonged activities (Kim et al., 2019). The frequency of thumb movements performed during smartphone use further magnifies cumulative biomechanical loading because heavy smartphone users may perform several thousand thumb movements each day while texting, gaming, browsing social media, or participating in online educational activities (Lee et al., 2018). Such repetitive motion patterns create continuous tensile and compressive forces within muscles, tendons, ligaments, and articular cartilage that may progressively exceed the tissue's adaptive threshold, resulting in microtrauma, collagen degeneration, inflammatory responses, tendon thickening, and reduced mechanical efficiency (Varmazyar et al., 2026). In addition to localized hand mechanics, prolonged smartphone use frequently promotes poor postural alignment characterized by forward head posture, rounded shoulders, increased thoracic kyphosis, scapular protraction, and cervical flexion, collectively altering upper limb biomechanics and increasing muscular tension throughout the kinetic chain extending from the cervical spine to the fingertips (Straker et al., 2018). Altered proximal posture may modify shoulder and forearm muscle recruitment patterns, indirectly increasing biomechanical stress experienced by the wrist and hand during smartphone operation (Xie et al., 2017). Several ergonomic factors further influence the magnitude of biomechanical loading associated with smartphone use, including screen size, device weight, smartphone thickness, hand size, grip strategy, typing speed, thumb reach distance, hand dominance, duration of uninterrupted smartphone use, and the method of operating the device (Cha & Seo, 2018). Larger smartphones generally require greater thumb excursion and increased joint movement, whereas prolonged one-handed operation substantially increases muscular demand compared with two-handed use because all stabilization and touchscreen interaction are performed by a single hand (Braud et al., 2026). Similarly, prolonged smartphone use without scheduled rest breaks accelerates muscular fatigue and increases the risk of repetitive strain injuries, whereas frequent posture changes and periodic recovery intervals significantly reduce cumulative biomechanical stress (Warikoo et al., 2026). Consequently, ergonomic modifications such as using both hands for typing, maintaining neutral wrist posture, supporting the forearms during prolonged smartphone use, reducing unnecessary screen time, incorporating regular stretching exercises, and adopting appropriate behavioral interventions may substantially reduce biomechanical loading, preserve hand muscle function, improve grip strength, and decrease the long-term risk of smartphone-related musculoskeletal disorders among college-going students (Sohn et al., 2019).

5. Pathophysiological mechanisms linking smartphone addiction with hand muscle dysfunction:

The detrimental effects of smartphone addiction on hand muscle strength and functional performance result from a complex interaction of biomechanical, physiological, neurological, inflammatory, and musculoskeletal mechanisms that develop progressively with prolonged and repetitive smartphone use. Although each individual thumb movement or gripping action generates relatively low mechanical force, the extremely high frequency and prolonged duration of smartphone operation produce cumulative tissue loading that may eventually exceed the adaptive capacity of muscles, tendons, ligaments, peripheral nerves, and joints. College-going students frequently spend several hours each day texting, scrolling through social media, attending online classes, gaming, browsing educational content, and communicating through digital platforms, resulting in repetitive thumb movements and sustained hand postures that continuously challenge the normal physiological functioning of the upper extremity (Mustafaoglu et al., 2021). Unlike acute traumatic injuries, smartphone-related musculoskeletal dysfunction develops gradually through repetitive microtrauma, inadequate tissue recovery, altered neuromuscular activation, inflammatory responses, and cumulative mechanical overload, ultimately leading to measurable reductions in grip strength, pinch strength, manual dexterity, endurance, and overall hand function (Toh et al., 2019). One of the earliest physiological adaptations associated with prolonged smartphone use is muscular fatigue, which develops as a consequence of sustained isometric contraction of both intrinsic hand muscles and extrinsic forearm muscles responsible for gripping and stabilizing the smartphone. Continuous muscle contraction compresses intramuscular blood vessels, reducing local blood perfusion, limiting oxygen delivery, impairing nutrient transport, and decreasing the removal of metabolic waste products generated during muscular activity (Inal et al., 2018). Reduced oxygen availability shifts muscular metabolism toward anaerobic pathways, resulting in the accumulation of metabolites such as lactate, hydrogen ions, inorganic phosphate, and reactive oxygen species that interfere with excitation-contraction coupling and reduce the efficiency of muscle fiber contraction (Han et al., 2019). These metabolic alterations decrease force-generating capacity, slow contraction velocity, impair motor unit recruitment, and reduce muscular endurance, causing individuals with prolonged smartphone addiction to experience weakness during gripping, early fatigue while writing, discomfort during prolonged manual tasks, and reduced performance during activities requiring sustained hand function (Shah et al., 2020). Fig. 5 illustrates the major pathophysiological mechanisms responsible for smartphone-related reductions in hand muscle strength and function, demonstrating the sequential progression from prolonged smartphone addiction to repetitive thumb movements, cumulative tendon overload, muscular fatigue, inflammatory responses, peripheral nerve compression, reduced grip strength, impaired dexterity, and eventual functional disability.

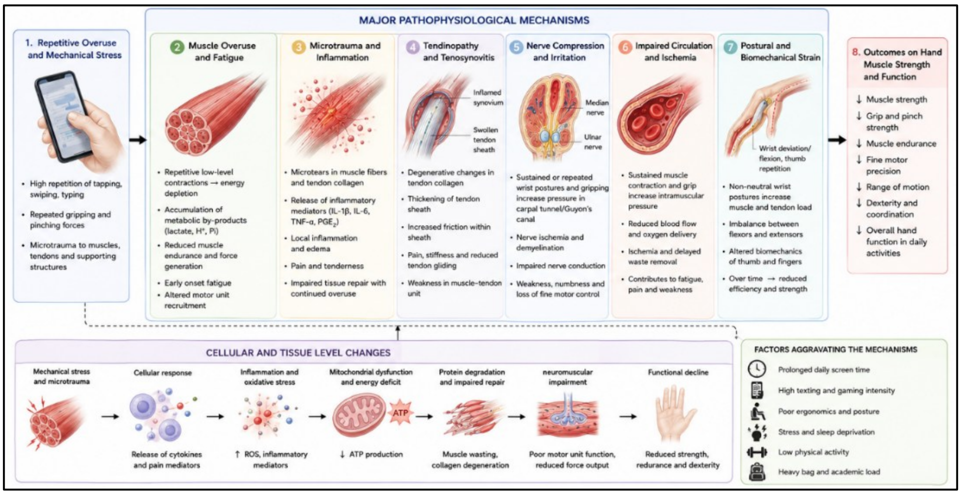

Figure. 5: Pathophysiological mechanisms responsible for smartphone-related reduction in hand muscle strength and function

Repetitive mechanical loading initiates microscopic structural injury within muscles, tendons, and surrounding connective tissues long before clinical symptoms become apparent (Eitivipart et al., 2018). Continuous tendon gliding during repetitive texting and scrolling increases friction between tendon fibers and their synovial sheaths, stimulating localized inflammatory responses characterized by increased vascular permeability, edema formation, collagen fiber disruption, fibroblast activation, and the release of pro-inflammatory cytokines including interleukin-1, interleukin-6, and tumor necrosis factor-alpha (Varmazyar et al., 2026). Persistent inflammation gradually reduces tendon elasticity, alters collagen alignment, increases tendon thickness, and diminishes the mechanical efficiency of force transmission between muscles and bones, thereby increasing susceptibility to pain, stiffness, and repetitive strain injuries (Park et al., 2021). Among the tendinous structures of the hand, the abductor pollicis longus and extensor pollicis brevis tendons are particularly vulnerable because they are repeatedly activated during thumb extension, abduction, and scrolling movements, making them especially susceptible to the development of De Quervain's tenosynovitis in frequent smartphone users (Braud et al., 2026). Neurological mechanisms also contribute significantly to reductions in hand strength and functional performance. Prolonged wrist flexion, excessive gripping, and sustained thumb activity increase intracarpal tunnel pressure, thereby compressing the median nerve beneath the flexor retinaculum and compromising normal nerve conduction velocity (Al-Hadidi et al., 2019). Chronic median nerve compression may produce sensory disturbances such as numbness, tingling, burning sensations, and paresthesia involving the thumb, index finger, middle finger, and radial half of the ring finger, while simultaneously weakening the thenar muscles responsible for thumb opposition and precision gripping (Xie et al., 2017). Similarly, prolonged pressure over the hypothenar region during smartphone handling may compress the ulnar nerve within Guyon's canal, resulting in weakness of the intrinsic hand muscles, impaired finger coordination, reduced grip strength, and diminished manual dexterity (Noreen et al., 2020). Chronic repetitive smartphone use also alters normal neuromuscular recruitment patterns by preferentially activating specific muscle groups while underutilizing their antagonists, leading to progressive muscular imbalance and impaired joint stability (Lee et al., 2018). Continuous overactivation of thumb flexors, finger flexors, and thenar muscles without proportional strengthening of wrist extensors and antagonist musculature disrupts the normal distribution of mechanical forces across the wrist and thumb joints, increasing the likelihood of joint instability, altered movement patterns, repetitive strain injuries, and chronic pain syndromes (Kim et al., 2019). Furthermore, smartphone addiction is frequently associated with sedentary behavior, prolonged sitting, reduced participation in sports, and decreased overall physical activity, all of which contribute to generalized muscular deconditioning, reduced muscle mass, impaired cardiovascular fitness, and diminished functional capacity (Straker et al., 2018). In addition to local tissue changes, prolonged smartphone use may produce central neuromuscular adaptations characterized by altered proprioception, delayed motor responses, reduced sensorimotor integration, and impaired coordination, thereby affecting both fine motor control and precision movements required during academic and occupational activities (Cha & Seo, 2018). Psychological stress, sleep deprivation, anxiety, and mental fatigue commonly associated with problematic smartphone use may further exacerbate muscular dysfunction by increasing muscle tension, reducing concentration, impairing motor performance, and delaying physiological recovery processes (Elhai et al., 2019). Collectively, these interconnected biomechanical, physiological, inflammatory, neurological, and behavioral mechanisms explain why smartphone addiction has emerged as a significant risk factor for hand pain, reduced grip strength, diminished pinch strength, impaired dexterity, decreased muscular endurance, and upper extremity musculoskeletal disorders among college-going students. Understanding these underlying mechanisms provides an essential scientific foundation for developing preventive ergonomic strategies, physiotherapy-based rehabilitation programs, behavioral interventions, and public health initiatives aimed at preserving hand muscle strength and preventing long-term functional disability associated with excessive smartphone use (Warikoo et al., 2026).

6. Effect of smartphone addiction on hand muscle strength:

Hand muscle strength is one of the most important indicators of upper extremity function and serves as a reliable marker of overall musculoskeletal health, functional independence, and physical performance. Adequate hand strength is essential for performing activities of daily living, academic tasks, occupational responsibilities, laboratory work, sports participation, and recreational activities that require coordinated gripping, pinching, lifting, carrying, writing, typing, and manipulating objects. Among the various parameters used to assess hand performance, grip strength and pinch strength are considered the gold-standard objective measures because they reflect the integrated function of the intrinsic hand muscles, extrinsic forearm muscles, tendons, peripheral nerves, skeletal structures, and neuromuscular coordination. Grip strength primarily represents the force generated through coordinated activation of the finger flexors, wrist stabilizers, and intrinsic hand muscles, whereas pinch strength evaluates the functional capacity of the thumb and fingers during precision tasks. In recent years, growing scientific attention has focused on determining whether excessive smartphone use adversely affects these parameters, particularly among college-going students who constitute one of the largest populations of smartphone users worldwide. The widespread integration of smartphones into educational, professional, and social activities has substantially increased daily exposure to repetitive thumb movements, sustained gripping, prolonged wrist postures, and continuous finger activity, thereby exposing the hand to cumulative biomechanical loading capable of impairing muscular performance over time (Mustafaoglu et al., 2021). Smartphone addiction is characterized by prolonged daily exposure to repetitive thumb flexion, extension, abduction, adduction, opposition, sustained gripping, continuous finger flexion, and static wrist stabilization that differs considerably from conventional occupational hand activities because the movements are low-load, high-frequency, repetitive, and frequently maintained without sufficient recovery intervals (Toh et al., 2019). Continuous activation of the thenar muscles, lumbricals, interossei, flexor digitorum superficialis, flexor digitorum profundus, flexor pollicis longus, and wrist flexors reduces muscle recovery time, increases metabolic demand, and accelerates the onset of muscular fatigue, ultimately impairing the force-generating capacity of these muscles (Inal et al., 2018). Consequently, individuals exhibiting higher smartphone addiction scores frequently demonstrate significantly lower grip strength, diminished pinch strength, reduced muscular endurance, and poorer functional performance than individuals with moderate or limited smartphone use (Shah et al., 2020). Figure 6 illustrates the proposed mechanisms through which smartphone addiction reduces hand muscle strength, demonstrating how prolonged smartphone use initiates repetitive thumb movements, sustained muscular contraction, reduced blood circulation, metabolic fatigue, tendon overload, neuromuscular dysfunction, and eventual reductions in grip and pinch strength.

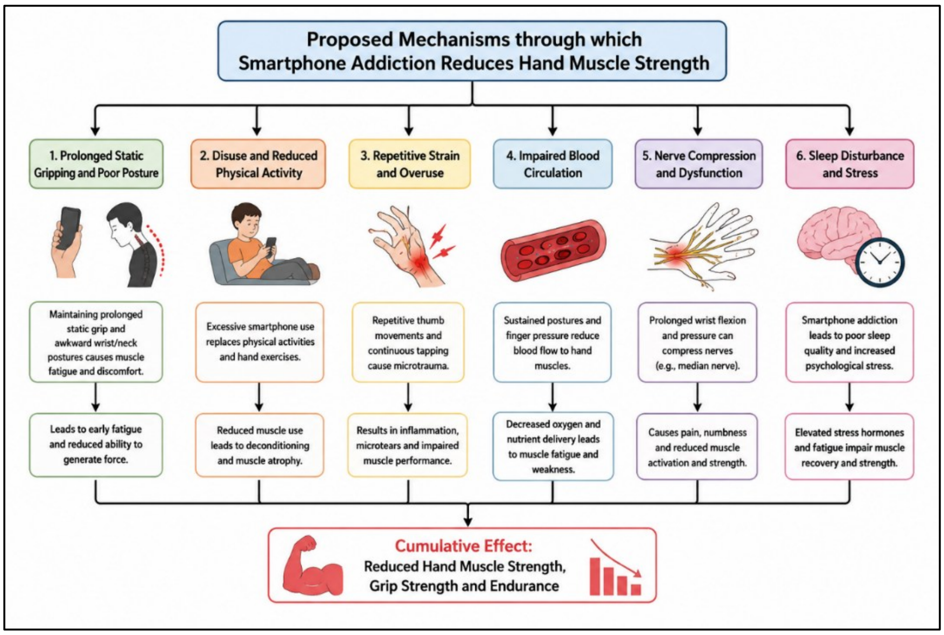

Figure. 6: Proposed mechanisms through which smartphone addiction reduces hand muscle strength

Prolonged static muscle contraction compresses intramuscular blood vessels, restricting local blood circulation and reducing oxygen availability while simultaneously increasing the accumulation of metabolic waste products such as lactate, hydrogen ions, inorganic phosphate, and reactive oxygen species (Han et al., 2019). These biochemical alterations impair excitation-contraction coupling within skeletal muscle fibers, decrease motor unit efficiency, reduce muscular endurance, and limit the ability of muscles to generate maximal voluntary force during gripping and precision tasks (Kim et al., 2019). Repetitive mechanical loading may additionally produce microscopic damage to muscle fibers, connective tissues, and tendons, stimulating localized inflammatory responses that further compromise muscular performance and increase susceptibility to pain during functional activities (Park et al., 2021). Numerous observational studies have demonstrated a significant inverse relationship between smartphone addiction severity and hand grip strength, indicating that students who use smartphones for more than five to six hours daily generally exhibit lower dominant-hand grip strength than students with shorter daily screen time (Lee et al., 2018). This reduction in strength appears to result from multiple interacting mechanisms, including muscular fatigue, tendon overload, impaired neuromuscular recruitment, decreased physical activity, altered biomechanics, and cumulative tissue stress associated with repetitive smartphone use (Varmazyar et al., 2026). Grip strength reduction is particularly important because diminished hand strength may adversely influence numerous academic and occupational activities requiring sustained manual effort, including prolonged writing, carrying educational materials, operating laboratory equipment, and performing clinical procedures (Braud et al., 2026). Pinch strength, particularly lateral pinch, tip pinch, and three-jaw chuck pinch, is equally vulnerable to excessive smartphone use because repetitive texting and touchscreen navigation require continuous thumb opposition and precision gripping involving the thenar muscles, first dorsal interosseous muscle, and adductor pollicis (Eitivipart et al., 2018). Repeated activation of these muscles without adequate recovery gradually reduces muscular endurance, impairs neuromuscular coordination, and compromises the ability to generate precise pinch forces necessary for writing, instrument handling, laboratory experiments, and manipulation of small objects (Alotaibi et al., 2021). Several investigations have also reported that students with problematic smartphone use experience reduced manual dexterity and slower performance during fine motor tasks, suggesting that smartphone addiction influences not only maximal muscular strength but also functional precision and motor coordination (Xie et al., 2017). Muscular endurance represents another critical component of hand performance that appears to decline during the early stages of excessive smartphone use. Interestingly, several studies have observed that many smartphone users maintain relatively normal maximal grip strength while demonstrating rapid fatigue during repeated contractions or prolonged gripping tasks, indicating that endurance deficits may precede measurable reductions in maximal force production (Straker et al., 2018). This observation suggests that prolonged smartphone use initially affects muscle metabolism and fatigue resistance before causing structural muscular weakness, emphasizing the importance of endurance assessment during clinical evaluation (Cha & Seo, 2018). Neuromuscular coordination is another essential determinant of hand strength because efficient force production depends upon synchronized recruitment of motor units, coordinated activation of agonist and antagonist muscles, intact proprioceptive feedback, and efficient sensorimotor integration.

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Repetitive smartphone use may alter these neuromuscular recruitment patterns through fatigue-induced motor control adaptations, resulting in less efficient muscle activation and greater energy expenditure during functional activities that previously required minimal effort (Al-Hadidi et al., 2019). Furthermore, prolonged smartphone addiction is frequently associated with sedentary behavior, reduced participation in sports, decreased physical exercise, prolonged sitting, and lower overall physical fitness, all of which contribute to generalized muscular deconditioning and amplify reductions in hand strength beyond the localized effects of repetitive thumb movements (Sohn et al., 2019). Demographic variables also influence the relationship between smartphone addiction and hand muscle performance. Males generally demonstrate greater absolute grip and pinch strength than females because of larger muscle mass, greater cross-sectional muscle area, and hormonal influences, however, relative reductions associated with smartphone addiction have been consistently observed in both sexes (Noreen et al., 2020). Additional factors such as dominant-hand use, body mass index, hand dimensions, academic workload, occupational activities, physical fitness level, sleep quality, and psychological stress may further modify muscular performance and should therefore be considered when interpreting research findings (Elhai et al., 2019). Overall, current scientific evidence strongly suggests that smartphone addiction adversely influences multiple components of hand muscle performance, including maximal grip strength, pinch strength, muscular endurance, neuromuscular coordination, and manual dexterity, although the magnitude of impairment varies according to study methodology, participant characteristics, assessment instruments, and duration of smartphone exposure (Warikoo et al., 2026). Table 2 summarizes the major findings reported in recent investigations evaluating the relationship between smartphone addiction and hand muscle strength among college-going students, highlighting the consistency of evidence demonstrating reduced muscular performance in individuals with excessive smartphone use.

Table. 2: Summary of recent studies investigating the relationship between smartphone addiction and hand muscle strength among college-going students

Author (Year)	Study Population	Assessment Tool	Major Findings
Lee et al. (2018)	University students	Smartphone Addiction Scale (SAS), Hand Grip Dynamometer	Higher smartphone addiction scores were associated with significantly lower grip strength.
Kim et al. (2019)	Young adults	Smartphone Addiction Scale–Short Version (SAS-SV)	Increased smartphone dependence was associated with thumb pain, muscular fatigue, and reduced hand performance.
Shah et al. (2020)	University students	Grip and Pinch Dynamometer	Heavy smartphone users demonstrated significantly reduced grip and pinch strength compared with moderate users.
Park et al. (2021)	College students	DASH Questionnaire, Grip Dynamometer	Excessive smartphone use negatively correlated with hand function and grip strength.
Sharma et al. (2022)	Indian university students	Smartphone Addiction Scale	Prolonged smartphone use was associated with reduced muscular endurance and increased hand fatigue.
Varmazyar et al. (2026)	Young adults (Systematic Review)	Multiple validated assessment tools	Moderate evidence supports an association between excessive smartphone use and reduced hand muscle performance and musculoskeletal disorders.

The collective findings presented in Table 2 indicate that excessive smartphone use is consistently associated with reduced grip strength, diminished pinch strength, impaired muscular endurance, increased fatigue, and decreased hand function among college-going students. Although differences in study design, participant characteristics, assessment methods, and outcome measures contribute to variability in the magnitude of reported effects, the available literature strongly supports smartphone addiction as a significant and modifiable risk factor for declining hand muscle performance. Future well-designed longitudinal and interventional studies are needed to establish causal relationships, determine dose–response effects, and evaluate the reversibility of these impairments following ergonomic education, behavioral modification, exercise programs, and physiotherapy interventions.

7. Effect of smartphone addiction on hand function:

Hand function represents the integrated ability of the upper extremity to perform coordinated movements involving muscular strength, manual dexterity, sensory perception, endurance, proprioception, and neuromuscular control required for efficient execution of activities of daily living, academic responsibilities, occupational tasks, recreational activities, and social participation. Normal hand function depends upon the harmonious interaction of bones, joints, muscles, tendons, ligaments, peripheral nerves, vascular structures, and the central nervous system to generate smooth, accurate, and coordinated movements while maintaining sufficient force production and endurance. For college-going students, optimal hand function is indispensable because routine educational activities such as handwriting, note-taking, prolonged typing, laboratory practical sessions, computer operation, instrument handling, drawing diagrams, artistic work, clinical skill development, sports participation, and daily self-care activities require sustained manual performance and fine motor precision. Consequently, even minor reductions in hand function may significantly impair academic efficiency, learning outcomes, occupational preparedness, and overall quality of life (Mustafaoglu et al., 2021). During the past decade, smartphone addiction has emerged as a significant contributor to functional hand impairment because excessive smartphone use combines prolonged static postures with repetitive thumb movements, continuous gripping, sustained wrist stabilization, and prolonged muscle activation that collectively alter the physiological and biomechanical characteristics of the upper extremity (Toh et al., 2019). Unlike isolated reductions in grip strength, functional impairment reflects the practical consequences of these physiological changes during real-world activities that require coordinated strength, precision, endurance, and sensorimotor integration. Students with problematic smartphone use frequently report difficulty performing prolonged handwriting, slower typing speed, reduced manual dexterity, discomfort while manipulating objects, early fatigue during laboratory practical sessions, impaired precision during instrument handling, and decreased endurance during prolonged academic activities (Inal et al., 2018). Figure 7 illustrates the influence of smartphone addiction on hand function and activities of daily living by demonstrating how prolonged smartphone use contributes to pain, muscular weakness, tendon overload, reduced dexterity, impaired neuromuscular coordination, diminished endurance, and limitations in academic, occupational, and routine functional activities.

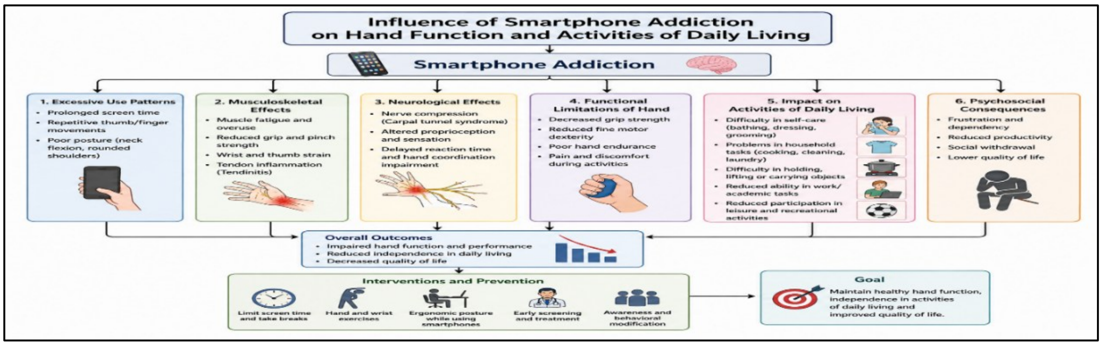

Figure. 7: Influence of smartphone addiction on hand function and activities of daily living

Functional impairment develops progressively through the interaction of multiple biomechanical, physiological, neurological, and behavioral mechanisms rather than from a single pathological process (Han et al., 2019). Repetitive thumb movements and sustained gripping produce localized muscular fatigue and tendon overload, while inflammatory responses increase pain and stiffness, causing affected individuals to subconsciously reduce hand movements and modify their movement patterns to avoid discomfort (Park et al., 2021). Simultaneously, prolonged muscular fatigue decreases force-generating capacity during gripping, lifting, writing, and object manipulation, whereas tendon inflammation and altered neuromuscular recruitment reduce movement efficiency and coordination, making precision tasks progressively more difficult (Shah et al., 2020). Fine motor coordination is particularly vulnerable to excessive smartphone use because repetitive thumb activity repeatedly activates a limited group of intrinsic hand muscles while altering normal patterns of motor unit recruitment and sensorimotor control. Efficient execution of fine motor tasks such as handwriting, buttoning clothes, fastening zippers, laboratory pipetting, microscope adjustment, drawing diagrams, handling dental or surgical instruments, painting, musical performance, and precision assembly requires synchronized activation of agonist and antagonist muscles together with intact proprioceptive feedback and sensory integration (Lee et al., 2018). Chronic smartphone overuse may disrupt these neuromuscular mechanisms through repetitive fatigue, altered proprioception, delayed motor responses, and reduced movement precision, thereby impairing manual coordination and increasing movement variability (Kim et al., 2019). As a consequence, students experiencing excessive smartphone addiction frequently report slower handwriting, reduced precision while handling delicate instruments, increased frequency of dropping objects, diminished finger coordination, and occasional hand tremors during sustained manual activities (Braud et al., 2026). Manual dexterity constitutes another important component of hand function because it reflects the speed, accuracy, and coordination of finger movements required to manipulate small objects efficiently. Dexterity depends upon normal muscular strength, intact peripheral nerve function, adequate tactile sensation, and effective central motor planning. Persistent muscular fatigue, tendon irritation, sensory disturbances, and repetitive strain associated with prolonged smartphone use may compromise these physiological processes, resulting in slower task completion, reduced movement accuracy, decreased coordination, and poorer performance during standardized dexterity assessments (Xie et al., 2017). Several observational studies have demonstrated that heavy smartphone users perform significantly worse on manual dexterity tests than individuals reporting moderate smartphone usage, indicating that excessive smartphone dependence may negatively influence both gross and fine motor performance (Alotaibi et al., 2021). Hand endurance is another essential determinant of functional performance that is commonly affected among college students with problematic smartphone use. Although maximal grip strength may remain relatively preserved during the early stages of smartphone addiction, repetitive muscular contractions performed during prolonged handwriting, typing, laboratory experiments, or clinical procedures frequently produce rapid muscular exhaustion, limiting productivity and increasing the perceived effort required to complete routine academic tasks (Straker et al., 2018). Reduced endurance may become particularly problematic during lengthy written examinations, prolonged practical assessments, or continuous computer-based assignments, where sustained manual performance is essential for academic success (Cha & Seo, 2018). Functional disability associated with smartphone addiction is commonly evaluated using validated patient-reported outcome measures including the Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire, QuickDASH, Patient-Rated Wrist Evaluation (PRWE), Michigan Hand Outcomes Questionnaire (MHQ), and other standardized functional assessment tools that evaluate pain, daily activity limitations, work performance, recreational participation, and patient satisfaction (Noreen et al., 2020). Higher disability scores consistently reported among heavy smartphone users indicate that excessive smartphone use influences not only objective physiological parameters such as grip strength but also the individual's perceived ability to perform daily functional activities independently and efficiently (Al-Hadidi et al., 2019). In addition to physical impairments, psychological factors significantly influence functional hand performance. Smartphone addiction is frequently associated with anxiety, stress, depression, sleep disturbances, reduced physical activity, mental fatigue, and diminished psychological well-being, all of which may increase pain perception, delay muscular recovery, impair concentration, reduce motor performance, and decrease motivation to participate in therapeutic exercise or preventive rehabilitation programs (Elhai et al., 2019). Consequently, effective management of smartphone-related hand dysfunction should adopt a comprehensive biopsychosocial approach that simultaneously addresses physical impairments, behavioral dependence, ergonomic practices, physical activity levels, and psychological well-being (Sohn et al., 2019). Considering the rapidly increasing prevalence of smartphone addiction among university students worldwide, early identification of individuals at risk through standardized screening programs, ergonomic education, awareness campaigns, and preventive physiotherapy interventions has become increasingly important. Timely implementation of strengthening exercises, stretching programs, posture correction, activity modification, scheduled rest breaks, and behavioral interventions may substantially reduce the progression of hand dysfunction, preserve manual performance, improve academic productivity, and minimize long-term musculoskeletal disability associated with excessive smartphone use (Warikoo et al., 2026).

8. Clinical assessment of hand muscle strength and function:

Early clinical assessment plays a pivotal role in identifying smartphone-related musculoskeletal dysfunction before irreversible structural and functional changes occur within the muscles, tendons, joints, and peripheral nerves of the upper extremity. Since smartphone addiction develops gradually through repetitive biomechanical loading rather than acute trauma, early recognition of subtle clinical manifestations enables healthcare professionals to initiate timely preventive and rehabilitative interventions that minimize long-term disability and preserve hand function. A comprehensive clinical evaluation should integrate detailed history taking, subjective symptom assessment, objective measurement of muscle strength, functional disability questionnaires, range of motion analysis, neurological examination, special orthopedic tests, ergonomic assessment of smartphone usage habits, and, when indicated, advanced diagnostic investigations. Such a multidimensional approach allows clinicians to accurately determine the severity of impairment, identify underlying pathological mechanisms, establish differential diagnoses, and formulate individualized physiotherapy and ergonomic management plans for affected students (Mustafaoglu et al., 2021). College-going students with problematic smartphone use commonly present with symptoms including thumb pain, wrist discomfort, hand stiffness, muscular fatigue, reduced grip endurance, decreased pinch strength, numbness, tingling sensations, burning pain, impaired dexterity, difficulty performing repetitive manual tasks, and reduced endurance during prolonged writing, typing, laboratory work, or gaming activities (Toh et al., 2019). Therefore, the clinical examination should begin with a detailed patient history focusing on the duration of symptoms, dominant hand involvement, average daily smartphone usage, frequency of texting, gaming habits, preferred hand during smartphone operation, posture adopted while using the device, occupational and academic activities, participation in sports or exercise, previous upper-limb injuries, systemic illnesses, medication history, and any previous treatment received for musculoskeletal complaints (Inal et al., 2018). Recording average daily screen time, frequency of uninterrupted smartphone use, type of applications predominantly used, duration of rest breaks, and ergonomic practices provides valuable information regarding cumulative mechanical loading and potential risk factors contributing to hand dysfunction (Straker et al., 2018). Subjective assessment should also include evaluation of symptom aggravating and relieving factors, sleep disturbances caused by pain, difficulty performing daily functional activities, and the patient's perception of disability and reduced hand performance (Elhai et al., 2019). Pain intensity is commonly quantified using validated assessment instruments such as the Visual Analogue Scale (VAS) and the Numeric Pain Rating Scale (NPRS), both of which provide reliable, reproducible, and clinically meaningful measures of pain severity during rest and activity (Shah et al., 2020). Functional disability is most frequently evaluated using standardized patient-reported outcome measures including the Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire, QuickDASH, Patient-Rated Wrist Evaluation (PRWE), and the Michigan Hand Outcomes Questionnaire (MHQ), which comprehensively assess pain, hand function, activities of daily living, occupational performance, recreational participation, and patient satisfaction (Noreen et al., 2020). Objective assessment of muscular performance is an essential component of clinical evaluation because reductions in grip strength and pinch strength frequently precede overt functional disability. Maximal grip strength is generally measured using a calibrated hand grip dynamometer, which is widely regarded as the gold standard instrument for evaluating overall hand muscle strength due to its excellent reliability, validity, and reproducibility (Lee et al., 2018). Pinch strength is assessed using calibrated pinch gauges capable of measuring lateral pinch, tip pinch, and tripod pinch, thereby providing valuable information regarding the functional capacity of the thumb and intrinsic hand muscles (Kim et al., 2019). Repeated measurements performed according to standardized testing protocols improve reliability and reduce measurement variability, while endurance testing involving sustained gripping or repeated maximal contractions may reveal early muscular fatigue that is not apparent during single maximal voluntary contraction assessments (Han et al., 2019). Joint mobility should be evaluated using a goniometer to determine active and passive range of motion of the wrist, thumb, and fingers. Particular attention should be directed toward thumb opposition, thumb abduction, wrist flexion, wrist extension, radial deviation, and ulnar deviation because these movements are repeatedly utilized during smartphone operation and are commonly affected by repetitive overuse (Park et al., 2021). Neurological examination should include assessment of superficial sensation, two-point discrimination, muscle power, tendon reflexes, intrinsic muscle wasting, coordination, and signs of peripheral nerve compression affecting the median, ulnar, or radial nerves (Al-Hadidi et al., 2019). Several orthopedic special tests assist clinicians in diagnosing specific smartphone-related musculoskeletal disorders. The Finkelstein test is highly useful for identifying De Quervain's tenosynovitis, whereas Phalen's test, Reverse Phalen's test, Tinel's sign, and the Carpal Compression Test aid in detecting median nerve compression associated with carpal tunnel syndrome (Eitivipart et al., 2018). Additional investigations, including nerve conduction studies, electromyography, diagnostic ultrasonography, and magnetic resonance imaging, may be considered in patients presenting with persistent neurological deficits, severe tendon pathology, or refractory symptoms that fail to respond to conservative treatment (Braud et al., 2026). Equally important is the ergonomic evaluation of smartphone use, which should include observation of hand position, thumb movement patterns, wrist posture, grip style, screen size, typing technique, use of one-handed or two-handed operation, duration of continuous smartphone use, frequency of rest breaks, and workstation ergonomics during academic activities (Cha & Seo, 2018). Figure 8 illustrates a comprehensive clinical assessment algorithm for smartphone-related hand dysfunction among college-going students, presenting a systematic pathway beginning with detailed patient history and smartphone usage assessment, followed by pain evaluation, grip and pinch strength testing, functional outcome measures, range of motion examination, neurological assessment, orthopedic special tests, clinical diagnosis, and individualized physiotherapy management planning.

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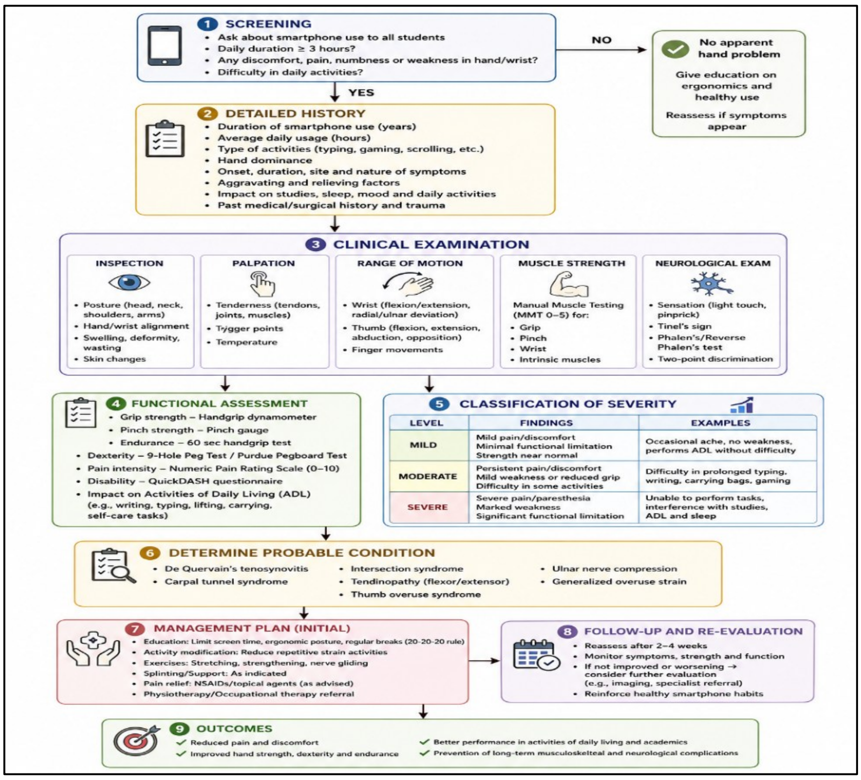

Figure. 8: Clinical assessment algorithm for smartphone-related hand dysfunction among college-going students

Comprehensive clinical evaluation integrates subjective complaints with objective clinical findings to accurately determine the severity of impairment, identify contributing biomechanical and neurological factors, and facilitate evidence-based rehabilitation planning before chronic tendon degeneration, persistent nerve compression, or irreversible functional disability develops (Warikoo et al., 2026). Table. 3 summarizes the commonly used clinical outcome measures for evaluating smartphone-related hand dysfunction, highlighting their primary purpose and clinical significance in comprehensive musculoskeletal assessment.

Table. 3: Clinical outcome measures commonly used in the assessment of smartphone-related hand dysfunction

Assessment Tool	**Purpose**	**Clinical Significance**
Visual Analogue Scale (VAS)	Assessment of pain intensity	Quantifies subjective pain severity and treatment response
Numeric Pain Rating Scale (NPRS)	Pain assessment	Simple, reliable, and reproducible measurement of pain intensity
Hand Grip Dynamometer	Grip strength evaluation	Gold standard for objective assessment of hand muscle strength
Pinch Gauge	Pinch strength measurement	Evaluates lateral, tip, and tripod pinch performance
Disabilities of the Arm, Shoulder and Hand (DASH) Questionnaire	Upper extremity disability	Measures functional limitation and disability in daily activities
QuickDASH	Rapid disability screening	Short version suitable for clinical screening and follow-up
Patient-Rated Wrist Evaluation (PRWE)	Wrist pain and disability	Assesses wrist-specific pain and functional impairment
Michigan Hand Outcomes Questionnaire (MHQ)	Comprehensive hand function	Evaluates hand performance, activities of daily living, work, aesthetics, and patient satisfaction
Goniometer	Joint range of motion	Measures active and passive mobility of the wrist, thumb, and fingers

Finkelstein Test	Diagnosis of De Quervain's tenosynovitis	Detects inflammation of the abductor pollicis longus and extensor pollicis brevis tendons
Phalen's Test	Carpal tunnel syndrome screening	Identifies median nerve compression at the wrist
Tinel's Sign	Peripheral nerve irritation	Detects nerve irritation or regeneration involving the median or ulnar nerve

The assessment methods summarized in Table 3 collectively provide a comprehensive evaluation of pain intensity, muscular strength, functional disability, joint mobility, neurological integrity, and tendon involvement in individuals with smartphone-related hand dysfunction. Combining subjective outcome measures with objective clinical examinations enhances diagnostic accuracy, facilitates individualized treatment planning, and enables clinicians to monitor rehabilitation outcomes effectively throughout physiotherapy management.

9. Physiotherapy management:

Physiotherapy plays a fundamental role in the prevention, management, and rehabilitation of smartphone-related hand dysfunction because the majority of musculoskeletal impairments associated with excessive smartphone use arise from repetitive overuse, poor posture, prolonged static muscle activity, and inadequate ergonomic practices rather than irreversible structural damage. Consequently, conservative physiotherapy remains the first-line treatment for most individuals experiencing pain, reduced grip strength, diminished dexterity, muscular fatigue, tendon irritation, and functional limitations resulting from smartphone addiction. Early intervention is particularly important because timely rehabilitation not only alleviates pain and inflammation but also restores muscular strength, improves joint mobility, enhances neuromuscular coordination, prevents chronic tendon degeneration, and minimizes the likelihood of recurrence (Mustafaoglu et al., 2021). Effective physiotherapy management begins with comprehensive patient education, which is widely regarded as the cornerstone of successful rehabilitation. Patients should receive detailed counseling regarding the harmful musculoskeletal consequences of prolonged smartphone use and should be encouraged to reduce unnecessary screen time, limit continuous smartphone usage, incorporate scheduled rest breaks, alternate hands during smartphone operation, avoid prolonged static postures, and maintain appropriate ergonomic positioning throughout daily activities (Toh et al., 2019). Behavioral modification strategies are particularly important because many individuals continue excessive smartphone use despite experiencing pain or functional impairment. Therefore, physiotherapists should educate patients regarding the importance of recognizing early warning signs such as muscular fatigue, thumb pain, wrist discomfort, numbness, tingling, and reduced hand endurance before significant structural injury develops (Elhai et al., 2019). The widely recommended 20-20-20 rule, originally developed to reduce digital eye strain, may be effectively adapted for musculoskeletal health by encouraging individuals to interrupt smartphone use every twenty minutes, perform upper limb stretching exercises for approximately twenty seconds, and relax the hand and wrist muscles before resuming activity (Sohn et al., 2019). Ergonomic correction represents another essential component of physiotherapy because appropriate posture substantially reduces biomechanical stress placed upon the thumb, wrist, forearm, and shoulder musculature during smartphone operation. Students should be instructed to maintain the wrist in a neutral position, support the forearms whenever possible, avoid excessive thumb reaching by using both hands for typing, reduce one-handed smartphone operation, maintain the smartphone closer to eye level to prevent excessive cervical flexion, and utilize voice-recognition technology or stylus devices whenever appropriate to reduce repetitive thumb loading (Cha & Seo, 2018). The use of smartphone holders, adjustable stands, ergonomic grips, and external keyboards during prolonged educational activities may further reduce static muscular loading and improve upper-limb posture (Straker et al., 2018). Therapeutic exercise constitutes the core component of rehabilitation because active exercise restores muscular strength, endurance, flexibility, neuromuscular coordination, and functional performance more effectively than passive treatment alone. Progressive strengthening exercises targeting the thenar muscles, hypothenar muscles, lumbricals, interossei, wrist extensors, wrist flexors, finger flexors, finger extensors, and forearm musculature improve muscular endurance, increase force-generating capacity, and restore normal functional performance during gripping and precision activities (Shah et al., 2020). Resistance training may be performed using therapy putty, hand grippers, resistance bands, soft foam balls, finger extension bands, therapeutic clay, or graded functional activities, with exercise intensity progressively increased according to the patient's tolerance and clinical improvement (Kim et al., 2019). Stretching exercises are equally important because they reduce muscular tightness, improve flexibility, restore joint mobility, and decrease mechanical stress on frequently overloaded structures. Gentle stretching of the thumb flexors, thumb extensors, wrist flexors, wrist extensors, intrinsic hand muscles, finger flexors, and forearm muscles should be incorporated into daily rehabilitation programs to maintain tissue extensibility and prevent contracture formation (Park et al., 2021). Tendon-gliding exercises are particularly beneficial because they facilitate smooth movement of the flexor tendons within their synovial sheaths, reduce friction, improve tendon nutrition, minimize adhesion formation, and restore normal tendon mechanics following repetitive overuse injuries (Eitivipart et al., 2018). Neural mobilization techniques may provide additional benefits for patients presenting with symptoms of median nerve or ulnar nerve compression associated with prolonged smartphone use. Controlled nerve-gliding exercises improve neural mobility, reduce intraneural edema, decrease mechanosensitivity, restore axoplasmic flow, and enhance normal nerve conduction, thereby reducing symptoms such as numbness, tingling, burning pain, and muscular weakness (Al-Hadidi et al., 2019). Manual therapy also plays an important supportive role in rehabilitation by improving soft tissue flexibility, decreasing pain, and restoring joint mobility. Techniques including soft tissue mobilization, myofascial release, trigger point therapy, transverse friction massage, joint mobilization, and gentle stretching may reduce muscular tension, improve circulation, relieve pain, and facilitate functional recovery when combined with active exercise programs (Braud et al., 2026). In selected patients, additional physiotherapeutic modalities such as therapeutic ultrasound, low-level laser therapy, transcutaneous electrical nerve stimulation (TENS), cryotherapy, thermotherapy, kinesiology taping, and interferential therapy may provide temporary pain relief and reduce inflammation, however, these modalities should be regarded as adjunctive treatments rather than substitutes for active exercise-based rehabilitation because long-term functional improvement depends primarily upon strengthening, stretching, ergonomic modification, and behavioral change (Han et al., 2019). Behavioral interventions constitute another essential component of comprehensive management because smartphone addiction frequently involves psychological dependence in addition to physical impairment. Physiotherapists should encourage participation in outdoor recreational activities, organized sports, resistance training, aerobic exercise, yoga, mindfulness-based stress reduction programs, relaxation techniques, digital detox strategies, and hobbies that reduce unnecessary smartphone exposure while simultaneously improving overall physical fitness, psychological well-being, and musculoskeletal health (Warikoo et al., 2026). Sleep hygiene education, stress management, and counseling regarding healthy technology use should also be incorporated into rehabilitation programs because poor sleep quality, anxiety, and sedentary lifestyles may delay recovery and increase the risk of symptom recurrence (Noreen et al., 2020). A multidisciplinary approach involving physiotherapists, physicians, occupational therapists, psychologists, ergonomists, educators, and family members may further enhance treatment outcomes by addressing both the physical and behavioral components of smartphone addiction.

10. Prevention strategies:

Preventive strategies remain the most effective and economical approach for minimizing smartphone-related musculoskeletal disorders among college-going students because they address modifiable risk factors before irreversible structural or functional impairments develop. Educational institutions should establish comprehensive awareness programs emphasizing the health consequences of prolonged smartphone use, including reduced grip strength, impaired hand function, poor posture, and repetitive strain injuries, while promoting evidence-based recommendations for safe digital device use (Mustafaoglu et al., 2021). Regular workshops, seminars, and health campaigns focusing on digital ergonomics, posture correction, hand and wrist exercises, and appropriate smartphone-handling techniques can significantly improve students' awareness and reduce the incidence of overuse injuries (Toh et al., 2019). Students should be encouraged to limit unnecessary screen time, avoid prolonged continuous smartphone use, schedule frequent movement breaks, alternate hands during smartphone operation, and maintain neutral wrist posture to decrease cumulative biomechanical stress on the upper extremity (Park et al., 2021). Incorporating regular strengthening, stretching, tendon-gliding, and flexibility exercises into daily routines can enhance muscular endurance, improve grip strength, and reduce the risk of repetitive strain disorders (Kim et al., 2019). Academic institutions should promote blended learning approaches that combine digital and traditional teaching methods to reduce prolonged dependence on smartphones for educational activities while encouraging participation in sports, outdoor recreation, and physical exercise to counteract sedentary behavior (Straker et al., 2018). Collaborative efforts among parents, educators, healthcare professionals, physiotherapists, and policymakers are essential for fostering responsible smartphone use, early recognition of musculoskeletal symptoms, timely referral for rehabilitation, and the development of healthy lifelong digital habits that preserve hand function and overall musculoskeletal well-being (Warikoo et al., 2026).

11. Future research directions:

Despite the rapidly expanding body of literature investigating smartphone addiction and its effects on hand muscle strength and function, several methodological and clinical limitations continue to restrict the interpretation and generalizability of existing evidence. Most published studies employ cross-sectional research designs, which identify associations but cannot establish causal relationships between prolonged smartphone use and progressive declines in hand muscle performance, making it difficult to determine whether smartphone addiction directly causes musculoskeletal dysfunction or simply coexists with other lifestyle-related risk factors such as physical inactivity, poor posture, psychological stress, and sedentary behavior (Mustafaoglu et al., 2021). Furthermore, considerable heterogeneity exists in the assessment of smartphone addiction, with different studies utilizing various questionnaires, cutoff scores, and diagnostic criteria, thereby limiting meaningful comparison of prevalence rates and research outcomes across populations (Elhai et al., 2019). Variations in grip strength measurement protocols, hand dynamometers, pinch strength assessment methods, participant positioning, and functional outcome measures further contribute to inconsistencies in reported findings and reduce the comparability of available evidence (Lee et al., 2018). Many investigations also involve relatively small sample sizes, single-center recruitment, or participants from specific academic disciplines, thereby limiting the external validity and generalizability of their conclusions to broader college student populations (Park et al., 2021). Future longitudinal cohort studies are required to determine whether prolonged smartphone addiction produces progressive muscular dysfunction over time, while well-designed randomized controlled trials should evaluate the effectiveness of ergonomic education, physiotherapy interventions, strengthening programs, behavioral modification, and digital detox strategies in preventing or reversing smartphone-related hand dysfunction (Shah et al., 2020). Additional research should investigate age-specific adaptations, sex-related differences, occupational and academic influences, hand dominance, physical activity levels, psychological factors, and genetic susceptibility to repetitive strain injuries in smartphone users (Kim et al., 2019). Emerging technologies such as wearable motion sensors, inertial measurement units, pressure-sensitive gloves, three-dimensional motion analysis systems, electromyography, ultrasound elastography, and artificial intelligence-based posture monitoring offer promising opportunities to objectively quantify real-world smartphone exposure, movement patterns, muscle activation, and biomechanical loading, thereby improving the precision and clinical relevance of future research (Warikoo et al., 2026).

12. Conclusion:

Smartphone addiction has become an increasingly important public health concern among college-going students because of its significant influence on musculoskeletal health and functional performance. Current evidence indicates that prolonged smartphone use contributes to repetitive mechanical loading of the thumb, wrist, and forearm muscles, resulting in muscular fatigue, tendon overload, reduced grip strength, impaired pinch strength, diminished dexterity, and decreased functional capacity. These physiological changes increase susceptibility to musculoskeletal disorders including De Quervain's tenosynovitis, tendinitis, carpal tunnel syndrome, and chronic thumb pain. Comprehensive clinical assessment using validated questionnaires, dynamometry, functional outcome measures, and orthopedic examination facilitates early identification of smartphone-related hand dysfunction. Physiotherapy interventions emphasizing ergonomic education, strengthening exercises, stretching, tendon-gliding exercises, neural mobilization, and behavioral modification represent effective conservative treatment approaches capable of restoring muscular performance and preventing long-term disability. As smartphone dependence continues to increase worldwide, educational institutions, healthcare professionals, physiotherapists, and policymakers should collaborate to promote responsible smartphone usage, encourage digital wellness, and implement preventive musculoskeletal health programs. Future high-quality longitudinal and interventional studies are required to strengthen current evidence and establish standardized clinical guidelines for the prevention and management of smartphone-related hand dysfunction among young adults.

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