Supplementary Table S1. Mixed method appraisal of the included studies

1. Qualitative Study

Study Reference	S1. Are there clear research questions.	S2. Do the collected data allow to address the research questions?	Q1. 1. Is the qualitative approach appropriate to answer the research question?	Q1.2. Are the qualitative data collection methods adequate to address the research question?	Q1.3. Are the findings adequately derived from the data?	Q1.4. Is the interpretation of results sufficiently substantiated by the data?	Q1.5. Is there coherence between qualitative data sources, collection? analysis, and interpretation?	Comments
Almalki et al. (2017)[13]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	Nonresponse bias not reported.

2. Quantitative Randomized Controlled Trials

Study Reference	S1. Are there clear research questions.	S2. Do the collected data allow to address the research questions?	2.1. Is randomization appropriately performed?	2.2. Are the groups comparable at baseline?	2.3. Are there complete outcome data?	2.4. Are outcome assessors blinded to the intervention provided?	2.5 Did the participants adhere to the assigned intervention?	Comments
Beeson et al. (2024)[1]	Yes	Yes	Yes	Yes	Yes	No	Yes	Participants were aware of the difficulty level (High vs. Low load)
Rosenfield et al. (2015)[2]	Yes	Yes	Yes	Yes	Yes	No	Yes	Blinding was not possible

Portello et al. (2013)[7]	Yes	Yes	No	Yes	Yes	No	Yes	No report of randomisation/blinding
Cagnie et al. (2017)[138]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	Clear RCT design, validated measures, task-specific lens comparison.
Lan et al. (2022)[77]	Yes	Yes	Yes	Yes	No	Yes	Yes	Strong experimental design. Lack of explicit blinding,
Yoshimoto et al. (2017)[81]	Yes	Yes	Yes	Yes	Yes	No	Yes	well-controlled psychophysical experiment.
Cajochen et al. (2011)[111]	Yes	Yes	Yes	Yes	Yes	No	Yes	Rigorous crossover design with objective hormonal markers.
Hou et al. (2021)[82]	Yes	Yes	Can't tell	Yes	Yes	No	Yes	Study integrated multiple ergonomic factors
Fan et al. (2023)[90]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	The study uses a randomized crossover design with both objective (eye tracking) and subjective measures
Soundari et al. (2025)[112]	Yes	Yes	Yes	Can't tell	Yes	Can't tell	Can't tell	Key methodological details are missing from the available text,
Lin Y et al. (2015)[73]	Yes	Yes	Yes	Yes	Yes	No	Yes	It introduced novel objective metrics (Relative Pupil Size, Average Eyeball Movement Speed) to corroborate subjective data, strengthening the validity of the findings.
Lee Si et al. (2018)[142]	Yes	Yes	Can't tell	Yes	Yes	No	Yes	The study used a rigorous experimental design with a controlled environment and objective hormonal (melatonin) markers.
Chen & Epps (2014)[26]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	Pupil diameter fails to indicate cognitive load if the user is already visually overloaded.
Fukuie et al. (2025)[139]	Yes	Yes	Yes	Yes	No	No	Yes	This study uses VDT work to induce cognitive fatigue,

Puma et al. (2018)[95]	Yes	Yes	Yes	Yes	Yes	No	Yes	No blinding
Siemiginowska Iskra-Golec (2020)[87]	Yes	Yes	Yes	Yes	Yes	No	Yes	Counterbalanced; chronotype analysis; No blinding
Gulbinaite et a. (2017)[88]	Yes	Yes	Yes	Yes	Yes	No	Yes	Frequency tagging method.
Quaedflieg et al. (2016)[107]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Placebo-controlled; Small sample
Ridder III & Tomlinson (1993)[38]	Yes	Yes	Yes	Yes	Yes	No	Yes	Very small sample
Yammouni & Evans (2020)[130]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Clear question, randomized crossover design, objective and subjective measures
Manna et al. (2025)[131]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Modest sample size,
Heiland et al. (2021)[71]	Yes	Yes	Yes	Yes	Yes	No	Yes	Small sample size,
Zeidan et al. (2010)[132]	Yes	Yes	No	Yes	Yes	Can't tell	Yes	Small sample size
Yi Z et al (2024)[116]	Yes	Yes	Yes	Yes	Yes	No	Yes	Nil
Dahlqvist et al. (2025)[75]	Yes	Yes	Yes	Yes	Yes	No	Yes	Controlled lab setting
Kajita et al. (2020)[66]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Nil
Kolbe et al. (2023)[141]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	The study is described as "single-blinded"
Chen & Chan (2023)[59]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Blinding was not possible
Domkin et al. (2018)[57]	Yes	Yes	Yes	Yes	Yes	No	Yes	Blinding was not done

Richter et al. (2015)[70]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	Participants were not blinded
Richter et al. (2010) [58]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	Blinding not done
Mork et al. (2016)[72]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	Blinding not done
Monterio et al. (2025)[86]	Yes	Yes	Yes	Yes	Yes	No	Yes	Does not mention about blinding
Bhargava et al. (2023)[137]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	The subjects were masked to the contents.
Gowrisankaran et al. (2012)[17]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	Blinding not done
Sharvit et al. (2025)[20]	Yes	Yes	Yes	Yes	Yes	No	Yes	Blinding not done
Johnson & Rosenfield (2023)[135]	Yes	Yes	Yes	Yes	Yes	No	Yes	Blinding was not possible
Redondo et al (2025)[94]	Yes	Yes	Yes	Yes	Yes	No	Yes	Blinding was not possible
Berntsen et al (2019)[129]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Masking was done
Watcharapalakorn et al (2024)[89]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Double - blinded
Maity et al (2025)[136]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	The intervention was a single drop instillation performed in a controlled environment
Ali A Abusharha (2017)[34]	Yes	Yes	Yes	Yes	Yes	No	Yes	Blinding was not done.
Vaz et al. (2023)[128]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No mention of drop out
Reilly et al. (2018)[102]	Yes	Yes	Yes	Yes	Yes	No	Yes	Intervention was not blinded.

Arita et al (2025)[127]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Examiners were blinded
3. Quantitative Non – Randomized Study								
Study Reference	**S1. Are there clear research questions.**	**S2. Do the collected data allow to address the research questions?**	**3.1. Are the participants representative of the target population?**	**3.2. Are measurements appropriate regarding both the outcome and intervention (or exposure)?**	**3.3. Are there complete outcome data?**	**3.4. Are the confounders accounted for in the design and analysis?**	**3.5. During the study period, is the intervention administered (or exposure occurred) as intended?**	**Comments**
Argilés et al. (2015)[6]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No mention of drop out
Collins et al. (2006)[37]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Small sample
Cardona et al. (2011)[8]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Small sample size
Talens-Estarelles et al. (2022)[31]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	The authors acknowledge they did not control for screen brightness, humidity, or temperature at the individual workplaces.
Kastelan et al. (2024)[43]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	The tests were performed in a standardized order with 10-minute intervals to prevent reflex tearing from one test affecting the next .
Feng et al. (2024)[40]	Yes	Yes	Yes	Yes	Yes	No	Yes	There is no no sham/placebo group.
Luo et al. (2024)[46]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	The study used 129SvEv/CD-1 mixed mice,

Berens and Stark (1932)[51]	Yes	Yes	No	Can't tell	no	no	Yes	Classic ergographic study of accommodative fatigue. Measurement and exposure clearly described; sampling and bias reporting insufficient by modern standards.
Collier et al. (2011)[54]	Yes	Yes	No	Yes	Yes	Yes	Yes	Accommodation/vergence metrics valid, but small sample size reduces representativeness
Chellapan et al. (2024)[10]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	Clear design, sample size calculated with Cochran's formula, inclusion/exclusion criteria well defined.
Gray et al. (2000)[16]	Yes	Yes	Yes	Can't tell	Yes	Can't tell	Yes	Clear experimental design. Very small sample size limits.
Hynes et al. (2018)[60]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	Clear design, strict inclusion/exclusion criteria, randomized tasks.
Yu et al. (2022)[11]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	Clear design, strict inclusion/exclusion criteria, controlled exposure
Ghosh et al. (2011)[61]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	Clear design, strict inclusion/exclusion criteria, controlled exposure.
Thigpen et al. (2010)[76]	Yes	Yes	No	Yes	Yes	Yes	Yes	Clear design, validated measures, posture classification.
Abu-Ghosh et al. (2024)[74]	No	Yes	Yes	Yes	Yes	Can't tell	Yes	Nonresponse bias remains unclear due to lack of reporting on recruitment flow and refusals
Laurent et al. (2018)[78]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	"natural experiment" design with objective environmental logging and repeated daily cognitive testing.

Li J(2025)[114]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	The use of an app to track screen time objectively is a major methodological strength.
Nelles et al. (2010)[119]	Yes	Yes	No	Yes	Yes	No	Yes	The primary weakness is the failure to control for age differences between the groups.
Madigan et al. (2019)[123]	Yes	Yes	yes	Yes	yes	Yes	Yes	The use of a Random-Intercepts Cross-Lagged Panel Model (RI-CLPM) is a major strength,
Dahlstrom-Hakki et al. (2024)[92]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Nil
Ryu et al. (2024)[117]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Study introduces a novel way to induce differential fatigue levels without changing the task itself
Mihelcic & Podlesek (2023)[100]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	The study highlights that cognitive load doesn't just change the mean accommodation (focus), but the variability (SD) of accommodation.
Krigolson et al. (2025)[96]	Yes	Yes	Yes	Yes	Yes	No	Yes	This directly supports the feasibility of using consumer-grade wearables for "real-world" monitoring,
Lee C et al. (2020)[91]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	There is no mention of data exclusion or dropout.
Liu C et al. (2020)[28]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Small sample size
Kaido et al. (2024)[44]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	The study uses objective EEG monitoring to link ocular surface physiology (dry eye) with central nervous system activity (stress).
Zhou et al. (2021)[39]	Yes	Yes	Yes	Yes	Yes	No	Yes	Single-arm (no control).

Korkmaz et al. (2024)[104]	Yes	Yes	No	Yes	Yes	No	Yes	The Gamma frequency band (30–100 Hz) provided the highest classification accuracy.
Park et al (2014)[49]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Robust design
Wylie et al. (2021)[106]	Yes	Yes	Can't tell	Yes	Yes	Yes	Yes	Study provides example of applying Signal detection theory
Boere & Krigolson (2024)[109]	Yes	Yes	Yes	Yes	Yes	No	Yes	Nil
Tian et al. (2022)[85]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	This paper proposes a novel composite metric for visual fatigue
Kaido et al. (2017)[67]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	This study introduces a brilliant methodological control for distinguishing eye from cognitive fatigue/stress
Kaido et al. (2017)[68]	Yes	Yes	Yes	Yes	Yes	No	Yes	small data size
Jeng et al. (2014)[65]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	there is no mention of missing data or subject dropout.
Metlapally et al. (2014)[64]	Yes	Yes	No	Yes	Yes	Yes	Yes	Higher-Order Aberrations (HOAs) generally reduce the contrast signal
Roberts et al. (2018)[101]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	The child sample covers a crucial developmental window
Ayaki et al. (2023)[47]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No administration of intervention
Watanabe et al. (2025)[45]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Small sample size
Lin et al. (2024)[83]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	The paper offers a clear design recommendation for reducing visual fatigue.
Wu Y et al. (2024)[99]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Study conducted in a controlled laboratory

Davis et al. (2015)[79]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	The experiment was strictly controlled.
Zhang et al. (2021)[98]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Nil
Himebaugh et al. (2009)[36]	Yes	Yes	Yes	Yes	Yes	No	Yes	There was a significant Age Confounder
Kim M (2022)[93]	Yes	Yes	No	Yes	Yes	Yes	Yes	No human subjects
Li et al. (2022)[19]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	small sample size
Kim J et al. (2022)[33]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No mention of data loss
Kim J et al. (2018)[32]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	The study used a within-subjects design
Cardona et al. (2023)[29]	Yes	Yes	No	Yes	Yes	No	Yes	Small sample size and lack of statistical analysis
Golebiowski et al (2019)[35]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	small sample size
Hirota et al (2013)[30]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Subjects with pre-existing dry eye were excluded.
Svede et al (2024)[134]	Yes	Yes	Yes	Yes	No	No	No	The intervention was home-based and unsupervised. The groups were not formed randomly.
Gani et al. (2024)[110]	Yes	Yes	No	Yes	Yes	No	Yes	Randomisation was not performed

4. Quantitative Descriptive Study

Study Reference	**S1. Are there clear research questions.**	**S2. Do the collected data allow to address the research questions?**	**4.1. Is the sampling strategy relevant to address the research question?**	**4.2. Is the sample representative of the target population?**	**4.3. Are the measurements appropriate?**	**4.4. Is the risk of nonresponse bias low?**	**4.5. Is the statistical analysis appropriate to answer the research question?**	**Comments**

del Mar et al. (2015)[3]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	The study follows psychometric protocol
Gonzalez-Perez M et al. (2014)[4]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	The questionnaire was administered via personal interview or direct distribution
Mylona et al. (2022)[5]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	the lack of reporting on the non-response rate is a minor limitation
Ünlü et al. (2012)[42]	Yes	Yes	Yes	No	Yes	Yes	Yes	The participants were employees of the ophthalmology department
Zetterberg et al. (2013)[56]	Yes	Yes	Yes	Can't tell	Yes	Can't tell	Yes	EMG and accommodation measures appropriate. Sampling strategy relevant, but representativeness and nonresponse bias not clearly reported.
Padavettan et al. (2021)[9]	Yes	Yes	Yes	Can’t tell	Yes	Can't tell	Yes	Small, single-center sample of optometry students limits representativeness; recruitment not fully reported.
Allen & Mehta (2023)[53]	Yes	Yes	Yes	Can’t tell	Yes	Can't tell	Yes	Pilot study with validated measures. Small sample size and limited representativeness; recruitment/attrition details not reported
Kang et al. (2021)[15]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	Clear design, strict inclusion/exclusion criteria, randomized exposure order.
Hussaindeen et al. (2018)[55]	Yes	Yes	Yes	Yes	Yes	No	Yes	Large multicenter sample with clear inclusion/exclusion criteria.
Maayah et al. (2023)[12]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	Large sample, clear inclusion/exclusion criteria, validated measures.

Shan et al. (2013)[14]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	Large sample, randomized school and student selection, trained surveyors.
Shi et al. (2021)[84]	Yes	Yes	Yes	Yes	Yes	No	Yes	he sample size is small ($n=10$), although this is partially mitigated by the repeated-measures design which increases statistical power.
Ramteke and Satgunam (2023)[69]	Yes	Yes	Yes	No	Yes	Can't tell	Yes	The study used objective measurements (photodocumentation) for viewing distance rather than self-report, which increases the validity of the findings.
Reindel et al. (2018)[52]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	The study is observational and single-arm
McCrann et al. (2021)[115]	Yes	Yes	Yes	yes	Yes	Yes	Yes	The study used objective device-recorded data usage to quantify smartphone exposure, addressing a common weakness
Lee et al. (2023)[126]	Yes	Yes	Yes	Yes	No	Yes	Yes	The primary weakness is the high attrition rate (>50% loss to follow-up)
Mechó-García M et al. (2024)[62]	Yes	Yes	Yes	No	Yes	Can't tell	Yes	Use of objective wavefront sensing technology (Hartmann-Shack) allows for precise measurement of accommodation and aberrations
Fernandez-Alonso et al. (2024)[63]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	The study uses rigorous objective instrumentation (photorefraction)
Xu et al. (2025)[121]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	The study used objective imaging technology (Keratograph 5M) and standardized grading scales.

Twenge et al. (2017)[125]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	The study utilizes massive, nationally representative datasets
Arshad et al. (2021)[122]	Yes	Yes	No	Yes	Yes	No	Yes	LED ceiling lights (Panasonic HH-LC569A) adjusted to low (3000 K) and high (6200 K) color temperatures. Exposure from 19:00 until ~1 h after habitual bedtime.
Page et al. (2024)[27]	Yes	Yes	Can't tell	Yes	Yes	Yes	Yes	Small sample
Studenova et al. (2023)[105]	Yes	Yes	Yes	Yes	Yes	No	Yes	mechanistic signal analysis.
Portello et al. (2012)[41]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	Self-report survey. Large sample
Rajabpour et al. (2024)[118]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	The study uses a validated QOL instrument (NEI-VFQ 25) and objective clinical refraction.
Iskra - Golec & Smith (2009)[108]	Yes	Yes	Can't tell	Yes	No	No	Yes	Small sample size
Galindo-Romero C et al. (2023)[120]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	online survey, response rate in unknown
Enthoven et al. (2021)[50]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Large cohort

This table presents the methodological appraisal of all included studies using the Mixed Methods Appraisal Tool (MMAT, 2018 version). Each criterion is marked as Yes, No, or Can't tell based on the information reported in the original study. The MMAT categories include: (1) qualitative studies, (2) randomized controlled trials, (3) non-randomized quantitative studies, and (4) quantitative descriptive studies. Comments summarize key methodological strengths or limitations identified during appraisal. The MMAT does not generate a total score; instead, each criterion is reported independently to ensure transparency.

Supplementary Table S2: Master list of all included studies

Author/Year/ Ref No.	Study Design	Sample Size	Age range/Mean	Study Domain	Device/Exposure	Result	Limitations	Conclusion	DOI
Beeson et al. (2024)[1]	Prospective experimental study assessing symptom progression and performance over 60 mins of digital tasks	35	≥18 years / 23.2 ± 4.0 years	Digital eye strain (DES), cognitive load, productivity, and task accuracy.	Lenovo ThinkPad L13 Gen 2, 13.3 inch screen size, 250 nits screen brightness.	Visual-ocular symptoms worsened ($F = 87.783$, $p < 0.001$) with time, higher cognitive load ($F = 7.110$, $p < 0.001$). Productivity declined ($F = 138.830$, $p < 0.001$), while task accuracy remained unaffected ($F = 1.729$, $p = 0.197$).	Short task duration (60 minutes), limited generalizability to real-world work settings, and reliance on self-reported symptoms.	DES symptoms intensify with task duration, especially under high cognitive load. This leads to reduced productivity but does not affect task accuracy. Implications for global productivity may be less severe than previously assumed	https://doi.org/10.1016/j.chbr.2024.100489
Rosenfield et al. (2015)[2]	Repeated-measures experimental study comparing blink rates across cognitive load and display type	16	16 - 17 years / 16.5 years	Blink rate modulation in response to cognitive demand and digital versus print reading formats	Apple iPad Mini, Printed hard copy page	Cognitive demand significantly reduced blink rate ($F = 3.87$, $p = 0.05$); method of presentation (tablet vs. print) had no effect ($F = 0.00$, $p = 0.98$); interaction between cognition and display type was significant.	Small sample size (N = 16), short task duration (10 minutes), and limited age range (16–17 years) restrict generalizability.	Cognitive demand, not screen type, primarily drives blink rate reduction; modern digital displays may resemble print more closely than older screens in their impact on blinking.	https://doi.org/10.1016/j.chb.2015.04.073
del Mar et al.(2015)[3]	Cross-sectional validation study, pilot testing, and Rasch psychometric analysis	266	26 - 69 years/ 43.18 ±9.43 years	Occupational health—development and validation of a Computer Vision Syndrome Questionnaire (CVS-Q)	Development of CVS-Q	CVS-Q showed good Rasch model fit, sensitivity and specificity >70%, ICC = 0.802, $\kappa = 0.612$	Validation limited to Spanish-speaking computer users; generalizability to other populations and languages not yet tested	CVS-Q is a valid, reliable tool for assessing visual symptoms in computer workers and suitable for clinical and research applications	https://doi.org/10.1016/j.jclinepi.2015.01.015
Gonzalez-Perez M et al. (2014)[4]	Cross-sectional validation study using Rasch analysis and test–retest reliability in VDT workers	576	18 to 65 years / 42.8±10.1 years	Occupational optometry—development and psychometric validation of a scale for computer-related visual and ocular symptoms (CRVOS)	Development of CVS17	CVSS17 showed strong internal consistency (Cronbach's $\alpha = 0.92$), good Rasch fit, ICC = 0.849, and moderate correlation with VDS ($r = 0.60$, $p < 0.001$)	Validation limited to Spanish-speaking VDT workers; further research needed for broader populations and longitudinal sensitivity	CVSS17 is a valid, reliable linear scale for quantifying CRVOS in computer users, suitable for clinical and research applications	https://doi.org/10.1167/iovs.13-13818
Mylona et al. (2022)[5]	Cross-sectional validation study using factor analysis and clinical comparison groups	200	18 to 45 years / 30.9±10.28 years	Digital eye strain (DES) assessment in general and gaming-addicted outpatient populations	Screen-enabled digital devices (computers, smartphones, gaming consoles). • Ophthalmic group: 222 minutes/day screen time • Gaming-addicted group: 277 minutes/day screen time.	DESQ showed excellent reliability (Cronbach's $\alpha = 0.94$), confirmed 3-factor structure (61.02% variance), and strong concurrent/convergent validity with CVS-Q and PIUQ-9	Limited to Greek outpatient sample; generalizability to broader populations and languages requires further validation	DESQ is a reliable, valid tool for assessing DES symptoms in clinical populations, including those with excessive gaming behavior	https://doi.org/10.1177/11206721211073262
Argilés et al. (2015)[6]	Randomized controlled trial with repeated-measures design across six reading conditions	50	18 to 74 years/34.1±16.4 years	Ocular physiology—impact of reading format on spontaneous eye blink rate (SEBR) and incomplete blinks	Read a text in various conditions, either in hard-copy or electronic format, in silence or aloud.	All reading tasks reduced SEBR compared to baseline ($P < 0.001$); incomplete blinks increased only during electronic reading	Short task duration (6 minutes), limited ecological validity, and no symptomatic dry eye participants	Reading reduces blink rate regardless of format, but electronic displays uniquely increase incomplete blinks, potentially contributing to digital eye strain	https://doi.org/10.1167/iovs.15-16967

Portello et al. (2013)[7]	Repeated-measures experimental study with 21 participants performing a 15-minute computer reading task	21	21 to 29 years / 24.4 years	Ocular surface physiology—blink behavior and symptom correlation during computer use	Desktop computer screen (Compaq Evo 5500 with a 15-in monitor)	Mean blink rate was 11.6 blinks/min; incomplete blinks averaged 16.1%; symptom severity positively correlated with incomplete blink percentage ($p = 0.002$) and negatively with blink rate ($p = 0.035$)	Small sample size, short task duration, and limited generalizability to varied screen tasks or populations	CVS symptoms are linked to both reduced blink rate and incomplete blinking; promoting complete blinks may be more effective than simply increasing blink frequency.	https://doi.org/10.1097/OPX.0b013e31828f09a7
Collins et al. (2006)[37]	Observational study using high-speed video analysis of blink kinematics and fluorescein staining in healthy and soft contact lens wearers	26	22±2 years	Ocular surface physiology—relationship between blink completeness and corneal staining patterns	a sellen letter was presented as a target and Phantom 5.0 camera was used to capture the blinking pattern	22% of blinks were incomplete in both groups; in lens wearers, mean closed palpebral aperture correlated significantly with inferior corneal staining ($r^2 = 0.40$, $p < 0.05$)	Small sample size (N = 26), short recording duration (~3 minutes), and limited generalizability beyond young adults	Incomplete blinking is associated with increased inferior corneal staining, especially in soft contact lens wearers, highlighting the importance of blink mechanics in ocular	https://doi.org/10.1097/01.icl.0000224551.58399.9a
Cardona et al. (2011)[8]	Repeated-measures experimental study evaluating at baseline, slow-paced, and fast-paced computer tasks	25	20 - 35 years / 26 years	Ocular surface physiology—blink rate, blink amplitude, and tear film integrity under varying visual display terminal (VDT) task dynamism	Two different dynamic computer games (fast-paced vs. slow-paced)	Blink rate dropped to ~1/3 during fast-paced and ~1/2 during slow-paced tasks compared to baseline; incomplete blinks increased; tear stability was more affected than tear volume (all $p < 0.001$)	Small sample size, short task duration, and limited age range reduce generalizability to broader populations and real-world screen use	Dynamic VDT tasks compromise blink rate, amplitude, and tear film stability, with faster visual input worsening ocular surface metrics; frequent breaks and blink-awareness training are recommended	https://doi.org/10.3109/02713683.2010.544442
Ünlü et al. (2012)[42]	Prospective observational study on employees using computers daily	35	20 - 46 years / 29.09 ± 6.73 years	Ocular surface diagnostics—comparison of subjective (OSDI) and objective (TBUT, Schirmer) tests for dry eye in computer users	Computer use (daily occupational exposure)	OSDI and TBUT were significantly correlated ($r = –0.385$, $p = 0.022$); no significant correlation between OSDI and Schirmer's test; TBUT diagnosed 42% with dry eye, OSDI 35%	Small sample size, single-center design, and exclusion of previously diagnosed dry eye patients may limit generalizability	OSDI combined with TBUT offers a quick, noninvasive, and effective approach to support dry eye diagnosis in computer users, while Schirmer's test may be less reliable due to reflex tearing	https://doi.org/10.2147/OPTH.S33588
Talens-Estarelles et al. (2022)[31]	Prospective repeated-measures experimental study onyoung adults across five conditions (control, computer, tablet, e-reader, smartphone)	80 (40 computer workers and 40 controls)	20 - 40 years / Computer workers: 28 ± 5 years; Controls: 26 ± 5 years	Ocular physiology—blink kinematics during digital display reading under natural viewing conditions using Medmont E300 dynamic corneal topography; Hartmann–Shack wavefront sensor → measured ocular aberrations; Optec 6500 Functional Vision Analyzer → photopic and mesopic visual acuity, contrast sensitivity.	Occupational computer use (≥4 hours/day vs. ≤1 hour/day).	Blink rate decreased across all displays vs. control ($p < 0.0005$); incomplete blinks highest with computer, lowest with smartphone; blink amplitude and speed varied with gaze angle and device type	Limited to young healthy adults, short recording duration (150 s), and controlled lab conditions may not reflect real-world variability	Blinking kinematics differ significantly across digital displays, influenced by gaze angle, viewing distance, and cognitive demand; handheld devices may mitigate blink disruption compared to computers.	https://doi.org/10.1111/opo.13147
Kastelan et al. (2024)[43]	Cross-sectional observational study comparing between symptomatic dry eye patients and healthy controls	62 (Group A: 31 & Group B: 31)	18 to 79 years / 32 years	Ocular surface physiology—evaluating tear film stability and its effect on visual clarity using PBBT and TBUT	Digital acuity system	Symptomatic group had significantly lower PBBT (8.95 s) and TBUT (4.77 s) than controls (PBBT 14.66 s, TBUT 7.63 s); strong positive correlation between PBBT and TBUT ($r = 0.455$, $p < 0.001$)	Small sample size, limited to Caucasian adults, and reliance on subjective symptom questionnaires without broader diagnostic tools	Tear film stability critically affects visual function; PBBT is a promising, non-invasive screening tool for dry eye disease and may complement TBUT in clinical practice	https://doi.org/10.3390/vision8010008

Feng et al. (2024)[40]	Prospective single-center clinical trial with pre- and post-treatment assessments in adults with meibomian gland dysfunction	32	31 to 79 years / 55.9 years	Ocular surface and visual function—evaluating TearCare's effect on clinical signs, symptoms, and reading speed in dry eye disease	Single TearCare treatment in patients with MGD and dry eye disease	52% showed >10 wpm improvement in IReST scores; significant gains in MNREAD, VFQ-25, OSDI, TBUT, MGSS, and corneal staining (all $p < 0.05$)	Small sample size, short follow-up (1 month), and single-center design limit generalizability and long-term conclusions	TearCare significantly improves both clinical and functional visual outcomes, including reading speed, after a single treatment in patients with dry eye from MGD.	https://doi.org/10.2147/OPTH.S469300
Luo et al. (2024)[46]	Controlled animal study using scopolamine and desiccating stress to induce dry eye in mice over 4 hours to 10 days	129SvEv/ CD-1 mixed mice	aged 6 - 8 weeks	Ocular surface immunology—MAPK pathway activation and cytokine/MMP-9 expression in experimental dry eye	ELISA for IL-1β and TNF-α in tear fluid and epithelia. RT-PCR, real-time PCR, and gene arrays for cytokine and receptor gene expression	IL-1β, TNF-α, and MMP-9 levels significantly increased in tears and ocular epithelia; phosphorylated JNK, ERK, and p38 MAPKs elevated within 4 hours and sustained up to 5 days	Mouse model may not fully replicate human dry eye pathophysiology; short-term exposure and lack of behavioral correlates limit translational scope	Experimental dry eye rapidly activates MAPK signaling and upregulates inflammatory mediators, implicating these pathways in the pathogenesis of ocular surface damage and irritation symptoms	https://doi.org/10.1167/iovs.03-1145
Zetterberg et al. (2013)[56]	Controlled laboratory experiment on participants performing near work under four lens conditions	66	Group 1: 20 to 47 years / 39 years; Group 2: 19 to 47 years / 37 years	Occupational and visual ergonomics—examining how accommodation and convergence demands affect trapezius muscle activity	Visually demanding near work tasks performed at 65 cm distance (≈1.5 D demand) Four lens conditions: binocular −3.5 D, monocular −3.5 D, 0 D, and +3.5 D	Eye-lens accommodation alone did not significantly affect trapezius activity; however, incongruence between accommodation and convergence led to a significant increase in trapezius muscle activation	Low visual demand levels may underestimate real-world strain; auto refractor sampling was limited by pupil constriction, reducing data completeness	Incongruence between accommodation and convergence is a key factor linking visually demanding near work to increased trapezius muscle activity, potentially contributing to neck/shoulder discomfort over time.	https://doi.org/10.1016/j.jelekin.2013.06.003
Berens and Stark (1932)[51]	Observational and experimental study using ergographic recordings in aviators and office patients under varying oxygen conditions	number not specified	Not reported	Visual physiology—accommodative fatigue under hypoxic and clinical conditions	Ophthalmic ergograph to measure accommodation. Exposure: sustained near visual tasks	Aviators under low oxygen showed faster nearpoint recession; asthenopic office patients exhibited variable fatigue patterns; strong correlation between subjective and objective fatigue markers	Ergograph-based methods may lack precision; Duane's age-based nearpoint norms were unreliable; limited generalizability due to sample composition and historical context	Accommodation fatigue is multifactorial and not easily induced; objective and subjective measures correlate well, but standard age norms may not predict fatigue resilience accurately.	https://doi.org/10.1016/S0002-9394(32)90743-0
Collier et al. (2011)[54]	Repeated-measures experimental study on participants reading aloud from a laptop for 30 minutes at 50 cm	20	22 to 30 years / 24 years	Oculomotor physiology—accommodation and vergence behavior during sustained computer tasks	Subjects were required to perform a sustained fixation task consisting of reading a story aloud from a Dell Latitude D600 laptop computer at a distance of 50 cm	Mean accommodative response was 1.07 D; mean associated phoria was 0.74Δ base in; no significant change over time, but subjects with zero fixation disparity reported greater discomfort ($P = 0.02$)	Small sample size, short task duration, and lack of symptomatic CVS participants limit generalizability	CVS symptoms are more pronounced in individuals with zero fixation disparity; reduced vergence response may enhance comfort during sustained computer work	https://doi.org/10.1016/j.optm.2010.10.013
Padavettan et al. (2021)[9]	Prospective comparative study with healthy emmetropic adults reading N6 text on a smartphone for 30 minutes	47	18 - 30 years / 21.2 ± 2.06 years	Binocular vision and accommodation—impact of near smartphone use on vergence and accommodative parameters	Device: smartphone (COOL PAD NOTE 3 LITE with a 5-inch LCD screen, 720 x 1280 pixels resolution and 294 ppi pixel density). in a room with ambient lighting of 480 – 500 lux from LED lamps with no glare from windows.	Significant deterioration in negative and positive fusional vergence, accommodative lag, and relative accommodation; vergence facility dropped from 13.51 to 10.71 cpm ($p < 0.05$)	Short exposure duration, limited age range (18–30 years), and absence of symptomatic or clinical dry eye assessment	Short-term smartphone reading significantly impairs both accommodative and vergence functions, with greater impact on vergence; prolonged near screen use may compromise visual quality.	https://doi.org/10.4103/ijo.IJO_2956_20

Allen & Mehta (2023)[53]	Prospective pilot study assessing accommodative and convergence measures before and after 30 minutes of habitual smartphone use	18	16 - 40 years /24±7.6 years	Binocular vision and accommodation—short-term effects of smartphone use on near triad functions	30 minutes of sustained smartphone use at participants' usual working distance	Trends showed worsened near point of accommodation (NPA) and convergence (NPC), but improved accommodative facility (AF); however, none were statistically significant after Bonferroni correction	Small sample size, lack of randomization, uncontrolled smartphone activity and device settings, and no illumination measurement	No statistically significant change in accommodative or convergence measures after 30 minutes of smartphone use; further research with larger samples and controlled conditions is needed to clarify effects	https://doi.org/10.1080/09273972.2023.2179076
Chellapan et al. (2024)[10]	Cross-sectional experimental study, evaluating pre- and post-smartphone exposure assessments	62	13 - 17 years / 14.58 years	Pediatric binocular vision—effects of habitual smartphone use on accommodation and convergence functions	Subject was instructed to play the same game, namely, Candy Crush in a Huawei Nova 3i smartphone for 30min at a distance of 40 cm with the refractive correction	30 minutes of smartphone use significantly reduced amplitude of accommodation, accommodative facility, and positive relative accommodation; increased lag of accommodation and negative relative accommodation; near point of convergence and fusional vergence also deteriorated (all $p < 0.001$)	Short exposure duration, single device/task (Candy Crush), and lack of long-term follow-up or clinical symptom tracking	Frequent smartphone use weakens accommodation and convergence responses in teenagers, underscoring the need for visual hygiene strategies like the 20-20-20 rule and regular binocular assessments in digital-age youth	https://doi.org/10.18240/ijo.2024.11.16
Kang et al. (2021)[15]	Prospective comparativestudy on healthy adults using a smartphone (6.1″) and tablet (9.7″) for 1 hour each	46	19 - 39 years / 27.5 ± 5.9 years	Ocular physiology—impact of smart device display size on accommodation and ocular discomfort	Watching a documentary video for 1 hour at 30 cm, maximum brightness, 280 lux ambient illumination, using iPhone XR 6.1 inch vs. iPad 9.7 inch	Both devices reduced near point of accommodation (NPA) and convergence (NPC), but changes were 1.8× and 2.5× greater with smartphones; ocular discomfort scores and fatigue onset were significantly worse with smartphones ($p = 0.035$ and $p = 0.012$)	Small sample size, short exposure duration,	Smaller display sizes exacerbate accommodative strain and ocular discomfort more than larger ones, even within 20 minutes of use; display size should be considered when prescribing screen-based tasks or interventions	https://doi.org/10.1186/s12886-020-01789-z
Hussaindeen et al. (2018)[55]	Cross-sectional observational study using ROC analysis to derive a minimum test battery from the BAND dataset and validate it in a rural school	305	9 - 17 years / 12.2 years	Pediatric binocular vision screening—identifying efficient, high-yield tests for NSBVAs in large-scale community programs	Standardized vision screening protocol administered by trained optometrists in school settings	Three tests—near point of convergence (NPC) with penlight and red filter > 7.5 cm, monocular accommodative facility < 10 cpm, and difference between near and distance phoria > 1.25Δ—showed optimal sensitivity and specificity; NPC > 10 cm had 80% sensitivity and 73% specificity for convergence insufficiency	Limited to school-aged children in rural India; may not generalize to other age groups or urban populations; lacks longitudinal follow-up	A minimal 3-test battery (NPC, monocular accommodative facility, phoria difference) is effective for NSBVA screening in community settings, balancing diagnostic yield with feasibility	https://doi.org/10.1111/cxo.12628
Gray et al. (2000)[16]	Experimental study with five visually normal emmetropic young adults performing a 20-minute reading task across five display types at 50 cm	5	Mean age : 22.5 ± 3.0 years	Visual ergonomics and oculomotor physiology—examining accommodation microfluctuations and pupil responses during sustained VDT viewing	Displays tested: Hard copy (HC) Cathode ray tube (CRT) Electroluminescent panel (EP) Gas plasma display (GP) Liquid crystal display (LCD)	No significant change in low-frequency (≤0.6 Hz) or high-frequency (1.0–2.1 Hz) accommodation microfluctuations or mean pupil diameter across time or display type; two-way ANOVA confirmed stability	Small sample size (N = 5), short task duration, and lack of symptomatic or clinical endpoints limit generalizability to real-world fatigue or CVS contexts	Accommodation microfluctuations and pupil size remain stable during short-term VDT use, suggesting these parameters may serve as objective indicators of display quality rather than fatigue onset	https://doi.org/10.1046/j.1475-1313.2000.00474.x
Hynes et al. (2018)[60]	Experimental Cross Sectional study	24 (12 emmetropes, 12 myopes)	18 -35 years	Visual psychophysiology—examining how cognitive load modulates accommodative microfluctuations (AMFs) during sustained near tasks	Reading aloud single/double-digit numbers; Addition/subtraction of single-digit numbers; Addition/subtraction of double-digit numbers	High-frequency component (HFC) power of AMFs increased significantly with cognitive demand (CA > SA > Num, $p < 0.005$); root mean square (RMS) accommodation also trended higher, though not significant in pairwise comparisons	Small sample size, short task duration (20 s per trial), and absence of real-time cardiovascular monitoring to confirm physiological correlates	Cognitive demand modulates AMFs, particularly the HFC, likely reflecting increased autonomic or cardiovascular arousal; AMFs may serve as sensitive indicators of cognitive load during near work	https://doi.org/10.3390/vision2030036

Yu et al. (2022)[11]	Controlled experimental study assesing 40 minutes of tablet-based near work at 33.3 cm	60 children (30 myopes, 30 emmetropes)	7 - 12 years	Pediatric visual physiology—accommodative microfluctuations (AMFs) and fatigue during sustained digital near work	40 minutes of tablet gaming (Huawei M5, 1920×1200 px) at 33.3 cm (3.0 D demand). 210 cd/m² screen luminance, 300 lux ambient (classroom standard)	Myopes showed significant increase in low-frequency (LFC) and high-frequency (HFC) AMFs peaking at 30 minutes (LFC $p = 0.043$; HFC $p = 0.036$); emmetropes showed no significant change; accommodative response and pupil diameter remained stable in both groups	Short exposure duration (40 min), limited age range (7–12 years), and lack of long-term follow-up or behavioral correlates	Myopic juveniles exhibit unstable accommodative microfluctuations during sustained near work, peaking at 30 minutes; AMFs may serve as sensitive indicators of visual fatigue and help define optimal near work duration in children	https://doi.org/10.3390/ijerph19127066
Ghosh et al. (2011)[61]	Repeated-measures experimental study using a modified Shack–Hartmann wavefront sensor to assess ocular aberrations under four gaze-accommodation conditions	26 young adults (12 emmetropes.14 myopes)	19 - 30 years / 25 years	Visual optics and ocular biomechanics—interaction of gaze angle, accommodation, and time on higher-order aberrations (HOAs)	Modified Shack–Hartmann wavefront sensor used to measure ocular aberrations	Without accommodation: Downward gaze induced a small myopic shift (−0.12 D), ATR astigmatism, and significant increases in vertical coma, trefoil, and secondary spherical aberration—all of which recovered immediately post-task; With accommodation (2.5 D): Downward gaze led to greater negative shift in primary spherical aberration (C(4,0)) and increased secondary spherical aberration (C(6,0)) over time; changes peaked at 10 minutes	Fixed pupil sizes (5.0 mm and 3.0 mm) may not reflect natural dynamics; short task duration (10 min); no direct biometric or corneal-lens separation	Downward gaze, especially during accommodation, significantly alters ocular aberrations over time—likely due to eyelid pressure and gravitational effects on the crystalline lens. These changes are dynamic and recoverable, underscoring the need to consider gaze angle in wavefront assessments and near-task visual ergonomics	https://doi.org/10.1167/11.10.17
Maayah et al. (2023)[12]	Cross-sectional survey study on students	867	≥18 years / 21 ± 2.95 years	Musculoskeletal health and digital ergonomics—examining predictors of neck and shoulder pain in smartphone users	Smartphone usage patterns (duration, position, handedness, study vs. leisure use)	History of neck/shoulder pain ($p \leq 0.018$); Significant predictors of neck pain severity (multivariate model): History of neck/shoulder pain (95% CI: −2.357 to −1.268, $p < 0.001$) Hand dominance for writing (95% CI: 0.254–0.512, $p < 0.001$) These factors explained 8.4% of variance in pain duration and 11.3% in pain severity	Self-reported data, cross-sectional design, and lack of objective posture or ergonomic assessment	Smartphone-related neck pain is influenced by both behavioral (usage time, study posture) and personal (history, handedness) factors. Preventive strategies should include ergonomic education and monitoring of device use habits in student populations	https://doi.org/10.1371/journal.pone.0285451
Almalki et al. (2017)[13]	Cross-sectional survey study over undergraduate students	355	not mentioned	Musculoskeletal health and digital ergonomics—assessing device-related risk factors for non-specific neck pain	Using smartphones and iPads for entertainment	98% of students used electronic devices 92% used smartphones and iPads for entertainment; 32% used them for study 8.2% reported frequent neck pain; 64% reported no symptoms Neck pain was significantly associated with female gender, use of smartphones/iPads for entertainment, and use of small devices for study	Self-reported data, lack of clinical examination, and absence of longitudinal tracking	Use of small portable devices—especially smartphones and iPads—is significantly associated with neck pain among university students, with higher prevalence in females and those using devices for entertainment or study. Ergonomic education and posture awareness are recommended to mitigate risk.	https://doi.org/10.12816/0041690

Shan et al. (2013)[14]	Cross-sectional epidemiological study with 3,016 valid questionnaires from high school students across 30 randomly selected schools in Shanghai	3,016 valid questionnaires	15–19 years (stratified by grade: Year 1 = 15–17, Year 2 = 16–18, Year 3 = 17–19)	Pediatric musculoskeletal health—examining associations between neck/shoulder pain (NSP), low back pain (LBP), and digital device use, physical activity, and psychological status	30 minutes of sustained use of digital devices (PC, mobile phone, tablet)	Prevalence: NSP = 40.8%, LBP = 33.1%; higher in girls and third-year students Risk factors for NSP: Gender, grade, soreness after exercise, prolonged PC use, tablet use, sitting time after school, academic stress Risk factors for LBP: Gender, grade, soreness after exercise, prolonged PC/mobile phone use, sitting time, academic stress, CES-D depression score ≥16 Multivariate analysis: Strong associations between pain and digital habits, sedentary behavior, and psychological distress	Cross-sectional design limits causal inference; self-reported data may introduce bias; no clinical confirmation of musculoskeletal conditions	NSP and LBP are highly prevalent among Shanghai adolescents and closely linked to digital device use, sedentary lifestyle, and psychological stress. Interventions should target posture, screen time, and emotional well-being.	https://doi.org/10.1371/journal.pone.0078109
Cagnie et al. (2017)[138]	Randomized controlled trial on VDU workers assigned to progressive VDU lenses or standard progressive lenses, followed over 6 months	35 VDU workers (17 progressive VDU lenses, 18 standard progressive lenses)	45–65 years / VDU group: 51.1 ± 4.2 years; Progressive group: 53.7 ± 4.0 years	Occupational optometry and ergonomics—evaluating lens type effects on visual fatigue, neck pain, posture, and pressure pain thresholds during VDU tasks	Type of spectacle lenses worn during VDU (computer) work.: Progressive office lens and standard progressive lenses.	Both groups showed reduced visual fatigue and neck pain at 3 and 6 months No significant differences in head posture or disability scores Pressure pain thresholds increased in both groups, independent of lens type VDU lenses rated significantly more suitable for VDU work; progressive lenses rated better for far vision	Small sample size, dropout imbalance, lack of blinding, and limited generalizability due to specific occupational setting	Both lens types improved symptoms over time, but VDU-specific lenses were preferred for computer work; lens selection should be tailored to task-specific needs and visual habits	https://doi.org/10.1186/s12199-017-0611-1
Thigpen et al. (2010)[76]	Controlled experimental study classifying as having forward head and rounded shoulder posture (FHRSP) or ideal posture	80	not mentioned	Biomechanics and kinesiology—examining how FHRSP affects scapular kinematics and muscle activity during overhead tasks	Loaded arm flexion task Overhead reaching task Both performed while scapular kinematics and muscle activity were recorded	FHRSP group showed significantly greater scapular internal rotation and anterior tilting during loaded flexion and overhead reaching tasks Serratus anterior activity was significantly reduced in FHRSP individuals during both tasks Greater scapular upward rotation was observed during flexion in the FHRSP group	No symptomatic participants; short-term task duration; posture classification lacked standardized criteria	FHRSP alters scapular mechanics and muscle activation patterns even in pain-free individuals, supporting its role as an intrinsic risk factor for shoulder dysfunction independent of pain status	https://doi.org/10.1016/j.jelekin.2009.12.003

Abu-Ghosh et al. (2024)[74]	Controlled comparative study onasymptomatic adults, assessing gait parameters under single-task and dual-task cognitive load conditions	90	FHP: 20.5±2, NHP: 20±3	Postural neuroscience and motor-cognitive integration—exploring how FHP affects dual-task gait performance and cognitive cost	Walking along a 10 m platform under two conditions: Single-task: Walking only Dual-task: Walking while performing cognitive tasks (yes/no questions, counting, simple math)	No significant differences in gait parameters under single-task conditions. Under dual-task conditions, 12 of 13 gait parameters were significantly altered in the FHP group ($p < 0.01$), including reduced stride length, velocity, and increased double-support phase. Dual-task cost (DTC) was significantly higher in FHP participants across all gait metrics ($p < 0.02$) Craniovertebral angle (CVA) correlated with DTC and dual-task gait parameters, but not with single-task metrics	Cross-sectional design, short exposure duration, and limited generalizability beyond university students and staff	FHP significantly increases cognitive cost during walking under dual-task conditions, suggesting impaired sensorimotor integration and executive function; posture correction may benefit cognitive-motor performance	https://doi.org/10.3390/jcm13164653
Lan et al. (2022)[77]	Controlled experimental study on participants exposed to three temperature conditions (24°C, 26°C, 28°C) for 4.5 hours each, with clothing and air velocity adjusted to maintain thermal comfort	36	Males: 25.0±4.1 years / Females: 23.5±4.4 years	Environmental physiology and cognitive ergonomics—exploring how ambient temperature affects cognitive performance even under perceived comfort	T24 (24 °C): rated as comfortably cool T26 (26 °C): rated as comfortably neutral T28 (28 °C): rated as comfortably warm for 4.5 hours	All participants rated the environments as thermally comfortable (T24 = cool, T26 = neutral, T28 = warm) Objective cognitive performance declined by 10% at 26°C and 6% at 28°C compared to 24°C Parasympathetic nervous system activity (PNN50) and arterial oxygen saturation (SpO_2) decreased at higher temperatures Participants reported greater acute subclinical symptoms and mental workload at elevated temperatures	Short exposure duration (4.5 hours), limited age range, and absence of long-term performance tracking	Even within thermally comfortable ranges, higher ambient temperatures impair cognitive performance—likely due to physiological stress responses. Cooling strategies like fans or natural ventilation may help mitigate these effects in work and learning environments.	https://doi.org/10.1111/ina.12916
Laurent et al. (2018)[78]	Prospective observational cohort study over university students in Boston, USA, tracked before, during, and after a 12-day heat wave in July 2016	44	18 - 29 years (mean age 20.2 years)	Environmental health and cognitive ergonomics—examining indoor temperature effects on cognitive function in real-world residential settings	two cognition tests were self administered daily for daily of 12 days, the stroop colour - word test	Indoor temperatures: Non-AC group averaged 26.3°C vs. 21.4°C in AC group ($p < 0.001$) Cognitive impact: Reaction time increased by 13.4% (Stroop) and 13.3% (Addition/Subtraction) in non-AC group Throughput decreased by 9.9% (Stroop) and 6.3% (Addition/Subtraction) Stroop performance followed a U-shaped curve, with optimal indoor temperature at 22–23°C ADD performance declined linearly with rising indoor temperature	Cognitive tests were administered immediately after waking; effects during the rest of the day were not assessed	Even healthy young adults are vulnerable to cognitive decline during heat waves if living in non-air-conditioned buildings. Indoor temperature regulation is critical for maintaining cognitive performance during extreme heat events.	https://doi.org/10.1371/journal.pmed.1002605
Yoshimoto et al. (2017)[81]	Experimental study on paired comparisons of flickering stimuli	23	33.25 ±13.30 years	Visual psychophysiology and temporal discomfort	within subject: resting, visual stimulation, and auditory stimulation, duration 10 mins total	Discomfort increased with deviations from natural 1/f amplitude spectra and was significantly higher for random phase flicker than fixed phase	Small sample size, short stimulus duration, no direct neural or physiological measurements	Both amplitude and phase spectra influence visual discomfort; unnatural temporal modulations and random phase patterns are particularly aversive	https://doi.org/10.1016/j.visres.2017.05.015

Cajochen et al. (2011)[111]	Controlled crossover laboratory study where participants were exposed to LED-backlit vs. non-LED screens for 5 hours in the evening	13	19 - 35 years / 23.8 ±5.0 years	Chronobiology and cognitive neuroscience—examining how screen-emitted short-wavelength light affects melatonin, alertness, and performance	patients underwent 5 hour of evening exposure to one screen type per session where seated in dim laboratory	LED-backlit screens suppressed melatonin rise, reduced sleepiness (EEG and subjective), and enhanced sustained attention, working memory, and declarative memory performance	Small sample size, male-only cohort, short-term exposure, and lack of follow-up on sleep or circadian phase shifts	Evening use of LED-backlit screens alters circadian physiology and boosts cognitive performance acutely, but may risk circadian misalignment and sleep disruption with chronic exposure	https://doi.org/10.1152/japplphysiol.00165.2011
Hou et al. (2021)[82]	Controlled experimental study over participants exposed to 25 combinations of ambient illuminance and display luminance in a simulated cockpit	10	22 - 26 years / 24.20 years	Visual ergonomics and human–computer interaction—modeling optimal display luminance using visual performance (VP), visual comfort (VC), and visual fatigue (VF) metrics	participants were exposed to dark adaptation, light adaptation, 5 minute visual search	VP increased with luminance and peaked with moderate illuminance; VC showed a parabolic trend with optimal combinations; VF rose with mismatched luminance–illuminance pairs; a dimming model was derived using polynomial fitting and analytic hierarchy process	Small sample size, narrow age range (22–26 years), negative polarity display only, and limited generalizability beyond cockpit settings	A wide-range dimming model integrating VP, VC, and VF was proposed to optimize display luminance under varying ambient light, offering ergonomic guidance for adaptive screen technologies	https://doi.org/10.1117/1.OE.60.3.035110
Shi et al. (2021)[84]	Controlled comparative study with subjective questionnaires and objective measures (EEG, ECG, ocular parameters) across three smartphone display types under matched luminance and CCT	10	22 - 35 years / 26.19 ±7.12 years	Visual ergonomics and display physiology—quantifying spectral effects on visual fatigue using retinal photoreceptor illuminance and neurophysiological markers	10 item visual fatigue questionnaire, best corrected visual acuity	Visual fatigue was lowest with displays having reduced retinal illuminance of S-, M-, L-cones and ipRGCs; blue-shifted LCDs with longer-wavelength peaks reduced dry-eye symptoms and EEG fatigue markers compared to normal LCD and OLED	Small sample size (n = 10), short exposure duration, and limited generalizability beyond controlled lab conditions	Spectral tuning—especially shifting blue light toward longer wavelengths—can mitigate visual fatigue in smartphone displays, supporting photoreceptor-targeted ergonomic design	https://doi.org/10.1016/j.displa.2021.102066
Ramteke and Satgunam (2023)[69]	Prospective cross-sectional study assessing habitual viewing distances and symptom scores for smartphones and computers	114	19 - 50 years / 26 ± 6 years	Binocular vision and digital ergonomics—examining how device viewing distance correlates with asthenopic symptoms	Smartphone at 30 -40 cm; Computer 50 - 70 cm; Tablets: 40 - 50 cm; Television: 2 - 3 meters	Symptomatic users viewed smartphones at ~30 cm and computers at ~56 cm, significantly closer than asymptomatic users (~35 cm and ~62 cm); font size had no significant effect	Institutional cohort, limited age range, and weak correlation coefficients ($r \approx -0.34$) between symptoms and distance	Closer viewing distances are associated with higher visual discomfort; maintaining ≥35 cm for smartphones and ≥62 cm for computers may help reduce digital eye strain	https://doi.org/10.1038/s41433-023-02781-9
Fan et al. (2023)[90]	A crossover experimental study using eye-tracking and subjective questionnaires to assess visual fatigue in VR gameplay.	33	23.85±2.12 years	Visual neuroscience and optometric assessment of eye movement behavior in virtual reality environments.	HTC VIVE Pro Eye headset with built-in Tobii eye tracke	Both primary and 360° VR modes induced visual fatigue, with the primary mode showing higher blink frequency and reduced pupil diameter.	Subjective questionnaires lacked sensitivity, and short gameplay duration may have underestimated fatigue effects.	Objective eye movement metrics are more reliable than questionnaires for detecting VR-induced visual fatigue, especially across interaction modes.	https://doi.org/10.3389/fnins.2023.1173127
Soundari et al. (2025)[112]	Experimental design with randomized allocation	170	8 -15 years	Pediatric optometry and visual ergonomics, focusing on refractive error and eye strain in school-aged children.	Children with refractive error and eye strain were assessed using structured questionnaires, convergence insufficiency symptom survey, retinoscopy, and visual acuity charts.	The intervention group showed significant reduction in eye strain and refractive error (−0.5 diopters), with improved visual acuity ($P < 0.001$).	Reliance on self-reported symptoms and short-term post-test evaluation may limit generalizability.	Eye strain negatively impacts visual acuity in children, and targeted interventions can significantly improve refractive status and reduce symptoms.	https://doi.org/10.4103/jpbs.jpbs_1551_24

Reindel et al. (2018)[52]	Prospective observational study involving symptomatic myopic contact lens wearers across 25 clinical sites.	253	30 - 40 years / 35 ± 3.2 years	Clinical optometry and binocular vision assessment in pre-presbyopic individuals with near work–related asthenopia.	2-3 hours of consecutive near work (digital devices)	Mean AC: 8.04±3.09 D vs Hofstetter's predicted 6.23±0.80 D. 22.5% had AC below their predicted value (≈5.36±0.99 D). Mean NPC: 12.0 ± 4.69 cm. Push-up AC values were higher than push-down; NPC push-up values worse than push-down. Ill-sustained accommodation (54%) was most frequent diagnosis, followed by accommodative insufficiency (18%) and accommodative infacility (12%).	Cross-sectional design and reliance on push-up/push-down methods may limit precision; lack of longitudinal follow-up restricts insight into progression.	Pre- and early-presbyopes with asthenopia often show functional accommodation deficits despite being younger than typical presbyopes. Ill-sustained accommodation is the dominant binocular dysfunction, highlighting the need for early detection and management strategies in patients reporting near-work fatigue.	https://doi.org/10.2147/opto.s151294
McCrann et al. (2021)[115]	Cross-sectional observational study using questionnaires and device-recorded smartphone data among students.	418	16.8 years	Pediatric and adolescent visual health, focusing on environmental risk factors for myopia.	Device-recorded smartphone data usage (MB/day) and self-reported time (minutes/day).	Myopic students used significantly more smartphone data daily than non-myopes ($p = 0.001$), though time spent was not statistically different.	Reliance on self-reported time estimates and lack of longitudinal follow-up limits causal inference.	Increased smartphone data usage is associated with myopia, highlighting the need for objective digital behavior metrics in myopia management strategies.	https://doi.org/10.1111/cxo.13092
Lee et al. (2023)[126]	Longitudinal cohort study tracking refractive changes and environmental/genetic exposures	624	Participants born 1989–1992; assessed at 20 years and again at 28 years.	Ophthalmic epidemiology and gene-environment interaction in young adult refractive development.	Screen time: computer, television, mobile devices (self-reported at ages 20, 22, 27, 28). Sun exposure: quantified via conjunctival ultraviolet autofluorescence (CUVAF). Genetics: polygenic score (PGS) for refractive error.	Higher screen time, lower ocular sun exposure, and greater genetic predisposition were each independently associated with faster myopic shift.	Environmental factors explained only ~1% of variance each; no significant interaction effects among predictors.	Myopic progression in young adulthood is modestly influenced by screen use, sun exposure, and genetics, but other unidentified factors likely contribute substantially.	https://doi.org/10.1167/iovs.64.14.28
Li J(2025)[114]	Prospective cohort study tracking over two years with structured eye exams and smartphone usage	523	6 - 14 years / 10.6 ± 2.1 years.	Pediatric ophthalmology and digital behavior research, focusing on environmental predictors of myopic progression.	Daily smartphone use measured via monitoring app + questionnaire. • Mean use: 4.3 ± 1.2 h/day. • Outdoor activity: 1.7 ± 0.8 h/day. • Mean viewing distance: 28.4 ± 6.2 cm	Longer daily smartphone use was significantly associated with faster myopia progression, while increased outdoor activity and greater screen distance were protective.	Reliance on app-based tracking and self-reported questionnaires may introduce measurement bias; parental myopia was not stratified by severity.	Daily smartphone use, reduced outdoor time, close screen viewing, and parental myopia are key predictors of childhood myopic progression, underscoring the need for behavioral interventions.	https://doi.org/10.1186/s12887-025-05715-4
Nelles et al. (2010)[119]	Functional MRI-based comparative study on performing visually guided prosaccades.	20 (9 with refractive error, 11 controls.)	Subjects without refractive errors: 23 - 66 years/ 38 ± 14 years); Subjects with decreased visual acuity: 25 - 70 years/ 52 ± 14 years.	Neuro-ophthalmology and visual neuroscience, focusing on cortical control of eye movements in the presence of refractive error.	Participants performed prosaccade tasks inside the fMRI scanner.	Subjects with refractive error showed increased activation in bilateral frontal and parietal eye fields, supplementary eye fields, and extrastriate cortex compared to controls.	Small sample size and lack of refractive correction during scanning may limit generalizability and isolate refractive error effects.	Refractive error leads to enhanced cortical recruitment during simple eye movement tasks, underscoring the need for matched visual acuity in neuroimaging control groups.	https://doi.org/10.2147/eb.s9823

Lin Y et al. (2015)[73]	Experimental psychophysical study using electro-oculogram (EOG) and Tobii eye-tracking glasses to measure involuntary responses under controlled glare conditions.	20	Young: 20–30 years/24.5 years; Seniors: 55–65 years/ 61 years	Visual psychophysics and physiological optics, focusing on objective markers of discomfort glare.	Controlled lighting environment with manipulated glare source (LED luminaire) and background illumination. Participants rated glare using the de Boer scale (1 = unbearable, 9 = just noticeable).	Severe glare discomfort led to faster eye movements and greater pupil constriction; subjective glare ratings correlated strongly with eye movement ($R^2 > 0.94$, $p < 0.001$) and moderately with pupil constriction ($R^2 = 0.38$, $p < 0.001$).	Small sample size (10 young, 10 senior participants) and reliance on laboratory glare setups may limit ecological validity.	Involuntary physiological responses—eye movement speed and pupil constriction—are significantly correlated with subjective discomfort glare ratings. These measures provide an objective way to characterize glare discomfort, potentially overcoming biases in conventional subjective evaluation methods	https://doi.org/10.1167/iovs.14-15963
Mechó-García M et al. (2024)[62]	Experimental study used an aberrometer to measure accommodative response and Zernike coefficients under four different fixation stimuli	16	22–32 years/ 27.3 ± 3.5 years.	Visual optics and clinical optometry, focusing on accommodation, pupil dynamics, and wavefront aberrations.	irx3 aberrometer (Hartmann–Shack principle) with Badal system. Stimuli: • Snellen “E” (6/12 and 6/6) • Snellen “e” (6/6) • Maltese Cross “X” (6/12) • Maltese Cross “x” (6/6).	No statistically significant differences in accommodative response or Zernike coefficients across stimuli, though higher spatial frequency targets (“e”, “E”) elicited slightly larger accommodative responses and more stable pupil behavior.	Small sample size, short stimulus presentation time (2 seconds), and inclusion of mild astigmatism may have introduced variability; only spherical equivalent was corrected.	Stimulus design and spatial frequency modestly influence accommodative response and pupil size, but overall aberration changes remain consistent, underscoring the need for standardized fixation stimuli in clinical accommodation testing.	https://doi.org/10.3390/photonics11111090
Fernandez-Alonso et al. (2024)[63]	Experimental study measuring pupil size, accommodative responses, and visual acuity under narrowband LED illuminants of different peak wavelengths compared to broadband light.	27	26–29 years.	Visual optics and neuro-ophthalmology, focusing on the role of longitudinal chromatic aberration (LCA) in accommodation control.	Narrowband LEDs (441, 460, 527, 588, 661 nm) and broadband D65 illuminant; AMOLED screen primaries (459, 528, 610 nm, RGB). Stimuli: Maltese cross or Landolt C targets.	Observers successfully accommodated under narrowband light, compensating for LCA; compensation was stronger at nearer distances, with steeper response slopes for longer wavelengths and shallower slopes for shorter ones; visual acuity was poorest under blue narrowband light despite accurate accommodation.	Small sample size and reliance on narrowband LED stimuli may limit ecological validity; spectral bandwidth effects at shorter wavelengths complicate interpretation.	LCA provides a robust cue for accommodation even under narrowband illuminants, but wavelength-dependent differences—especially in blue light—highlight the need for considering chromatic effects in modern display design and clinical testing.	https://doi.org/10.1167/jov.24.2.11
Xu et al. (2025)[121]	Cross-sectional study using meibography, OSDI questionnaires, and tear breakup time (BUT) assessment among children	200	13.1 ± 2.4 years.	Pediatric ophthalmology and ocular surface disease, focusing on overweight/obesity as a risk factor for meibomian gland dysfunction (MGD) and dry eye disease (DED).	Non-invasive ocular surface analyzer (Keratograph 5M) used for meibography, tear break-up time (BUT), tear meniscus height (TMH), and OSDI questionnaire.	Higher BMI percentile and weight were significantly correlated with increased meiboscore (atrophy), greater gland tortuosity, shorter BUT, and higher OSDI scores	Single-center design, modest sample size, and cross-sectional nature limit causal inference; lack of longitudinal follow-up prevents assessment of progression.	Childhood overweight is a significant risk factor for structural changes in meibomian glands and dry eye symptoms, highlighting the need for early preventive strategies in pediatric populations.	https://doi.org/10.1186/s12886-025-04086-9

Twenge et al. (2017)[125]	Two nationally representative surveys of U.S. adolescents and national suicide mortality statistics.	506,820	13–18 years	Clinical psychology and adolescent psychiatry, focusing on environmental risk factors (digital media exposure) for depression and suicidality	New media screen time (smartphones, social media, electronic devices) vs. nonscreen activities (in-person social interaction, sports/exercise, homework, print media, religious services).	Depressive symptoms: ↑33% between 2010–2015 (esp. females, +58%). Suicide-related outcomes: ↑12% overall; ↑14% among females. Suicide deaths: ↑31% overall; ↑65% among females. Adolescents spending ≥5 h/day on electronic devices were 66% more likely to have at least one suicide-related outcome vs. ≤1 h/day. Protective factors: in-person social interaction, sports/exercise, homework, religious service attendance.	Cross-sectional design: Cannot establish causality between screen time and mental health outcomes.	The sharp rise in adolescent depressive symptoms and suicide-related outcomes after 2010 is temporally linked to increased new media screen time.	https://doi.org/10.1177/2167702617723376
Madigan et al. (2019)[123]	Prospective cohort study, with screen time reported at different ages, and developmental outcomes measured using the Ages and Stages Questionnaire (ASQ-3).	2,441	24 - 60 months	Pediatric developmental epidemiology, examining environmental risk factors (screen exposure) for early childhood developmental trajectories.	Maternal reports of children's weekly screen time (TV, movies, computer, gaming, other devices	Higher screen time at 24 and 36 months predicted poorer developmental scores (language, motor, socioemotional) at later ages; reverse causality (delays → more screen time) was not supported.	Reliance on parent-reported screen time and use of ASQ-3 as a screening rather than diagnostic tool; findings may not generalize beyond Canadian urban populations.	Excessive screen time in preschool years is a significant predictor of poorer developmental outcomes, underscoring the need for early monitoring and guidance on digital exposure.	https://doi.org/10.1001/jamapediatrics.2018.5056
Arshad et al. (2021)[122]	Prospective cohort of medical students over 30 days, with smartphone screen-time objectively tracked via an app and sleep quality assessed using the Pittsburgh Sleep Quality Index (PSQI).	280	21.9 ± 1.7 years	Sleep physiology, occupational health, and digital behavior epidemiology.	Android smartphones; ST measured directly via tracking app.	Mean screen-time was ~147.5 hours/month; 65.7% had poor sleep quality (PSQI > 5); longer screen-time correlated significantly with worse sleep ($R = 0.356$, $p < 0.001$).	Short follow-up, single-center student sample, exclusion of those with pre-existing sleep disorders limits generalizability.	Excessive smartphone use, especially near bedtime, deteriorates sleep quality and may contribute to adverse physical and psychological outcomes.	https://doi.org/10.5935/1984-0063.20200114
Lee Si et al. (2018)[142]	Between-subjects experiment, who are exposed to LED lighting at two color temperatures (3000 K vs 6200 K) across two nights, with salivary melatonin sampling and sleepiness ratings.	42	Children: mean age 8.9 years; adults: 41.7 years	Pediatric circadian physiology and environmental light exposure.	LED ceiling lights (Panasonic HH-LC569A) adjusted to low (3000 K) and high (6200 K) color temperatures. Exposure from 19:00 until ~1 h after habitual bedtime.	Children showed greater melatonin suppression than adults under both conditions; suppression was significantly stronger at 6200 K (blue-enriched) vs 3000 K; subjective sleepiness was lower in children under 6200 K light.	Small sample size, short exposure duration, and laboratory setting may limit ecological validity; only two color temperatures tested.	Blue-enriched LED lighting at night strongly suppresses melatonin and reduces sleepiness in children, suggesting that low-color-temperature lighting is preferable for protecting pediatric sleep and circadian health.	https://doi.org/10.14814/phy2.13942

Dahlstrom-Hakki et al. (2024)[92]	Experimental study on participants with (neurodivergent and neurotypical) performing visual search tasks in VR under varying distractor loads, lighting conditions, and background sound.	52	13 - 47 years / 24.9 years	Human–computer interaction, cognitive psychology, and inclusive STEM education using VR.	VR Headset VIVE Focus 3, hardwired to a high - end laptop	More distractors and non-optimal lighting reduced speed and accuracy for all; neurodivergent participants were disproportionately affected by distractors and lighting, but performed better under loud background sound compared to silence, unlike neurotypical peers.	Self-reported neurodiversity status, small heterogeneous sample, and limited stimulus types constrain generalizability.	VR design must consider sensory sensitivities—visual clutter and lighting can hinder neurodiverse learners, while certain auditory stimuli may paradoxically enhance focus, underscoring the need for inclusive, codesigned VR environments.	https://doi.org/10.1007/s10055-023-00933-6
Ryu et al. (2024)[117]	fMRI study on myopic participants performing demanding visual search tasks with and without corrective lenses, rating subjective fatigue and task difficulty after each trial	31	13.6 years	Cognitive neuroscience and visual physiology, focusing on neural correlates of visual fatigue during sustained attention tasks.	Defocus incorporated segments (DIMS) lens Vs. Single vision lens.	Wearing corrective lenses significantly reduced subjective fatigue; neural decoding implicated cuneus, lingual gyrus, middle occipital gyrus, and declive for joint fatigue/difficulty, while broader association areas (MTG, parahippocampal gyrus, precentral gyrus, precuneus) selectively decoded fatigue	Modest sample size, single refractive error group, laboratory setting with limited ecological validity.	Myopia-correcting lenses modulate both subjective and neural markers of visual fatigue, demonstrating that fatigue can be decoded from brain activity during complex visual search tasks	https://doi.org/10.3389/fnins.2024.1307688
Chen & Epps (2014)[26]	Experimental study inducing five levels of cognitive load across low- and high-perceptual load tasks, measuring pupil diameter and blink rate.	22	26.8 years	Human–computer interaction, cognitive load measurement, and psychophysiology.	Performed low perceptual load tasks - mental arithmetic, High perceptual load tasks: each tasks manipulated across 5 levels of cognitive load.	Pupil diameter reliably indexed cognitive load only under low perceptual load; blink rate was more sensitive to perceptual load than cognitive load.	Laboratory tasks with constrained stimuli; findings may not generalize to complex real-world environments.	Pupil diameter and blink rate provide complementary but load-specific indicators, highlighting the need to account for perceptual load when inferring cognitive effort in interface design.	https://doi.org/10.1080/07370024.2014.892428
Page et al. (2024)[27]	EEG study on adults performing the Multi-Attribute Task Battery under three cognitive load conditions, analyzing blink-related oscillations (BROs) in time and frequency domains.	8	21.1 years	Neuroergonomics and cognitive neuroscience, focusing on naturalistic workload monitoring in multitasking environments.	participants completed MATB tasks under low, medium, and high workload while EEG recorded.	Blink rate decreased with increasing cognitive load; BRO responses were reliably captured and reflected load differences, including reduced pre-blink theta desynchronization under higher load.	Small sample size, laboratory simulation, and limited ecological diversity constrain generalizability.	BROs provide a non-intrusive neural marker of cognitive workload, offering potential for real-world monitoring in aviation, driving, space exploration, and human–machine interaction.	https://doi.org/10.3390/s24041082

Mihelcic & Podlesek (2023)[95]	Experimental study on high school students performing three task types (numerical, textual, Stroop) at varying difficulty levels, with accommodative and pupillary responses measured via videoretinoscope at 50 Hz.	58	16.4 years	Visual psychophysiology and cognitive load research, linking near-point stress to ocular responses and myopia models.	Participants performed 3 tasks- - numerical tasks - textual tasks - stroop tasks	Pupil size was largest in Stroop tasks (mean 5.20 mm), intermediate in numerical (5.02 mm), and smallest in textual (4.78 mm); accommodative fluctuations were greatest in textual tasks, moderate in numerical, and lowest in Stroop.	Short-term laboratory tasks, adolescent sample only, limited ecological validity for real-world reading or screen use.	Short-term cognitive load alters both pupillary and accommodative responses, with task type shaping the balance—conflicting tasks enlarge pupils, while logical reasoning tasks increase accommodative instability, potentially linking to near-point stress and myopia progression.	https://doi.org/10.1016/j.optom.2022.05.001
Fukuie et al. (2025)[139]	Randomized crossover experiment on healthy university students performing either 3-minute static stretching (ST) or seated rest (RE) after cognitive load, followed by Stroop testing and psychophysiological measures.	30	19.5 years	Neuroergonomics, occupational health, and exercise physiology, focusing on interventions for VDT-induced cognitive fatigue.	VDT cognitive load; Recovery conditions (3 min static stretching); 13 postures, neck/ shoulders	Static stretching increased vitality, arousal, and muscle tension relief, and improved executive function compared with rest; improvements correlated with stretching frequency.	Short intervention duration, small homogeneous sample, and laboratory setting limit generalizability; physiological parameters (HRV, pupil diameter, prefrontal activity) showed correlations but not group differences.	Brief static stretching alleviates cognitive fatigue from VDT work, enhancing executive function and subjective arousal, with effects modulated by stretching habits.	https://doi.org/10.1007/s11332-025-01450-6
Krigolson et al. (2025)[96]	Prospective medical simulation study where medical students completed a simulated night on call, diagnosing cases; cognitive fatigue was assessed before and after using mobile EEG (mEEG) and behavioral measures.	16	25.4 years	Neuroergonomics, medical education, and cognitive neuroscience, focusing on objective fatigue monitoring in clinical decision-making.	participants were asked to complete 12 hour simulated night call in a hospital simulations.	EEG showed decreased amplitude of a neural response sensitive to cognitive fatigue from start to end of the shift, indicating increased fatigue; notably, no correlation was found between EEG markers and self-reported fatigue scores.	Small sample size, single simulation context, and lack of ecological diversity; subjective measures did not align with objective EEG findings.	Mobile EEG provides a reliable, real-time biomarker of cognitive fatigue in medical contexts, outperforming subjective self-report and offering potential for reducing diagnostic errors and improving patient safety.	https://doi.org/10.1007/s40670-025-02421-9

Lee C et al. (2020)[91]	Experimental EEG study using eight electrodes across brain regions, applying linear discriminant analysis and Min–Max scaling to quantify visual fatigue under different screen sizes (smartphone, tablet, computer) and presentation modes (2D, 3D, AR, VR).	30	2D: mean: 20.6 years 3D: mean: 20.1 years VR: mean 21.25 years AR: mean 22 years	Neuroergonomics, visual psychophysiology, and human–computer interaction.	2D video: 110 min viewing on smartphone 5", tablet 9", computer 19". 3D game: minecraft on 19" computer 1hr VR game: minecraft via Oculus Rift HMD 1hr AR game: smartphone/tablet camera-based shooting game 1h	2D/3D: Delta and theta waves at prefrontal poles (Fp1, Fp2) most affected. AR: Alpha bands at occipital poles (O1, O2) showed clear impact. VR: Delta and theta waves at central pole (C3) strongly associated with fatigue. Larger screens produced greater visual fatigue; VR induced the most severe fatigue, often accompanied by motion sickness.	Laboratory setting, limited ecological validity, and constrained to specific screen sizes and modalities.	Screen size and modality significantly modulate regional brain activity linked to visual fatigue; excessive stimulation (especially VR) increases visual load, underscoring the need for ergonomic design and cautious use of immersive displays.	https://doi.org/10.1007/s11227-020-03458-w
Liu C et al. (2020)[28]	EEG study examining spontaneous blinking healthy adults under visual vs auditory sensory environments, focusing on blink-related oscillations (BROs) across cortical regions.	28	33.25 ±13.30 years	Cognitive neuroscience, neuroergonomics, and ocular physiology.	Visual task: passive viewing of written words/word pairs. Auditory task: passive listening to tones + spoken word pairs. Resting task: fixation on crosshair, no dynamic stimuli.	Visual environment: BROs showed stronger modulation in occipital and parietal regions, reflecting visual cortical engagement. Auditory environment: BROs were more pronounced in frontal and temporal regions, indicating auditory processing load. Blink rate itself did not differ significantly between modalities, but oscillatory dynamics revealed modality-specific neural signatures.	Small sample size, laboratory setting, and limited ecological validity; only healthy adults tested.	Spontaneous blinking elicits distinct neural oscillatory patterns depending on sensory modality, suggesting BROs can serve as naturalistic markers of modality-specific cognitive workload and cortical engagement.	https://doi.org/10.1016/j.neuroimage.2020.116879
Puma et al. (2018)[95]	Experimental EEG study using multitasking tasks	20	19 - 38 years / 27.25±3.88 years	Cognitive workload assessment in human factors and neuroergonomics.	EEG spectral power (theta: 4–8 Hz; alpha: 8–12 Hz). Subjective workload (NASA-TLX). Pupil size (EyeLink 1000). Performance scores.	Increased multitasking raised theta and alpha band power, with lower power linked to better performance.	Small sample size and inter-individual variability reduced consistency of EEG workload markers.	EEG spectral power in theta and alpha bands can differentiate cognitive resource involvement but requires performance-stratified analysis for reliability.	https://doi.org/10.1016/j.ijpsycho.2017.10.004
Studenova et al. (2023)[105]	Large EEG study using auditory oddball paradigm to test baseline-shift mechanism.	2230	60 - 82 years	Cognitive electrophysiology, linking evoked responses (P300) with oscillatory alpha dynamics.	Auditory oddball paradigm (standard vs. deviant tones).	P300 amplitude and latency were systematically related to stimulus-triggered alpha attenuation, confirming baseline-shift mechanism predictions.	Elderly sample and limited electrode coverage (31 channels) constrain generalizability and spatial resolution.	P300 is at least partly generated by modulation of non-zero mean alpha oscillations, unifying evoked responses with ongoing brain rhythms.	https://doi.org/10.7554/eLife.88367.3
Portello et al. (2012)[41]	Questionnaire-based cross-sectional study of New York City office workers.	520	39.2 ±14.2 years	Occupational optometry and ocular surface disease in computer users.	Written questionnaire on visual symptoms, demographics, refractive correction, smoking, hours of computer use. Ocular Surface Disease Index (OSDI) survey	Tired eyes (40%), dry eye (32%), and discomfort (31%) were most prevalent, strongly correlated with daily computer hours and OSDI scores.	Self-reported symptoms and limited geographic sample reduce generalizability.	Computer use frequently induces visual symptoms linked to ocular surface disease, highlighting need for preventive regimens.	https://doi.org/10.1111/j.1475-1313.2012.00925.x

Siemiginowska Iskra-Golec (2020)[87]	Within-subjects counterbalanced experiment	30	22.87 ± 3.34 years	Lighting research and neurophysiology, focusing on how blue light interacts with circadian preference (chronotype) and exposure timing to modulate brain activity.	Monochromatic blue light (460 nm, irradiance 11.8 W/cm^2, photon density 2.7×10^{13} photons/cm^2/s). Polychromatic white light (6.5 lux, photon density 4.4×10^{12} photons/cm^2/s). Exposure duration: 4 hours in morning, afternoon, and evening sessions.	Significant interactions between chronotype, light condition, and time of day in theta and alpha1 bands. Morning-types showed higher theta and alpha1 spectral power under blue light in the afternoon compared to morning or evening.	Small, homogeneous sample (young males only) limits generalizability.	Chronotype moderates the effect of blue light on EEG activity, with timing of exposure critically shaping outcomes.	https://doi.org/10.1177/1477153519876969
Gulbinaite et a. (2017)[88]	EEG experiment with participants performing a modified Eriksen flanker task.	27	22.4 years	Cognitive neuroscience and visual attention, focusing on how exogenous rhythmic stimulation interacts with endogenous brain oscillations.	64-channel BioSemi ActiveTwo system, sampling at 1024 Hz. Targets and flankers flickered at 7.5 Hz, 10 Hz, or 15 Hz using sine-wave luminance modulation.	10 Hz flicker impaired stimulus processing, especially on incongruent trials requiring higher selective attention.	Laboratory setting may not fully capture real-world attentional demands.	Alpha-band flicker entrains endogenous rhythms, impairing selective attention when exogenous and endogenous frequencies align.	https://doi.org/10.1523/jneurosci.1163-17.2017
Quaedflieg et al. (2016)[107]	Randomized controlled trial assigned to right, left, or placebo neurofeedback groups.	60	18 - 31 years / 20.96 ± 2.82 years	Cognitive neuroscience and clinical psychophysiology, focusing on frontal alpha asymmetry modulation.	Frontal alpha asymmetry (F4–F3) based on individual alpha peak frequency (IAF). Subjective stress (PANAS, VAS). Neuroendocrine stress response (cortisol via Maastricht Acute Stress Test).	Right-hemisphere neurofeedback produced frequency- and location-specific asymmetry changes during rest, though effects did not persist at follow-up.	Trainability varied across individuals, and changes lacked stability at 1-week and 1-month follow-ups.	Individualized frontal alpha asymmetry neurofeedback can induce short-term modulation, but long-term validity and clinical utility remain limited.	https://doi.org/10.1093/scan/nsv090
Ridder III & Tomlinson (1993)[38]	Experimental psychophysical study using sine-wave gratings presented at varying post-blink intervals to measure contrast sensitivity thresholds	4	adults. (age specifically not mentioned)	Visual neurophysiology—mechanisms of blink-induced suppression and its spatial frequency dependence	Contrast sensitivity thresholds via psychometric functions. Weibull function fitting to determine suppression magnitude and duration.	Blink-induced contrast sensitivity suppression was strongest at low spatial frequencies and diminished over time post-blink, paralleling saccadic suppression patterns	Limited spatial frequency range tested; brief stimulus durations and artificial blink timing may not reflect natural viewing conditions	Eyelid blinks produce a transient suppression of contrast sensitivity, most pronounced at low spatial frequencies, supporting the hypothesis of a common neural mechanism with saccadic suppression. This ensures perceptual continuity despite frequent	https://doi.org/10.1016/0042-6989(93)90170-2
Kaido et al. (2024)[44]	Prospective cross-sectional EEG study comparing with aqueous-deficient dry eye patients, short breakup-time dry eye patients, and controls under eyes-closed, eyes-open, and ocular surface anesthesia conditions.	74	aqueous tear-deficient dry eye (mean age: 65.6 ± 13.6 years; range: 31–82 year); short tear breakup time dry eye (mean age: 59.0 ± 14.9 years; range: 33–80 years);	Neuro-ophthalmology and ocular surface neuroscience, linking peripheral ocular damage to central stress responses.	EEG recorded with KANSEI analyzer. Stress levels assessed under three conditions: eyes closed, eyes open, eyes open under ocular surface anesthesia.	Stress levels were significantly lower with eyes closed; ocular surface anesthesia reduced stress only in aqueous-deficient dry eye, with OSDI scores correlating to EEG stress in this group.	Modest sample size and reliance on laboratory EEG paradigms limit generalizability.	In aqueous-deficient dry eye, ocular surface damage triggers frontal lobe stress responses, whereas in short breakup-time dry eye, stress is unrelated to symptom development.	https://doi.org/10.1016/j.jtos.2024.02.007

Zhou et al. (2021)[39]	Prospective interventional study assessing chronic dry eye after SMILE or LASEK, treated with a spontaneously heating eye mask.	37 eyes	23 - 33 years/ 29.5 ± 6.3 years	Post-refractive surgery ocular surface rehabilitation and meibomian gland function.	Spontaneously heating eye mask (mean temperature ≈ 40.7 °C) applied for 20 minutes.	Warm compress increased tear film lipid thickness, tear break-up time, complete blink rate, and meibomian gland secretion scores, while reducing partial blink frequency.	Small sample size, short-term intervention, and lack of long-term follow-up limit generalizability.	Warm compress provides temporary improvement in tear film stability and meibomian gland function after corneal refractive surgery, supporting its role as a simple adjunct therapy.	https://doi.org/10.1186/s12886-021-02091-2
Rajabpour et al. (2024)[118]	Cross-sectional analysis of adults using standardized questionnaires (NEI-VFQ-25) and refraction data.	200	16 - 35 years / m 23.88 ± 5.87 years,	Public health ophthalmology, linking refractive error burden to patient-reported vision quality.	Persian version of NEI-VFQ-25 questionnaire.	Uncorrected refractive error significantly reduced vision-related quality of life scores, particularly in domains of near vision, distance vision, and role difficulties; correction improved scores across all domains.	Reliance on self-reported outcomes and single-timepoint assessment limits causal inference.	Refractive error is a major determinant of vision-related quality of life, underscoring the importance of timely detection and correction in population eye health.	https://doi.org/10.1186/s12886-024-03350-8
Yammouni & Evans (2020)[130]	Randomized controlled trial of pre-presbyopic adults with digital eye strain, testing low-powered convex lenses (+0.50D, +0.75D, +1.25D) vs. plano lenses using subjective preference and Wilkins Rate of Reading Test.	107	20 - 40 years / 31 years	Optometry and visual ergonomics, evaluating accommodative support for digital device users.	Low-power convex lenses: +0.50D, +0.75D, +1.25D. Compared against plano lenses. All participants wore full distance correction.	Dry eye symptoms were common; most participants preferred low adds, especially +0.75D. Adds of +0.50D and +0.75D significantly improved reading speed, with one-quarter reading >10% faster. +1.25D was less effective in this age group.	Study limited to younger adults and desktop computer use; effects may differ in older populations or closer viewing distances.	Low-power convex lenses can reduce eyestrain and improve visual performance in digital device users, with +0.75D showing the strongest benefit.	https://doi.org/10.1016/j.optom.2019.12.006
Manna et al. (2025)[131]	Randomized controlled trial ofnpatients with accommodative insufficiency, comparing conventional office-based therapy vs. conventional therapy plus EYEPORT II vision training device.	36	27.5 years	Pediatric and young adult binocular vision therapy, focusing on accommodative rehabilitation.	EYEPORT II system: Provides dynamic visual stimuli (convergent/divergent targets, accommodative demand changes) to train accommodation.	Both groups showed significant improvement in accommodative amplitude, lag, relative accommodation, and facility; the EYEPORT group demonstrated greater gains (e.g., +6.95 D amplitude, +13 cycles/min facility) and more stable outcomes at 3-month follow-up.	Modest sample size, single-center design, and short follow-up period limit generalizability.	Office-based vision therapy effectively treats accommodative insufficiency, with adjunctive EYEPORT II training yielding superior and more stable long-term outcomes.	https://doi.org/10.3928/01913913-20240807-01

Heiland et al. (2021)[71]	Randomized crossover study on middle-aged adults each completing three 3-hour prolonged sitting conditions interrupted every 30 minutes by either seated social interaction, walking, or simple resistance activities.	13	50.5 years	Cognitive neuroscience and occupational health, examining sedentary behavior and cortical activation.	Participants sat for 3 hours with breaks every 30 minutes: - SOCIAL: 3-min seated social interaction. - WALK: 3-min moderate treadmill walking. - SRA: 3-min simple resistance activities (squats, calf raises, knee lifts).	Walking breaks reduced right prefrontal oxygenated hemoglobin (Oxy-Hb) during demanding working memory tasks, with improved reaction times, mood, and alertness compared to social interaction; arterial stiffness moderated effects.	Small sample size, short intervention duration, and laboratory setting limit generalizability.	Frequent, short walking breaks during prolonged sitting reduce prefrontal activation while preserving working memory, mood, and alertness, supporting their use in sedentary work environments.	https://doi.org/10.3389/fnhum.2021.719509
Korkmaz et al. (2024)[104]	Experimental EEG study where EEG recorded across 32 channels; signals filtered into delta, theta, alpha, beta, gamma bands; features extracted from 1-, 3-, and 5-second segments; binary classification (single vs. multitask) using ANN, SVM, and LDA.	8	30 years	Cognitive neuroscience and neuroergonomics.	Block 1 & 2: Single-task (mental arithmetic). Block 3: Multitask (mental arithmetic + listening to news recordings simultaneously).	Gamma band (30–100 Hz) with 5-second EEG segments yielded the highest classification accuracy.	mall sample size (N=8), limiting generalizability.	Gamma band EEG features are highly effective for distinguishing single-task vs. multitask cognitive workload.	https://doi.org/10.1007/s00521-024-09627-9
Zeidan et al. (2010)[132]	Randomized controlled trial on mindfulness meditation	49	20 years	Cognitive neuroscience/psychology;	Mindfulness meditation: 4 sessions, 20 minutes/day, focusing on breath/body sensations. Control Group: 4 sessions, 20 minutes/day, listening to The Hobbit audiobook.	Mood improved in both groups. Mindfulness meditation imporved the cognition (visuo-spatial processing, working memory, and executive functioning). Improved working memory, sustained attention, and cognitive flexibility	Small sample size, short duration, healthy young adults only	Brief mindfulness meditation is a low-cost, accessible cognitive enhancer.	https://doi.org/10.1016/j.concog.2010.03.014
Park et al (2014)[49]	Cross-sectional experimental study of young adults in their twenties, measuring accommodative parameters before and after smartphone use	63	20- 28 years / 22.5±3.7 years	Visual ergonomics and accommodative physiology	30 mins of book reading; 30mins of smartphone movies	Smartphone use led to significant reductions in accommodative amplitude, facility, and increased lag, indicating transient accommodative fatigue;	Small sample size, short-term assessment, and limited generalizability beyond young adults;	Prolonged smartphone use induces accommodative dysfunction in young adults, highlighting the need for preventive strategies in digital visual ergonomics.	http://dx.doi.org/10.14479/jkoos.2014.19.2.253

Iskra - Golec & Smith (2009)[108]	Counter-balanced within-subject. Performance and mood measured every 30 min from 08:00–20:30 under intermittent bright light (IBL) vs. ordinary room light (ORL);	20	21.2 years	Chronobiology and visual ergonomics;	Intermittent bright light (IBL): Six 15-min pulses of 4000 lux at hourly intervals (11:00–16:00). Ordinary room light (ORL): ~300 lux. Sessions lasted 13 hours (07:30–20:30).	IBL modestly improved verbal logical task speed and spatial processing oscillations, with interactive effects on global vigor, but participants rated IBL as less comfortable, natural, and more glaring;	Small sample size, near-significant effects, and reduced ecological comfort limit real-world application	Daytime IBL can influence cognitive oscillations and mood but subjective discomfort may constrain practical use.	https://doi.org/10.1080/07420520802118103
Wylie et al. (2021)[106]	Experimental fMRI study using n-back working memory tasks	39	43.8 years	Cognitive neuroscience and fatigue research;	Participants performed repeated blocks of 0-back and 2-back tasks while reporting fatigue levels (VAS-F).	As fatigue increased, participants showed more conservative response bias (criterion) and reduced perceptual certainty (d'), with striatal activation correlating with both fatigue and SDT measures;	Modest sample size, laboratory task specificity, and short-term assessment limit generalizability;	Cognitive fatigue manifests as lower perceptual certainty and more conservative response bias, measurable via SDT. These behavioural changes are mirrored by striatal activation, offering a neurobiological basis for fatigue assessment.	https://doi.org/10.3389/fpsyg.2020.579188
Boere & Krigolson (2024)[109]	EEG-based experimental study assessing brain activity in adults wearing multi-colour light filtering glasses vs. control/no glasses	40	43 years	Neuro-ophthalmology and cognitive neuroscience, focusing on light exposure and cortical rhythms;	TrueDark® Twilight glasses; clear polycarbonate lenses.	Glasses filtering blue, violet, indigo, and green wavelengths significantly reduced frontal beta wave power (13–30 Hz), a marker of heightened mental states, thereby promoting relaxation	Modest sample size, single-center design, and short-term assessment limit generalizability and long-term inference;	Multi-colour light filtering glasses induce measurable neurophysiological changes, suggesting potential utility in mitigating adverse effects of high-energy light exposure and supporting relaxation in everyday screen environments.	https://doi.org/10.1186/s12868-024-00865-0
Dahlqvist et al. (2025)[75]	Laboratory EMG and inclinometry study of 29 non-presbyopic students performing standardized computer tasks across five workstation setups (single 27-inch, dual 27-inch L-formation, dual 27-inch V-formation, single 49-inch at 70 cm, single 49-inch at 90 cm);	29	19 - 28 years / median 24 years	Visual ergonomics and occupational health;	5 setup of workstations including 27 inch to 49 inch curved screens.	The 49-inch curved screen at 90 cm yielded the lowest trapezius load and most upright head posture, outperforming dual-screen setups, while the 27-inch L-formation produced the highest neck/shoulder exertion;	Young non-presbyopic sample, controlled lab setting, and inability to measure head rotation limit generalizability;	Larger curved screens at optimal viewing distance reduce musculoskeletal strain compared to dual-screen configurations, supporting ergonomic recommendations for workplace design.	https://doi.org/10.1080/00140139.2025.2507089
Tian et al. (2022)[85]	Experimental study using eye-tracking and EEG to assess visual fatigue under different paradigm colors and screen brightness levels at night;	24	21 to 27 years / mean 24.67 years	Visual ergonomics and neurophysiology;	4K display (adjustable brightness); eye tracker; g.tec EEG acquisition system Dark environment (<3 lx); paradigm colors varied (e.g., blue, red); screen brightness at low/medium/high; repeated short trials per condition	Dark background with bright text and lower screen brightness reduced eye movement load and EEG fatigue markers compared to bright backgrounds, indicating less visual strain;	Laboratory setting, limited participant pool, and short-term exposure constrain ecological validity;	Optimizing paradigm color and screen brightness can effectively mitigate night-time visual fatigue, supporting ergonomic display design.	https://doi.org/10.3390/s22114082

Kajita et al. (2020)[66]	Prospective, randomized, cross-over, subject-masked clinical trial.	68	20 to 35 years / 26.4 years	Digital eye strain and accommodative micro-fluctuations with contact lens optics.	Righton Speedy “i” series Auto Refractometer; 20-minute smartphone reading task on an iPhone 5 at 25 cm;	Aspheric lens design produced significantly smaller changes in accommodative micro-fluctuations than spherical design.	Short duration, controlled setting, and uncertain clinical significance of AMF reduction.	Lens optical design influences accommodative load; Biofinity® Energys may help reduce ciliary muscle stress during digital device use.	https://doi.org/10.1016/j.clae.2020.03.003
Kaido et al. (2017)[67]	Prospective comparative study	121	25 - 42 years / mean: dry eye 34.8 ± 5.5 years; Non-dry eye: 30.6 ± 4.7 years	Short tear break-up time (BUT) dry eye and accommodative microfluctuations (AMFs).	Accommodative microfluctuation (AMF) analysis with power-spectrum HFC metrics (HFC total, HFC1 for low accommodation/distance, HFC2 for high accommodation/deskwork); tear tests and functional visual acuity apparatus as described in Method	Dry eye group showed significantly higher blink frequency and elevated high-frequency component (HFC1) of AMFs.	Did not assess low-frequency components; volunteer bias and lack of detailed tear break-up pattern analysis.	Tear film instability in short BUT dry eye provokes abnormal accommodative microfluctuations and visual fatigue, linking AMFs to symptom generation	https://doi.org/10.1371/journal.pone.0184296
Kaido et al. (2017a)[68]	Cross-sectional observational study comparing patients with short tear break-up time (BUT) dry eye to controls.	12	23 to 77 years / mean 49.6 ± 18.3 years	Ocular surface instability, dry eye symptom severity, and accommodative microfluctuations (AMFs).	Dynamic autorefractometer AA-2™ (NIDEK) open-field autorefractor; Functional VA Measurement System (Kowa)	Patients with severe short BUT dry eye symptoms showed significantly elevated high-frequency components of AMFs, indicating unstable accommodation linked to visual fatigue.	Cross-sectional design limits causal inference; tear film dynamics and long-term outcomes were not fully explored.	Severe short BUT dry eye symptoms are closely associated with abnormal accommodative microfluctuations, suggesting that tear film instability contributes to accommodative stress and visual discomfort	https://doi.org/10.2147/opth.s128939
Jeng et al. (2014)[65]	Experimental comparative study using objective (AMF spectral analysis) and subjective (questionnaire) measures.	30	mean age 25.0± 3.8years	Visual fatigue induced by different display technologies (liquid crystal, laser, 2D vs. 3D).	Righton Speedy-K auto refract-keratometer (MF-1 analysis); Shutter 3D LCD (40"), Polarized 3D LCD (42"), Laser projector (44")	3D videos caused greater visual fatigue than 2D ($p < 0.001$); shutter-type 3D > polarized ($p = 0.012$); time-sharing > spatial-formation ($p = 0.008$); no difference between light source modules ($p = 0.162$); normal color discrimination linked to more fatigue ($p < 0.001$).	Laboratory setting, short exposure, limited generalizability to real-world device use	High-frequency components of accommodative microfluctuations are reliable indicators of visual fatigue, and display design strongly influences accommodative stress	https://doi.org/10.1364/ao.53.000h76
Metlapally et al. (2014)[64]	Experimental optical/psychophysical analysis using Shack–Hartmann wavefront sensing and computational modeling of accommodative microfluctuations.	4	18–25 years; mean age, 23 years	Interaction of higher-order aberrations (HOAs) with accommodative microfluctuations as directional cues for reflex accommodation.	Custom Shack–Hartmann wavefront sensor (4-mm artificial pupil); Maxwellian-view Badal imaging lens; high-resolution LCD Maltese-spoke stimulus	HOAs reduced contrast signals from microfluctuations, shrinking the effective stimulus range for reflex accommodation; baton-relay effect observed where low spatial frequencies drive responses at larger defocus, higher frequencies at smaller defocus.	Small sample size, monocular laboratory setup, limited spatial frequency range (≤4 cpd), and lack of real-world scene variability.	Higher-order aberrations weaken directional signals from accommodative microfluctuations, constraining the upper defocus limit and highlighting individual variability in optical profiles.	https://doi.org/10.1167/14.12.25
Roberts et al. (2018)[96]	Prospective experimental study comparing passive vs. active sustained near tasks in children (3–10 years) and adults.	74	Children: 3 to <10 years; Adults: 22–32 years	Cognitive demand, accommodative accuracy, and variability during sustained near viewing in emmetropes and uncorrected hyperopes.	Stimulus: iPad Air (2048×1536) at 33 cm presented through a beam-splitter; Accommodation measurement: PowerRef II eccentric photorefractor (25 Hz); Cycloplegic refraction: Grand Seiko WAM-5500 open-field autorefractor	Children showed more accurate and less variable accommodation when cognitively engaged; hyperopic children had greater variability; adults’ responses were stable across tasks.	Small sample size, short task duration, and limited generalizability beyond controlled near-work conditions.	Cognitive engagement improves accommodative stability in children, while uncorrected hyperopia increases variability, underscoring developmental and refractive influences on sustained near vision	https://doi.org/10.1097/OPX.0000000000001186

Kolbe et al. (2023)[141]	Randomized, single-blinded, cross-over study using surface electromyography in 32 artificially presbyopic subjects.	32	18 - 40 years /24 ± 3 years	Musculoskeletal load (trapezius activity) and subjective visual/postural comfort with general-purpose vs. computer progressive addition lenses (PALs).	Surface EMG (Ag/AgCl electrodes; analog-to-digital converter "Tower of Measurement"; 2048 Hz sampling); 24" matte monitor; ergonomic desk/chair; GP-PAL and PC-PAL spectacles; cyclopentolate for induced presbyopia	No significant difference in trapezius muscle activity between lens types, but computer PALs yielded superior subjective ratings for visual quality, tolerance, and field of view.	High dropout rate, small sample size, short-term lab setting, and inconclusive long-term musculoskeletal outcomes.	While objective SEMG data showed no clear differentiation, subjective evaluations strongly favored computer PALs, underscoring the importance of occupational history in prescribing presbyopic corrections	https://doi.org/10.1111/opo.13196
Chen & Chan (2023)[59]	Experimental study with 30 young adults (15 men, 15 women) assessing smartphone use across three postures (standing, supported sitting, unsupported sitting) and five head angles (0°–40°).	30	Men: 21–23 y; Women: 19–22 y Men: 21.7 ± 0.6 y; Women: 20.7 ± 1.0 y	Ergonomic impact of head flexion and posture on neck and shoulder muscle activity, discomfort, and visual parameters during smartphone use.	Motion capture: MacReflex (Qualisys) 2D system; EMG: TeleMyo 2400 with Ag/AgCl surface electrodes (SENIAM placement); Phones: participants' own smartphones; MVC apparatus for normalization; wall scale for viewing distance	Strain increased with head angle; discomfort rose markedly beyond 20°; unsupported sitting produced the poorest outcomes; sex differences noted in standing (women had lower neck flexion but higher cervical erector spinae activity).	Small sample size, short-term lab setting, limited generalizability to diverse age groups and prolonged real-world use.	Maintaining head angle within 20° and avoiding unsupported sitting reduces neck/shoulder strain during smartphone use; posture and sex influence ergonomic responses	https://doi.org/10.1080/00140139.2023.2270651
Domkin et al. (2018)[57]	Experimental study on young adults performing mouse-tracking tasks at near (25 cm) and intermediate (50 cm) viewing distances.	12	21 - 32 years / 26 ± 3 years	Interaction between ocular accommodation (ciliary-muscle contraction force) and musculoskeletal load (trapezius activity) during computer work.	Accommodation: PlusOptix Power Refractor II S04 (infrared photorefraction, 25 Hz); Muscle activity: bilateral trapezius EMG (Biopac EMG100C, 2000 Hz, normalized to reference contraction); Display: Dell U2311Hb 23" monitor (1920×1080 px); Input: standard optical computer mouse	At the nearest viewing distance, increased ciliary-muscle contraction force significantly elevated trapezius muscle activity on the dominant side ($p < 0.001$).	Small sample size, short-term controlled task, and limited generalizability to diverse populations or prolonged work.	High visual demands during near computer tasks raise ciliary-muscle contraction force, contributing to sustained trapezius activation and potential neck–shoulder complaints	https://doi.org/10.1007/s00421-018-4031-8
Richter et al. (2015)[70]	Experimental repeated-measures study on adults performing visually demanding near tasks under four lens conditions (binocular −3.5 D, monocular −3.5 D, 0 D, +3.5 D).	66	19 - 47 years / 38 years	Interaction of ocular accommodation/vergence demand and musculoskeletal load (trapezius muscle activity) during sustained near work.	Accommodation: PlusOptix Power Refractor R03 (infrared photorefraction, 25 Hz); Muscle activity: bilateral trapezius EMG (Biopac EMG100C, 2000 Hz, normalized to reference contractions); ECG: surface electrodes for HRV; Display: Sony F520 CRT monitor with Gabor grating stimulus	Trapezius muscle activity increased significantly over time across all lens conditions, independent of accommodation/vergence congruence.	Short task duration, controlled laboratory setting, and limited generalizability to real-world occupational exposure.	Sustained near visual tasks elevate trapezius muscle activity regardless of optical demand, likely reflecting increased mental effort and visual attention to counteract fatigue	https://doi.org/10.1007/s00421-015-3125-9

Richter et al. (2010) [58]	Experimental repeated-measures study investigating if sustained periods of oculomotor load impacts on neck/scapular area muscle activity	28	19 - 42 years / 29 ± 8 years	Relationship between ocular accommodation load and musculoskeletal strain (static trapezius muscle activity) during sustained computer work.	Accommodation: PlusOptix PowerRefractor R03 (infrared photorefraction, 25 Hz); Muscle activity: bilateral trapezius EMG (Biopac EMG100C, 2000 Hz, normalized to submaximal reference contraction); ECG: for HR/HRV filtering	Trapezius muscle activity increased significantly over time across all accommodative/vergence conditions, independent of optical demand level.	Laboratory setting, short task duration, and lack of long-term occupational exposure data.	Sustained near visual tasks elevate trapezius muscle activity regardless of accommodation load, suggesting that visual attention and cognitive effort drive musculoskeletal strain	https://doi.org/10.1007/s00421-010-1629-x
Mork et al. (2016) [72]	Experimental repeated-measures study on healthy young adults exposed to glare vs. appropriate lighting during 30-minute computer reading sessions.	15	19 - 25 years / 21 ± 2 years	Visual ergonomics — impact of glare on ocular (orbicularis oculi) and musculoskeletal (trapezius) responses during computer work.	Muscle activity: EMG of orbicularis oculi and trapezius; Muscle blood flow: photoplethysmography (PPG); Posture: inclinometers; Display: 24" LCD monitor (1920×1200 px, anti-reflective coating); Lighting: glare source with fluorescent luminaires (4268 cd/m^2) vs optimal lighting	Glare exposure significantly increased eye pain, orbicularis oculi muscle activity, and trapezius blood flow compared to optimal lighting.	Small sample size, short exposure duration, and limited generalizability beyond controlled lab conditions.	Direct glare induces eyestrain and elevates trapezius activity, highlighting the interaction between visual load, sympathetic activation, and neck–shoulder strain during computer tasks	https://doi.org/10.1097/OPX.0000000000000855
Ayaki et al. (2023) [47]	Large cross-sectional cohort study on first-visit outpatients with normal visual acuity.	6078	49.0 ± 20.4 years	Relationship between ocular surface instability (short tear break-up time, superficial punctate keratitis), retinal thickness, and visual symptoms (eye strain, blurred vision, photophobia).	Ocular surface tests: Tear break-up time (TBUT), Schirmer test, corneal staining for SPK; Retinal imaging: Spectral-domain OCT (RS-3000R, Nidek) measuring GCC, RNFL, macular thickness	Eye strain prevalence was 31.8%; significant risk factors included short TBUT (OR 1.88), SPK (OR 1.44), and thinner ganglion cell complex (OR 1.30). Blurred vision and photophobia were also linked to short TBUT and SPK.	Cross-sectional design limits causal inference; Schirmer test, peripapillary nerve fiber layer, and macular thickness showed no association; symptom reporting may be subjective.	Tear film instability and subtle retinal structural changes contribute to eye strain and related visual symptoms, underscoring the multifactorial basis of digital eye strain	https://doi.org/10.1371/journal.pone.0293320
Watanabe et al. (2025) [45]	Experimental study on young adult volunteers, using objective measures before and after a 30-minute visual task.	11	19 - 23 years / 20.7 ± 1.4 years	Tear film stability (non-invasive break-up time, NI-BUT) and binocular fusion maintenance (BFM) as markers of visual fatigue.	Tear film stability: RT-7000 TSAS (non-invasive TBUT, 3840 mire ring points); Binocular fusion: custom BFM system (video-oculography, liquid crystal shutter, Arduino control); Visual task: iPod Touch, Mario Kart Tour game	NI-BUT decreased significantly post-task (9.12 s → 5.69 s, p = 0.011); BFM also declined (0.95 → 0.75, p = 0.012); changes in NI-BUT positively correlated with changes in BFM (R^2 = 0.385, p = 0.042).	Small sample size, short exposure duration, and limited generalizability beyond controlled laboratory conditions.	Objective findings confirm that reduced tear film stability is associated with impaired binocular fusion and visual fatigue	https://doi.org/10.2147/opto.s522320

Lin et al. (2024)[83]	Experimental ergonomic study	36	22 - 27 years	Visual performance, fatigue, and discomfort in relation to display luminance and contrast polarity of desktop head-up displays.	Display: desktop head-up display (HUD) with virtual image distance ~3.8 m, FOV 30°×18°, ~70″ virtual image size; Lighting: office ambient 300 lx, 6500 K;	Positive contrast polarity reduced fatigue and discomfort compared to negative polarity; optimum luminance was calculated at 153 cd/m^2, higher than traditional desktop displays, to offset reduced contrast sensitivity at longer viewing distances.	Laboratory setting, modest sample size, and limited generalizability beyond office lighting conditions.	Positive polarity and ~153 cd/m^2 luminance optimize visual performance and reduce fatigue/discomfort in desktop HUDs under 300 lx office lighting	https://doi.org/10.1080/00140139.2024.2339439
Monterio et al. (2025)[86]	Double-blinded, randomized study on young adults exposed to white LED light with and without blue-blocking lenses (placebo, Crizal Prevencia, Duravision).	15	18 - 25 years / 21.3 ± 2.3 years	Effect of LED exposure on contrast sensitivity and the protective role of blue-blocking lenses.	Contrast sensitivity: Chart2020 software (computer-based, calibrated to 85 cd/m^2); Light source: two white LEDs (450 lx each, 45° angle, 80 cm distance); Lenses: placebo, Crizal Prevencia (CP), Duravision Blue Protect (DV)	LED exposure significantly reduced contrast sensitivity at 6 and 18 cpd; blue-blocking lenses ameliorated these losses compared to placebo.	Small sample size, short-term exposure, and limited generalizability beyond controlled laboratory conditions.	White LED exposure diminishes contrast sensitivity, while blue-blocking lenses provide partial protection, supporting their role in mitigating visual fatigue under LED lighting	https://doi.org/10.18240/ijo.2025.10.18
Galindo-Romero C et al. (2023)[120]	Cross sectional survey study over presbyopic computer users	198	45 - 65 years / 54 ± 8 years	Customized questionnaire was used covering demographics, optical correction, electronic device use habits, ergonomic conditions, and CVS-related symptoms.	Regular computer use (desktop, laptop, or both) as main work tool. Questionnaire on CVS symptoms (10 items scored 0–4), optical correction, daily hours of electronic device use, workplace ergonomics (lighting, breaks, posture), and musculoskeletal complaints.	Median Total Symptom Score (MTSS): 7 ± 5 symptoms. Most common symptoms was the dry eyes; ergonomic risk factor: lack of breaks ($P< 0.05$); Higher MTSS score was observed in Women ($P< 0.05$)	Reliance on self-reported questionnaire data (subjective bias possible)	CVS symptoms are highly prevalent among presbyopic computer workers. Workplace adaptation and adherence to basic visual ergonomics rules are essential, especially for home-based teleworkers	https://doi.org/10.1007/s10792-023-02724-z
Bhargava et al. (2023)[137]	Randomized controlled trial comparing omega-3 supplementation with placebo in visual display terminal users.	950	26 years	Ophthalmology and ocular surface health, focusing on dry eye syndrome in occupational screen users.	Four soft-gel capsules twice daily for 6 months. Each O3FA capsule contained 180 mg EPA + 120 mg DHA (total daily dose 2400 mg). Placebo capsules contained olive oil.	Omega-3 supplementation significantly improved omega-3 index, tear film stability, osmolarity, and symptoms, especially in those with low baseline omega-3 status.	Reliance on self-reported symptoms, olive oil placebo with possible biological effects, and limited generalizability beyond VDT users.	Dietary omega-3 fatty acids are effective for dry eye in screen-exposed individuals with low omega-3 index, supporting targeted supplementation.	https://doi.org/10.4103/ijo.ijo_2789_22

Wu Y et al. (2024)[99]	EEG experimental study on healthy participants exposed to stereoscopic depth motion in mixed reality, comparing comfort vs. fatigue states	18	24.17 ± 1.30 years.	Cognitive neuroscience and neuroergonomics of visual fatigue;	Microsoft HoloLens 2 presenting a stereoscopic depth-motion stimulus (chosen speed 3.25 m/s) in repeated blocks to induce visual fatigue. NeuSen Wireless 64-electrode cap with signals acquired at 1000 Hz; analysis focused on 24 electrodes covering frontal, temporal, central, parietal, and occipital regions.	Fatigue increased phase-locked values and enhanced brain connectivity in alpha, theta, and delta bands, with higher betweenness centrality, nodal efficiency, clustering coefficients, and characteristic path length across frontal, temporal, parietal, and occipital regions;	Young adult sample, short-term exposure, and threshold selection constraints limit generalizability;	EEG-based brain network topology provides valid indicators of visual fatigue in MR environments, with implications for monitoring cognitive load in high-demand fields.	https://doi.org/10.3390/brainsci14111126
Davis et al. (2015)[79]	Experimental psychophysical study.	12	20 - 29 years	Visual neuroscience and display ergonomics—exploring perceptual thresholds for flicker artifacts in high-frequency spatio-temporal displays	TI DLP Lightcrafter projector (variable frame rate up to 4000 Hz). Ambient illumination: Toshiba LCD projector. Subjects were positioned at 187 cm from projection wall; luminance calibrated; ambient adjustable. Frequency range tested: 20 Hz to 1000 Hz (increments across trials).	Flicker artifacts were perceived up to 500 Hz when high spatial frequency edges were present, far exceeding traditional critical flicker fusion rates (50–90 Hz)	Small sample size (n = 10), limited ecological validity, and reliance on subjective threshold reporting	Human flicker sensitivity is much higher than previously thought when spatial edges and natural eye movements are involved, challenging existing display standards and necessitating higher refresh rates for coded visual content	https://doi.org/10.1038/srep07861
Zhang et al. (2021)[98]	Experimental study using 64-channel EEG to assess effects of 40 Hz light flicker vs. random-frequency control in healthy adults	20	20 years	Neurotechnology and electrophysiology—exploring gamma-frequency visual entrainment and its impact on brain microstates and complexity	Visual stimulation: LED panel delivering 40 Hz flicker (square-wave, 2.5 ms cycle) or random flicker; subjects fixated at 40 cm for 30 s blocks. EEG recording: 64-channel Quick-Cap, Neuroscan SynAmps2 amplifier, 500 Hz sampling, artifact removal with ICA.	40 Hz flicker significantly increased EEG power in occipital electrodes (O1, Oz, O3), indicating strong visual cortex entrainment Altered EEG microstate metrics: increased coverage, transition duration, and Lempel-Ziv complexity (LZC) compared to rest and control conditions These microstate changes mirror patterns observed in Alzheimer's disease, schizophrenia, and stroke, suggesting relevance for therapeutic modulation	Small sample size, short-term exposure, and lack of clinical population; findings limited to healthy adults	40 Hz light flicker modulates brain dynamics in ways relevant to neurodegenerative and psychiatric conditions, laying groundwork for future therapeutic applications in non-invasive brain stimulation	https://doi.org/10.3389/fnins.2021.777183

Himebaugh et al. (2009)[36]	Observational experimental study where participants performed four visual tasks while blink behavior and tear film break-up were recorded in real time.	32	22 - 73 years / 49 ± 13 years	Ocular surface physiology—blink behavior and tear film stability during varied visual engagement	Looking straight ahead, watching movie, identifying rapidly changing targets and playing a computer game.	Dry eye subjects blinked more overall ($p = 0.017$), but both groups blinked less during game and letter tasks ($p < 0.04$); tear break-up was more central/superior in dry eye subjects	Small sample size, limited task diversity, and lack of long-term symptom tracking reduce generalizability	Reduced and incomplete blinking during common visual tasks contributes to tear instability and ocular discomfort, especially in dry eye patients	https://doi.org/10.1097/OPX.0b013e318194e962
Golebiowski et al (2019)[35]	Repeated-measures experimental study assessing asthenopic symptoms and blink rate under varying visual and cognitive loads	33	18–30 years.	Visual fatigue and ocular physiology—interaction of cognitive demand and visual stress on asthenopia and blinking	Visual stress conditions - good visual quality, Low contrast text, induced refractive error. Cognitive loads- watching video, reading fairy tales, reading technical articles, listening to technical articles.	Internal symptoms increased significantly under refractive error + high cognitive load ($p < 0.01$); external symptoms increased under low contrast + high cognitive load ($p < 0.05$); blink rate decreased with cognitive difficulty except in refractive error condition	Limited to young adults (18–30 years), short task durations, and artificial visual stress conditions	Cognitive and visual demands interact to exacerbate asthenopic symptoms; higher cognitive load amplifies symptom differentiation caused by visual stressors.	https://doi.org/10.1097/OPX.0b013e318236dd88
Kim M (2022)[93]	A cross-sectional experimental study assessing OLED flicker effects using PWM dimming measurements.	not included	not applicable	Human visual performance and health impacts of smartphone OLED display flicker.	LCD smartphones: Used PWM dimming at high frequencies (>2500 Hz) or DC dimming, minimizing flicker risk. OLED smartphone: Used PWM dimming at 240 Hz across all luminance levels.	OLED PWM dimming at 240 Hz showed detectable flicker at close viewing distances but diminished beyond 5 cm.	Findings were based on controlled lab conditions with limited devices and may not generalize to real-world use.	OLED flicker poses minimal risk under typical smartphone viewing distances, though further research is warranted.	https://doi.org/10.1080/15980316.2021.1950854
Li et al. (2022)[19]	EEG-based repeated-measures experimental study comparing cortical activity under two stereoscopic conditions	14	20 - 25 years	Neurophysiology of stereo vision—frontal and occipital lobe EEG responses to binocular disparity using dynamic random-dot stereograms (DRDS)	stimulus: DRDS videos generated in MATLAB, presenting 3D geometric shapes with varying parallax (5–300 arcsec). Exposure: Each video lasted 4 seconds; disparities of 20 arcsec (unperceived) and 100 arcsec (clearly perceived) were selected for EEG analysis.	Theta- and alpha-wave powers significantly increased in frontal and occipital electrodes during 3D perception (e.g., $F = 2.973$, $p = 0.0004$); functional connectivity (PLI) of theta-waves between frontal and occipital lobes was significantly enhanced	Small sample size ($N = 14$), limited generalizability beyond young healthy adults, and short stimulus duration may not reflect real-world depth processing	Frontal lobe activity and its connectivity with occipital regions intensify during binocular depth perception; theta-waves may play a key role in stereo vision processing.	https://doi.org/10.1167/iovs.63.5.7

Kim J et al. (2022)[33]	Experimental, repeated-measures study. Blink rate measured in four environments — natural state, monitor viewing, VR head-mounted display (HMD), and AR glasses.	21	26.87 ± 3.31 years.	Digital health and ocular physiology in immersive metaverse technologies (VR head-mounted displays and AR glasses).	Blink rate measured with a Sony TD20 camera. Monitor environment: 24-inch Ultron 2457 Ultra monitor at 1.0 m viewing distance. HMD environment: FOVE0 head-mounted display (VR demo game "Grandmother's Doll"). AR glasses environment: Microsoft HoloLens 2 with 3D modeling content.	Blink rate significantly decreased in all device environments compared to natural state, with the lowest rate in VR HMD (≈10.8 blinks/min vs. ≈18.0 natural).	Small sample size, short exposure duration, and controlled lab conditions limit generalizability to real-world use.	Immersive VR/AR use reduces blink rate, raising risk of ocular dryness; regular breaks and usage guidelines are recommended.	https://doi.org/10.3390/ijerph19148551
Kim J et al. (2018)[32]	Controlled experimental study measuring blink rate in participants while viewing content through a VR head-mounted display.	21	28.38 ± 6.87 years.	Ocular physiology and human–computer interaction in immersive virtual reality environments.	Blink rate measured with a Sony TD20 camera. Monitor environment: 24-inch Ultron 2457 Ultra monitor at 1.0 m viewing distance. HMD environment: FOVE0 head-mounted display (VR demo game "Grandmother's Doll").	Blink rate decreased significantly during VR HMD use compared to natural viewing, indicating reduced ocular lubrication.	Small sample size and short exposure duration limit generalizability to diverse populations and prolonged VR use.	VR HMD viewing suppresses blink rate, suggesting potential risk for digital eye strain and ocular surface dryness.	https://doi.org/10.3390/sym10090400
Cardona et al. (2023)[29]	Pilot experimental study measuring Spontaneous blink rate, incomplete blink rate and blink regularity, tear break up time through video recording	8	52.0 ± 16.6 years.	Ocular surface physiology, blink dynamics, and dry eye research.	silent fixation on landscape, reading from hard text, reading from electronic text	SEBR decreased during both reading tasks compared to baseline. Reading increased irregularity (higher coefficient of variation of IBI). Incomplete blinks: More frequent during electronic reading than hard-copy. Ocular surface exposure: Increased during reading tasks, especially in participants with shorter TFBUT.	Small sample size, controlled environment,	Loss of blink regularity, alongside reduced blink rate and incomplete blinks, significantly increases ocular surface exposure. Reading tasks (especially electronic) exacerbate irregular and incomplete blinking.	https://doi.org/10.3390/diagnostics13142362
Sharvit et al. (2025)[20]	Randomized crossoverstudy in which young adults performing four 30-minute reading tasks (high vs low cognitive demand, on tablet vs paper).	30	24 ± 1.6 years	Interaction of cognitive load, medium of presentation, and working distance in digital eyestrain.	Reading tasks on digital display vs printed hard copy under low vs high cognitive load; tasks performed at typical near working distances with concurrent assessment of viewing distance changes.	Greatest symptom increase occurred with high cognitive demand on a tablet. Working distance shortened from ~31.6 cm to ~28.9 cm in the first 10 minutes across all tasks, then stabilized. Distances were consistently closer than the 40 cm standard used in clinical testing.	Young adult sample only (limits generalizability to older populations). Short task duration (30 minutes). Did not assess long-term adaptation or ergonomic interventions.	Cognitive demand, rather than medium, drives eyestrain severity. Habitual working distances are closer than clinical norms, underscoring the need to consider task-driven viewing behavior in both diagnosis and ergonomic advice.	https://doi.org/10.1097/OPX.0000000000002238

Enthoven et al. (2021)[50]	Cross-sectional, population-based study using the Myopia App to objectively measure smartphone use, face-to-screen distance, and outdoor exposure. Participants: 525 Dutch teenagers aged 12–16 years from secondary schools and the Generation R birth cohort.	525	12 - 16 years	Association between smartphone use patterns (daily duration, continuous episodes, viewing distance) and refractive error/myopia prevalence.	Smartphone use pattern	Average smartphone use: ~3.7 hours/day on school days. Continuous use: ~6.4 episodes/day of ≥20 minutes without breaks. Myopia prevalence: 18.9%. Continuous use was significantly associated with more myopic spherical equivalent refraction (SER) and higher axial length-to-corneal radius (AL:CR) ratio. Face-to-screen distance (~29 cm) was not significantly linked to refractive error.	Cross-sectional design (no causal inference). Technical issues with app logging led to missing data.	Frequent, prolonged smartphone use (≥20 min episodes) is associated with more myopic refractive error, especially in teenagers with low outdoor exposure.	https://doi.org/10.1016/j.ophtha.2021.06.016
Vaz et al. (2023)[128]	Prospective, controlled, investigator-masked clinical study investigating preservative-free hyaluronic acid artificial tears as prophylaxis against gaming-induced ocular symptoms	56	18–45 years / 25.2 ± 5.8 years	Ergophthalmology and ocular surface	Gaming ≥6 hours/day for 3 consecutive days Devices used_ Computer 98%; Mobile phones 73.5%; Consoles 36%.	Control group: Significant increase in dry eye symptoms (p = 0.0320); Study group reported eyes felt better/much better after instillation	Short duration (3 days only) → limited ability to detect long-term effects	Preservative-free hyaluronic acid artificial tears combined with regular breaks were well tolerated and showed a protective effect against ocular fatigue and dryness during prolonged gaming. Findings suggest artificial tears may help prevent digital asthenopia (Computer Vision Syndrome) symptoms in heavy digital device users.	https://doi.org/10.3390/vision7010005
Svede et al (2024)[134]	Prospective, randomized, three-arm study with baseline, 4-week, and 8-week follow-ups	89	17 - 50 years /31 ± 7 years	Visual ergonomics and occupational optometry	EYE ROLL vision relaxation device (Class 3R 650 nm, 5 mW red laser), projecting a ~1.15° dot for guided tracking. Movement amplitude 10°–50°; speed ~20°/s; continuous dot visibility except far–near task	Eyeroll group: Significant reduction in vision discomfort at 4 weeks; significant reduction in eye fatigue at 8 weeks. No significant changes in accommodative amplitude (subjective), NRA/PRA, accommodative facility, heterophoria, NPC, or fusional reserves across groups	Home-based exercise execution not monitored; 26% did not submit compliance tables	EYE ROLL is a practical, workplace-integrable tool to support breaks and guided off-screen exercises; future controlled studies should standardize measurement conditions, balance refractive error across groups, and include larger, longer-duration cohorts	https://doi.org/10.3390/vision8030040
Ali A Abusharha (2017)[34]	Within-subject crossover, two visits (tablet vs hard copy), randomized order	40	24 ± 12 years	Blink behavior and ocular surface symptoms during near-vision tasks (reading)	15 minutes of reading per condition, same text/formatting, same room lighting, 40 cm viewing distance; blink rate video-recorded continuously, symptoms via visual analog scale every 5 minutes	Blink rate after using tablet: Baseline 19.74 ± 9.12, after 15 min 14.93 ± 10.90; Blink rate using Hard Copy: Baseline 19.74 ± 9.12, after 15 mins 11.35 ± 10.20	Each reading condition lasted 15 minutes, so findings reflect immediate effects only and cannot be extrapolated to typical prolonged screen use.	Near tasks reduce spontaneous blinking, likely due to increased attentional demand and down-gaze posture. Paper elicited lower blink rates but similar symptom levels; prior work indicates tablets may induce more incomplete blinks even if blink count is higher, which can still destabilize the tear film.	https://doi.org/10.2147/OPTO.S142718

Hirota et al (2013)[30]	Experimental within-subject visual display terminal (VDT) exposure with repeated measures.	11	19–32 years/ 21.3 ± 2.8 years.	Blink behavior (complete vs incomplete), tear-film stability, and anterior corneal higher-order aberrations during prolonged VDT use.	Task: 60-minute PC game (VDT) at 40 cm viewing distance. Logitech HD Pro Webcam C910 (video at 30 fps) mounted on display. RT-7000 Topographer with Tear Film Stability Analysis System (TSAS) measuring ring breakup time (RBUT) every 15 min. Optical aberrations: OPD-Scan II	Total blink rate: Dropped to about half the baseline once VDT viewing began. Complete vs incomplete blinks: Both rates fluctuated over time with a characteristic pattern: incomplete blinks dominated early (first 30 min), complete blinks increased between 30–50 min, then incomplete blinks rose again toward 60 min. Tear-film stability (RBUT): RBUT decreased significantly at 30 min. Anterior corneal higher-order aberrations increased during VDT exposure and showed temporal changes paralleling RBUT	Small sample size (n = 11) limits statistical power and generalizability.	Incomplete blinking during VDT use contributes more to tear-film instability than the mere reduction in total blink rate. Maintaining complete blinks appears critical for tear-film stability.	https://doi.org/10.1097/OPX.0b013e31829962ec
Maity et al (2025)[136]	Prospective, double-masked, randomized, controlled trial (single-dose, short-term crossover-style with internal control eye).	100	Teardrops 34.3 (±10.6) y; Refresh Liquigel 38.6 (±13.7) y; Systane Ultra 39.6 (±16.8) y; Systane Hydration 40.4 (±12.9) y; Trehalube 48.3 (±10.8) y.	Short-term effects of different commercially available artificial tear formulations on tear film stability and related parameters in moderate dry eye disease.	Controlled chamber (68–70°F; 35 ± 5% relative humidity; 200 lux). Single instillation of one of five commercially available artificial tears into the left eye. Noninvasive tear breakup time (NIBUT), tear meniscus height (TMH), and bulbar redness measured with Keratograph 5M at baseline and 15, 30, 45, 60 minutes.	All artificial tears produced a statistically significant increase in NIBUT at 15, 30, 45, and 60 minutes versus baseline ($p < 0.001$ for each group). Tear meniscus height & bulbar redness: No meaningful or consistent changes over time or between formulations.	Single-dose, short-term (1 hour) assessment—cannot infer longer-term efficacy or dosing schedules.	A single drop of CMC-, SH-, or PEG-based artificial tears improves tear film stability (NIBUT) for up to 1 hour, with no major differences in objective NIBUT response between formulations.	https://doi.org/10.1097/OPX.0000000000002206
Berntsen et al (2019)[129]	Randomized, 2×2 cross-over clinical trial with repeated measures	60	18 - 45 years / 27.5 ± 5.0 years.	Compare toric versus spherical daily disposable soft contact lenses for vision quality and objective eyestrain in low-to-moderate astigmats.	Lenses tested - Toric: 1-Day ACUVUE MOIST for astigmatism (Johnson & Johnson Vision). Spherical: 1-Day ACUVUE MOIST (same family, non-toric). Binocular fitting in randomized order; toric axis adjusted clinically as needed; Eyestrain was measured using surface Electromyography	Toric lenses produced statistically significant improvements versus spherical lenses in both high- and low-contrast distance acuity at the fitting visit and at follow-up. Objective eyestrain (EMG): Orbicularis oculi activity (log-transformed median RMS) was significantly lower with toric lenses at the fitting visit (least-square mean ratio toric/spherical ≈ 0.72, P = 0.0019), indicating less objective eyestrain/squinting. Subjective outcomes: Questionnaire scores (quality of vision and satisfaction) favored toric lenses at follow-up	Only one toric and one spherical daily disposable design were tested; results may not generalize to other brands or stabilization systems. Eyestrain was measured at distance with a single low-contrast task; near-work, prolonged tasks, and other real-world conditions were not evaluated.	In low-to-moderate astigmatic contact-lens wearers, toric daily disposable lenses provided better objective visual acuity (high and low contrast) and reduced objective eyestrain at initial fitting compared with spherical lenses; visual-acuity advantages persisted at follow-up, while the EMG measure of eyestrain did not remain significantly different after adaptation.	https://doi.org/10.1097/ICL.0000000000000528

Watcharapalakorn et al (2024)[89]	Double-blind, randomized crossover trial.	26	21.7 ± 2.6 years.	Effect of spectacle lens spectral filtering on dry-eye signs and symptoms during prolonged digital-screen exposure.	Lens conditions compared: (1) Uncoated CR-39 lenses; (2) Anti-reflective coated CR-39 lenses; (3) Lenses with blue-filtering (blue-blocking) filters. Exposure task: 120 minutes of continuous reading from a tablet at 50 cm and 10° below eye level; room lighting and screen luminance standardized.	Reading for 120 minutes produced significant increases in self-reported symptoms (DEQ-5) and worsening of tear-film measures (reduced TMH, NIBUT, fTBUT) across conditions. No statistically significant differences were found between uncoated, anti-reflective, and blue-filtering lenses for symptom scores or objective dry-eye signs. Blue-filtering spectacle lenses did not prevent or reduce dry-eye signs or symptoms during the 120-minute digital task in this healthy young cohort.	Single 120-minute sessions; does not address cumulative or long-term effects of habitual lens wear. Small sample size.	Wearing blue-filtering spectacle lenses provided no measurable benefit over anti-reflective or uncoated CR-39 lenses for preventing dry-eye signs or symptoms during a 2-hour tablet reading task. Practical management of screen-related ocular discomfort should prioritize ergonomics, regular breaks, blink awareness, and established dry-eye treatments rather than relying on blue-filtering lenses alone.	https://doi.org/10.1111/opo.13543
Redondo et al (2025)[94]	Randomized, repeated-measures crossover experiment.	24	21.14 ± 1.81 years	Vision science / optometry — digital eye strain (DES), accommodative function, and near-work-induced transient myopia (NITM).	40-minute reading on a laptop at 50 cm. Objective tools: Binocular open-field autorefractor (Grand Seiko WAM-5500) for dynamic accommodation and NITM; symptom questionnaire for subjective DES	Frequent (every-10-min) and self-paced breaks reduced certain DES complaints (notably eye irritation/burning and eyestrain) compared with no breaks or a single 20-min break. Accommodative lag did not change significantly across conditions; accommodative variability increased over time in the no-break and single-break conditions but remained more stable with frequent or self-paced breaks.	Small sample of healthy young adults Short task duration (40 min)	Short, frequent or self-paced breaks during prolonged near work better preserve accommodative stability and reduce some DES symptoms compared with no breaks or a single 20-min break; the 20-20-20 single break was less effective in this protocol.	https://doi.org/10.1016/j.exer.2025.110463
Johnson & Rosenfield (2023)[135]	Experimental study, in which subjects completed a 40-minute cognitively demanding reading task on a tablet and takes 20-second breaks allowed at intervals of 5, 10, 20, or 40 minutes (no break).	30	21 -31 years / 24.1 ± 1.77 years.	Digital eye strain and efficacy of scheduled breaks (20-20-20 rule).	Apple iPad (model MK9N2LL). Viewing distance 40 cm, Reading aloud random words, identifying those beginning with a specified letter.	Significant increase in ocular/visual symptoms after all tasks ($P < .001$). No significant difference in symptoms, reading speed, or accuracy across break intervals ($P = .70, .93, .55$ respectively).	Short trial duration (40 minutes only). Breaks were only 20 seconds; longer or different activities were not tested.	The 20-20-20 rule (20-second breaks) does not reduce digital eye strain symptoms or improve performance. Breaks are still important, but longer durations or different strategies (e.g., closing eyes, lubricating drops, moving away from workstation) may be more effective.	https://doi.org/10.1097/OPX.0000000000001971

Golebiowski et al (2019)[35]	Pilot, within-subjects experimental study with pre- and post-task measurements and repeated measures during a 60-minute smartphone reading task	12	18–23 years/ 18.5 years	Ocular surface and binocular vision: effects of prolonged smartphone reading on tear film stability, blinking behavior, ocular symptoms, and accommodative/binocular function.	Smartphone (iPhone 5, 4" screen). Continuous reading of a novel on the smartphone for 60 minutes at self-selected, habitual holding distance; screen at maximum brightness; font and room illumination controlled. Spontaneous blink rate and working distance were recorded every 10 minutes;	Eyestrain and ocular surface symptom scores increased after 60 minutes (notably tiredness, reduced comfort, and sleepiness). The number of incomplete blinks increased over the 60-minute reading period (incomplete blinks rose from a median of ~6/min at 1 min to ~15/min at 60 min); complete blink rate did not change significantly. Tear film: No statistically significant pre/post change in noninvasive tear breakup time (NIBUT), lipid layer grade, or tear meniscus height when measured ~10–15 minutes after the task. Binocular accommodative facility (BAF) decreased significantly after the task (median fell from ~11.3 cycles/min pre-task to ~7.8 cycles/min post-task). Fixation disparity did not change significantly.	Small sample size (pilot study, n=12) and only young adults limit generalizability.	One hour of smartphone reading in young adults produced worse ocular comfort, a reduction in binocular accommodative facility, and an increase in incomplete blinking, with the rise in incomplete blinks correlating with symptom worsening. Tear film parameters measured after a short delay did not show sustained change, suggesting that blinking quality (incomplete vs complete) and binocular function are important mediators of symptoms during smartphone use and warrant further study in larger and more diverse samples.	https://doi.org/10.1080/02713683.2019.1663542
Yi Z et al (2024)[116]	Randomized crossover experimental study. Participants read the same text for 4 hours on two separate days: once from a printed textbook and once using a virtual distant-viewing display; order was randomized and measurements were taken before and after each session.	26	21 - 29 years / 26.4 years	Myopia research and Visual ergonomics; and human factors	an optical electronic “virtual distant viewing” system consisting of a semitransparent/semi-reflective plane spectroscope, an AR total-reflection free-form concave mirror and a 5.5-inch LCD (1920×1080) that presents a virtual image at 5 m while the physical screen sits at ~33 cm; visual angle ≈30°.	Textbook (control) condition: significant transient myopic shift — spherical equivalent changed from −3.13 ± 2.65 D to −3.32 ± 2.70 D ($P < 0.001$); central corneal thickness and anterior chamber depth decreased; accommodative facility and subjective visual fatigue increased after 4 hours. Virtual distant-viewing condition: no significant change in spherical equivalent, corneal thickness, or anterior chamber depth after 4 hours; accommodative facility, choroidal thickness, positive relative accommodation, and amplitude of accommodation increased; subjective visual fatigue also increased.	Heterogeneous refractive status: enrollment did not restrict baseline refraction (only ~20% emmetropic), limiting subgroup comparisons between emmetropes and myopes.	Using a virtual distant-viewing display during prolonged nearwork prevented the transient myopic shift and several ocular parameter changes seen after 4 hours of textbook reading, while preserving reading speed and improving some measures of accommodative function; the device did not increase objective measures of ocular harm but did raise subjective visual fatigue similarly to textbook reading	https://doi.org/10.1177/20552076241259868

Gani et al. (2024)[110]	Quantitative Randomized Controlled Trial	5	22-25 years	Visual neuroscience, visual perception,	Emotiv 14-electrode headset (active electrodes placed according to standard labels such as F3/F4, FC5/FC6, O1/O2, T7/T8, P8, AF3/AF4) a silent video of 5-minute "Wonderful Indonesia" clip was presented.	participants without glasses showed lower spectral entropy (reported group averages 1.0) than with glasses (3.5), interpreted as greater irregularity in brain activity when not wearing corrective lenses.notable differences and transient signal surges were reported in frontal and occipital channels; occipital electrodes (O1/O2) and frontal sites (F7, FC5, F4, etc.) were repeatedly identified as showing condition-dependent changes.	Small sample size, the study reports overall spectral/entropy differences but does not deeply parse standard EEG bands	The study provides preliminary evidence that myopia and the use of corrective lenses alter EEG signatures during visual stimulation: spectral entropy and PSD measures differed when participants viewed video stimuli without versus with glasses, with lower entropy (more irregular activity) observed without correction. The authors propose that EEG spectral metrics can help characteri	https://doi.org/10.26740/jpfa.v14n1.p19-32
Reilly et al. (2018)[102]	Experimental within-subjects study with two tasks (auditory tone detection and visual word monitoring) that manipulated baseline pupil size via ambient illuminance to test whether task-evoked pupillary responses scale linearly or nonlinearly	Experiment 1: 24, and Experiment 2: 40	Experiment 1: 25.26 years; Experiment 2: 22.05 years	Psychophysiology and Cognitive Neuroscience	Infrared table-mounted eye tracker sampling at 120 Hz; chinrest used for head stabilization; Ambient illuminance set to bright (≈753 lux), mid (≈350 lux), and dark (≈16 lux) to produce different baseline pupil diameters	Task-evoked pupillary responses (TEPRs) scaled linearly and were independent of baseline pupil amplitude across lighting conditions and tasks; TEPR peak amplitudes and average dilations did not differ meaningfully between low and high illuminance	Practical and equipment constraints limited the tested luminance range (extreme darkness or intense light produced measurement or comfort issues)	The study concludes that phasic task-evoked pupillary responses behave as a linear function independent of baseline pupil diameter under the tested conditions, supporting subtractive (linear) baseline correction for discrete TEPR analyses and arguing for reexamination of studies that assume nonlinear scaling	https://doi.org/10.3758/s13428-018-1134-4
Arita et al (2025)[127]	Multicenter, prospective, randomized, parallel-group comparative study	100	19–52 years/ 38.4 ± 7.4 years	Dry eye disease, evaporative dry eye, meibomian gland dysfunction	Blinking exercise protocol: 5 sets per session; 5 sessions/day; 3 days; Exercises targeted both upper and lower orbicularis oculi;	Blinking exercise increased Palpebral fissure height; NIBUT; FBUT; Lipid layer thickness; and reduces Incomplete blink rate; Fluorescein staining	Short intervention duration (3 days) — limits understanding of long-term effects.	Blinking exercises performed five times daily for three days significantly improved palpebral fissure height, incomplete blinking, tear film stability, and subjective dry eye symptoms compared with artificial tears alone.	https://doi.org/10.1016/j.jtos.2025.02.003
Study domains correspond to the six mechanistic categories defined in the review. Limitations are extracted from each study or identified during MMAT appraisal. Abbreviations: RCT = randomized controlled trial; EMG = electromyography; EEG = electroencephalography. FHP: forward head posture, SVM: support vector machine, LDA: Linear Discriminant Analysis, ANN: Artificial Neural Network									