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Impact of Digital Dependency on Eye Strain, Fatigue, Grip Strength and Cognitive Development in Children

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ABSTRACT

Background: *Excessive use of digital devices has become increasingly prevalent among children and is associated with emerging concerns regarding visual health, fatigue, physical function, and cognitive development. Prolonged screen exposure during critical developmental periods may predispose children to digital eye strain, generalized fatigue, musculoskeletal weakness, and potential cognitive effects, yet evidence integrating these outcomes in younger age groups remains limited.* ***Objective****: To evaluate the association between digital device use and ocular surface symptoms, fatigue, hand grip strength, and cognitive failures among children aged 8–14 years.* ***Methods****: A cross-sectional observational study was conducted among 186 children in Lahore, Pakistan. Screen exposure was assessed using a structured screen-time questionnaire. Ocular symptoms, fatigue, and cognitive failures were evaluated using the Ocular Surface Disease Index, Chalder Fatigue Scale, and Cognitive Failures Questionnaire, respectively, while hand grip strength was measured using a dynamometer. Associations between screen-time categories and outcomes were analyzed using chi-square tests and Spearman's correlation.* ***Results****: High screen exposure (70–105 hours/week) was reported by 84.9% of participants. Increased screen time was significantly associated with greater ocular surface symptoms (χ^2=27.21, p<0.001), higher fatigue severity (χ^2=18.79, p=0.001), and reduced hand grip strength (ρ=−0.179, p=0.015). No significant association was observed between screen exposure and cognitive failure severity (χ^2=3.20, p=0.202).* ***Conclusion****: Excessive digital device use in children is strongly associated with ocular discomfort, fatigue, and reduced physical strength, while its relationship with self-reported cognitive failures appears limited. These findings highlight the need for early preventive strategies promoting balanced screen use and physical activity in pediatric populations.*

Keywords
Digital Dependency, Screen Time, Eye Strain, Fatigue, Grip Strength, Cognition

INTRODUCTION

Digital technologies have become deeply embedded in children's daily lives, reshaping patterns of learning, communication, recreation, and social interaction. While appropriately regulated screen use can support education and cognitive engagement, excessive and prolonged exposure has raised growing concerns regarding its impact on physical and neurodevelopmental health. Children represent a particularly vulnerable population, as critical periods of visual maturation, musculoskeletal development, and cognitive growth coincide with increasing access to smartphones, tablets, and other digital devices. Recent global trends indicate a substantial rise in screen exposure among school-aged children, accelerated further by shifts toward online education and home-based digital activities following the COVID-19 pandemic (1). This rapid normalization of prolonged screen engagement has intensified the need to understand its multidimensional health consequences.

One of the most consistently reported physical consequences of excessive screen use is digital eye strain, characterized by symptoms such as ocular dryness, irritation, blurred vision, burning sensation, and headaches. Mechanistically, sustained near-vision tasks reduce blink rate and disrupt tear film stability, leading to ocular surface dysfunction and discomfort (2). Pediatric populations may be particularly susceptible, as visual systems are still developing and children often lack awareness of ergonomic viewing practices. Previous studies have demonstrated a clear association between extended screen exposure and higher Ocular Surface Disease Index scores, indicating worsening dry eye symptoms even in young users (3). However, most existing evidence has focused on adolescents or young adults, with comparatively fewer studies examining school-aged children using standardized ocular symptom measures.

Beyond visual health, prolonged screen engagement has been linked to generalized physical and mental fatigue. Digital fatigue arises from sustained cognitive load, static postures, reduced physical activity, and sleep disruption associated with screen exposure, particularly blue-light emission (4). Fatigue in children is clinically relevant, as it may impair academic performance, emotional regulation, and participation in physical activities. Prior literature has shown that higher screen time correlates with increased fatigue severity scores, reflecting both physical exhaustion and mental tiredness (5). Despite this, fatigue remains underexplored as a primary outcome in pediatric digital exposure research, especially when assessed alongside other physical and functional indicators.

Musculoskeletal health is another emerging area of concern in the context of digital overuse. Handheld devices promote prolonged static gripping, repetitive fine motor movements, and reduced engagement in gross motor activities. Over time, these patterns may adversely affect muscle strength and endurance. Hand grip strength is a simple, reliable, and objective marker of overall muscular function and physical well-being in children. Reduced grip strength has been associated with sedentary behavior and decreased physical activity levels (6). Although studies in young adults have reported an inverse relationship between smartphone use duration and hand grip strength, evidence in children remains limited, and grip strength has rarely been incorporated as an outcome in pediatric screen-time research (7).

The relationship between excessive screen exposure and cognitive functioning is more complex and less consistent. Cognitive development during childhood involves the maturation of attention control, working memory, and executive functioning. Overexposure to fast-paced or passive digital content has been hypothesized to interfere with these processes by promoting attentional fragmentation and reduced sustained focus (8). Neuroimaging and behavioral studies suggest that excessive screen engagement may alter neural activation patterns involved in executive control and reward processing (9). However, empirical findings remain mixed, particularly when cognitive outcomes are assessed using self-reported instruments such as the Cognitive Failures Questionnaire. Some studies report increased cognitive lapses with higher screen use, while others fail to demonstrate significant associations after accounting for confounding factors (10). This inconsistency highlights a critical knowledge gap regarding whether perceived everyday cognitive failures are meaningfully related to screen exposure in children.

Taken together, existing literature suggests that excessive digital device use may adversely affect ocular health, fatigue levels, and physical strength, while its impact on cognitive functioning remains uncertain, particularly in younger age groups. Most prior studies have examined these outcomes in isolation, focused on older populations, or relied on limited subjective measures. There is a clear need for integrated research that simultaneously evaluates visual symptoms, fatigue, objective physical function, and perceived cognitive performance within a single pediatric cohort using validated tools. Addressing this gap is essential for developing evidence-based guidelines for parents, educators, and healthcare professionals aimed at promoting healthier digital habits in children.

Therefore, this study was designed to evaluate the association between digital device use and ocular surface symptoms, fatigue severity, hand grip strength, and cognitive failures among children aged 8–14 years. The primary objective was to determine whether higher levels of screen exposure are associated with increased eye strain and fatigue and reduced grip strength, while secondarily exploring its relationship with self-reported cognitive failures. We hypothesized that greater digital device use would be significantly associated with worse ocular symptoms, higher fatigue scores, and lower hand grip strength, but not necessarily with increased cognitive failures as measured by self-report instruments.

MATERIAL AND METHODS

This cross-sectional observational study was conducted to examine the associations between digital device use and ocular surface symptoms, fatigue, hand grip strength, and cognitive failures among school-aged children. The study was carried out in Lahore, Pakistan, with data collected from community and educational settings over a defined recruitment period. A cross-sectional design was selected to allow simultaneous assessment of exposure to digital devices and multiple health-related outcomes within a pediatric population, consistent with epidemiological approaches used to explore behavioral health correlates in children (11).

Children aged 8 to 14 years were considered eligible if they reported regular use of smartphones or tablets for prolonged durations consistent with high daily screen exposure and were able to understand and respond to study instructions and questionnaires. Participants were excluded if they had a known neurological or psychiatric disorder, pre-existing visual or musculoskeletal conditions that could interfere with outcome assessment, or if they or their guardians declined participation. Children with minimal daily screen exposure were also excluded to ensure adequate exposure contrast across participants. Eligible participants were identified through convenience sampling, and guardians provided written informed consent prior to enrollment, with assent obtained from the children in accordance with ethical standards for pediatric research (12).

Data collection was performed using a combination of validated self-report questionnaires and objective physical measurements, administered in a standardized manner. Screen exposure was assessed using a structured screen-time questionnaire designed to capture average weekday and weekend use of digital devices, including smartphones and tablets. Total weekly screen time was calculated by multiplying weekday use by five and weekend use by two, providing a composite measure of habitual exposure. This approach has been widely used in pediatric screen-time research to estimate cumulative exposure while accounting for weekday–weekend variation (13).

Ocular surface symptoms were evaluated using the Ocular Surface Disease Index, a validated 12-item instrument that quantifies the frequency of dry eye symptoms, visual disturbances, and their impact on daily activities. Scores range from 0 to 100, with higher scores indicating greater symptom severity and functional impairment. The OSDI has demonstrated strong reliability and validity across clinical and research settings and has been applied in studies assessing digital eye strain related to screen use (14). Fatigue was assessed using the Chalder Fatigue Scale, an 11-item questionnaire measuring both physical and mental fatigue symptoms. Total scores reflect fatigue severity, with higher values indicating greater levels of exhaustion and reduced functional capacity. This scale has been extensively used to assess fatigue across age groups and behavioral exposure contexts (15).

Perceived cognitive functioning was assessed using the Cognitive Failures Questionnaire, which captures the frequency of everyday cognitive lapses related to attention, memory, and action execution. Higher scores indicate more frequent self-reported cognitive failures. The CFQ has been shown to have good psychometric properties and is commonly used to assess subjective cognitive functioning in non-clinical populations (16). Physical function was objectively assessed through hand grip strength measurement using a hand dynamometer. Grip strength was measured according to standardized procedures, with participants instructed to squeeze the dynamometer with maximal effort. Hand grip strength was recorded as an indicator of upper limb muscular strength and overall physical function, a method supported by prior pediatric and musculoskeletal research (17).

Key study variables included total weekly screen time as the primary exposure variable, and OSDI score, Chalder Fatigue Scale score, CFQ score, and hand grip strength as outcome variables. Age and sex were recorded as demographic variables and considered potential confounders due to their known associations with physical strength, fatigue perception, and screen-use patterns. Standardized administration of questionnaires and measurements was used to minimize measurement bias, and all assessments were conducted under similar conditions to enhance internal consistency.

Sample size estimation was performed a priori to ensure adequate statistical power to detect meaningful associations between screen exposure and health outcomes. The calculation was based on an assumed proportion derived from prior literature, a 95% confidence level, and a predefined margin of error, with adjustment for potential attrition. This resulted in a target sample size sufficient to support inferential analyses of the primary

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outcomes (18). Data completeness was monitored throughout the study, and only participants with complete datasets were included in the final analysis to maintain analytic integrity.

Statistical analysis was conducted using SPSS version 21. Descriptive statistics were used to summarize demographic characteristics, screen-time exposure, and outcome measures. Categorical variables were expressed as frequencies and percentages, while continuous variables were summarized using appropriate measures of central tendency and dispersion. Associations between categorized screen-time exposure and categorical outcome measures were evaluated using chi-square tests or exact alternatives where assumptions were not met. Correlations between continuous or ordinal variables, such as hand grip strength and weekly smartphone and tablet usage, were assessed using Spearman's rank correlation coefficient. All statistical tests were two-tailed, and a p-value of less than 0.05 was considered statistically significant. Analytical decisions were guided by established biostatistical principles to ensure robustness and reproducibility of findings (19).

Ethical approval for the study was obtained from the relevant institutional review body, and all procedures adhered to the principles outlined in the Declaration of Helsinki. Participant confidentiality was maintained by anonymizing data prior to analysis, and access to study data was restricted to the research team. Standardized data entry procedures and verification checks were employed to ensure data accuracy and reproducibility, enabling independent researchers to replicate the methodology and analytical approach used in this study.

RESULTS

As shown in Table 1, the study population consisted of 186 children with a mean age of 11.18 years, demonstrating a near-normal age distribution and balanced sex representation. This demographic spread supports internal validity across late childhood and early adolescence.

Table 2 highlights a striking predominance of high digital exposure, with nearly 98% of participants exceeding 70 hours of weekly screen time, indicating a population at substantial risk for screen-related health effects.

Ocular outcomes presented in Table 3 reveal a strong, statistically significant gradient between screen exposure and dry eye severity. Moderate OSDI symptoms increased from 0% in moderate users to 83.3% in excessive users, with a moderate effect size (Cramér's V=0.27), underscoring a clinically meaningful association.

Table 1. Demographic Characteristics of the Study Population (N = 186)

Variable	Category	n	%
Age (years)	Mean ± SD	11.18 ± 1.99	—
	8	24	12.9
	9	19	10.2
	10	34	18.3
	11	20	10.8
	12	28	15.1
	13	33	17.7
	14	28	15.1
Sex	Male	86	46.2
	Female	100	53.8

Table 2. Weekly Total Screen-Time Exposure Categories

Weekly Screen Time (hours)	Category	n	%
35–70	Moderate use	4	2.2
70–105	High use	158	84.9
>105	Excessive use	24	12.9

Table 3. Association Between Weekly Screen Time and Ocular Surface Disease Index (OSDI) Severity

Screen Time Category	Normal (0–12)	Mild (13–22)	Moderate (23–32)	Total
35–70 hrs	0	4	0	4
70–105 hrs	5	104	49	158
>105 hrs	0	4	20	24
Statistic	Value			
χ^2 (df=4)	27.21			
p-value	<0.001			
Cramér's V	0.27			

Table 4. Association Between Weekly Screen Time and Fatigue Severity (Chalder Fatigue Scale)

Screen Time Category	Mild (0–11)	Moderate (12–21)	Severe (22–33)	Total
35–70 hrs	0	4	0	4
70–105 hrs	1	106	51	158
>105 hrs	0	6	18	24
Statistic	Value			
χ^2 (df=4)	18.79			
p-value	0.001			
Cramér's V	0.23			

Table 5. Association Between Weekly Screen Time and Cognitive Failure Questionnaire (CFQ) Severity

Screen Time Category	Moderate (41–60)	Severe (61–100)	Total
35–70 hrs	1	3	4
70–105 hrs	39	119	158
>105 hrs	2	22	24
Statistic	Value		
χ^2 (df=2)	3.20		
p-value	0.202		
Cramér's V	0.13		

Table 6. Distribution of Hand Grip Strength Among Participants

Grip Strength Category	n	%
0	91	48.9
1	53	28.5
2	31	16.7
3	10	5.4
4	1	0.5

Table 7. Correlation Between Hand Grip Strength and Weekly Smartphone + Tablet Use

Variables	Spearman's ρ	95% CI	p-value
Grip strength vs weekly device hours	−0.179	−0.31 to −0.04	0.015

Similarly, Table 4 demonstrates a significant escalation in fatigue severity with increasing screen exposure. Severe fatigue prevalence rose from 0% in moderate users to 75% among excessive users, reflecting a dose–response pattern with both statistical and clinical relevance.

In contrast, Table 5 shows no statistically significant association between screen time and CFQ severity, despite a high absolute prevalence of severe cognitive lapses across all exposure groups. The small effect size (Cramér's V=0.13) suggests that perceived cognitive failures may be influenced by factors beyond screen duration alone.

Musculoskeletal findings in Tables 6 and 7 indicate a high prevalence of reduced hand grip strength, with nearly half of participants in the lowest strength category. The inverse correlation between grip strength and weekly device use, although weak ($\rho=-0.179$), was statistically significant, suggesting that increased digital engagement may be associated with diminished upper-limb muscular function.

DISCUSSION

The present study provides an integrated evaluation of the physical and cognitive correlates of digital device use among children aged 8–14 years and demonstrates that higher levels of screen exposure are significantly associated with adverse ocular symptoms, increased fatigue, and reduced hand grip strength, whereas no statistically significant association was observed with self-reported cognitive failures. These findings contribute to the growing body of pediatric evidence indicating that excessive digital engagement primarily manifests through physical and functional health domains, while its relationship with perceived cognitive functioning appears more nuanced and less direct.

A key finding of this study is the strong association between weekly screen time and ocular surface symptoms, as measured by the Ocular Surface Disease Index. Children with high and excessive screen exposure showed markedly greater prevalence of mild-to-moderate dry eye symptoms, with a clear dose–response gradient across screen-time categories. This aligns with prior research demonstrating that prolonged near-work and digital viewing reduce blink rate, destabilize the tear film, and increase ocular surface evaporation, thereby precipitating symptoms of digital eye strain (20). Studies in adolescents and young adults have similarly reported higher OSDI scores among heavy screen users, supporting the biological plausibility of these findings (21). Importantly, the current study extends this evidence to a younger age group, highlighting that ocular surface compromise may begin early in childhood when screen exposure is sustained and frequent.

Fatigue emerged as another outcome strongly associated with digital device use. The majority of participants reported moderate to severe fatigue, with severity increasing significantly among children in higher screen-time categories. This observation is consistent with earlier work suggesting that prolonged screen engagement contributes to both physical and mental fatigue through sustained cognitive load, reduced physical activity, and prolonged static postures (22). Additionally, screen exposure—particularly during evening hours—has been linked to circadian disruption and reduced sleep quality, which may indirectly exacerbate daytime fatigue in children (23). Although sleep parameters were not directly measured in this study, the observed association between screen exposure and fatigue underscores the potential cumulative burden of digital behaviors on children's energy levels and daily functioning.

The inverse relationship between weekly device use and hand grip strength, although modest in magnitude, is a notable and clinically relevant finding. Hand grip strength is widely recognized as a proxy for overall muscular strength and physical health in pediatric populations. Reduced grip strength among children with higher screen exposure may reflect a combination of decreased participation in physical activities and prolonged engagement in fine motor, low-force tasks associated with handheld device use (24). Similar inverse associations between smartphone use and grip strength have been reported in young adults, suggesting that musculoskeletal effects of digital behaviors may span across age groups (25). The inclusion of hand grip strength as an objective physical outcome represents a strength of this study and adds novel insight into the potential musculoskeletal implications of excessive screen use in children.

In contrast to physical outcomes, no statistically significant association was observed between screen exposure and cognitive failures as measured by the Cognitive Failures Questionnaire. Although a high prevalence of moderate-to-severe cognitive lapses was reported across all screen-time categories, the lack of between-group differences suggests that self-perceived cognitive failures may be influenced by factors other than screen duration alone. Previous literature has reported mixed findings regarding screen time and cognitive functioning, with some studies identifying associations with attention and executive function deficits, while others report null findings after adjusting for confounders such as sleep, stress, and educational context (26). The use of a self-report measure may also contribute to this inconsistency, as children's insight into their own cognitive performance may be limited. It is possible that objective neurocognitive testing would reveal subtler associations not captured by subjective reporting, an important consideration for future research.

Several strengths of this study warrant consideration. The simultaneous assessment of ocular, fatigue-related, musculoskeletal, and cognitive outcomes provides a comprehensive view of the multifaceted impact of digital device use in children. The use of validated instruments and the inclusion of an objective physical measure enhance the robustness of the findings. However, certain limitations must also be acknowledged. The cross-sectional design precludes causal inference, and the reliance on self-reported screen-time data introduces the possibility of recall bias. The use of convenience sampling and recruitment from a single geographic area may limit generalizability to broader pediatric populations. Additionally, potential confounding factors such as physical activity levels, sleep duration, ergonomic posture, and content type were not directly measured and may have influenced observed associations.

Despite these limitations, the findings have important clinical and public health implications. They suggest that excessive screen exposure in children is more strongly linked to physical strain and fatigue than to perceived cognitive dysfunction, emphasizing the need for early preventive strategies focused on visual health, regular breaks, ergonomic awareness, and physical activity promotion. Future longitudinal studies incorporating objective cognitive testing, sleep assessment, and activity monitoring are recommended to clarify temporal relationships and underlying mechanisms. Such research will be critical in informing evidence-based guidelines aimed at optimizing digital technology use while safeguarding children's physical and developmental health.

CONCLUSION

In conclusion, this study demonstrates that excessive digital device use among children aged 8–14 years is significantly associated with increased ocular surface symptoms, higher levels of fatigue, and reduced hand grip strength, while no significant relationship was observed with self-reported cognitive failures. These findings align with the study objective and underscore that prolonged screen exposure predominantly affects visual and physical health domains rather than perceived cognitive functioning in this age group. From a clinical perspective, the results highlight the importance of early screening for digital eye strain and fatigue in children with high screen exposure, as well as the promotion of regular breaks, ergonomic practices, and physical activity to mitigate musculoskeletal deconditioning. From a research standpoint, the findings support the need for longitudinal and mechanistic studies incorporating objective cognitive, sleep, and activity measures to better delineate causal pathways and inform evidence-based guidelines for healthy digital technology use in pediatric populations.

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