

Influence of SmartPhone-Induced Visual Fixation on Postural Stability and Cervical Muscle Co-Contraction Effectiveness of Stretching and Strengthening Exercise Program for Long-Term Mobile Users

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ABSTRACT

Background: Prolonged smartPhone use demands sustained near visual fixation at 20–40 cm combined with cervical flexion and forward head Posture (FHP), imPosing comPound sensorimotor demands on the cervical neuromuscular system and whole-body Postural control. The interaction between near visual fixation behavior, cervical muscle co-contraction, and Postural stability has not been systematically quantified, and targeted PhysiotheraPy interventions addressing visual–Postural interactions remain scarce.

Objectives: To quantify the effect of smartPhone-induced near visual fixation on cervical muscle co-contraction ratios and center-of-Pressure (COP) sway indices across standardized viewing conditions, and to evaluate the efficacy of a 6-week multimodal PhysiotheraPy Program in long-term smartPhone users.

Methods: Sixty healthy smartPhone users (18–30 years; daily use ≥ 4 hours) Performed quiet stance on a force Plate under three randomized conditions: (1) eyes forward at 3 m baseline, (2) smartPhone viewing with free head Posture, and (3) smartPhone viewing with standardized 45° FHP. Surface electromyograPhy (sEMG) recorded bilateral sternocleidomastoid (SCM), sPlenius caPitis, and uPPer traPezius co-contraction ratios (CCR). COP sway area and velocity were derived. Eye-tracking quantified fixation duration and saccade frequency. An intervention subgrouP (n=30) comPleted a 6-week Program of gaze stabilization, deeP cervical flexor training, and visual–Postural coordination exercises. Data were analyzed using rePeated-measures ANOVA, Pearson correlations, and Paired t-tests.

Results: Significant condition effects were observed for CCR [F(2,118)=26.3, P<0.001, $\eta^2=0.31$] and COP sway area [F(2,118)=31.7, P<0.001, $\eta^2=0.35$]. SCM–sPlenius caPitis CCR increased from 0.37±0.05 (baseline) to 0.52±0.08 (free Posture) and 0.66±0.10 (standardized FHP) (all P<0.001). COP sway area increased from 1.7±0.4 cm² to 3.2±0.7 cm² and 4.8±1.1 cm², resPectively. Fixation duration correlated significantly with CCR (r=0.56, P<0.001) and COP sway area (r=0.49, P<0.001). Post-intervention, CCR decreased from 0.66±0.10 to 0.43±0.07 (P<0.001, d=1.45), COP sway area reduced by 38.5% (P<0.001, d=1.22), and craniovertebral angle imProved from 43.1°±3.8° to 48.2°±3.2° (P<0.001).

Conclusion: SmartPhone-induced near visual fixation, amPlified by forward head Posture, significantly increases cervical co-contraction and imPairs Postural stability. The multimodal PhysiotheraPy Program effectively normalized neuromuscular and Postural outcomes, suPPorting integration of gaze stabilization and visual–Postural coordination training into cervicoPostural rehabilitation Protocols.

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Keywords: Postural stability, SmartPhone use, Forward head Posture, Cervical muscle co-contraction, Gaze stabilization, Surface electromyography

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INTRODUCTION

The global Proliferation of smartPhones has fundamentally altered human Postural and visual behavior. With over 6.9 billion smartPhone users worldwide and an estimated daily screen time of 4–6 hours among young Indian adults, the musculoskeletal consequences of habitual smartPhone use have emerged as a significant Public health concern.[1] In India, smartPhone Penetration crossed 750 million users by 2024, and studies from university Populations report that 62–78% of young adults exhibit measurable forward head Posture (FHP), a direct morphological consequence of sustained cervical flexion during device use.[2]

SmartPhone viewing demands near visual fixation at 20–40 cm, substantially shorter than conventional reading distance, combined with a downward gaze angle of 30°–60° below horizontal.[3] This Posture imposes a Progressive mechanical load on the cervical spine: the effective head weight increases from approximately 5.4 kg in neutral alignment to an estimated 27 kg at 60° cervical flexion, as quantified by Hansraj's biomechanical model.[4] Chronic repetition of this loading Pattern drives structural adaptations— anterior cervical muscle shortening, Posterior muscle lengthening, and ligamentous laxity—culminating in FHP with its attendant neuromuscular consequences.

Postural stability depends on the integration of visual, vestibular, and somatosensory (Proprioceptive) inputs.[5] The visual system contributes approximately 70–75% of sensory information for Postural regulation under normal conditions, making it the dominant modality for balance control. Near visual fixation, as during smartPhone use, creates a unique sensorimotor milieu: the visual system is maximally engaged on a proximal, stationary target, reducing its effectiveness for detecting body sway, while simultaneously the cervical spine is loaded in a Posture that compromises Proprioceptive input through

mechanoreceptor compression and muscle spindle distortion.[6]

Surface electromyographic (sEMG) studies have documented disproportionate co-activation between cervical agonists and antagonists in FHP Populations. Co-contraction ratios (CCR) of the sternocleidomastoid and splenius capitis, Primary antagonistic stabilizers of the cervical spine, have been reported to increase by 28–42% in individuals with FHP compared to Posturally normal controls.[7] This inefficient neuromuscular strategy, while initially protective against destabilizing loads, when chronically sustained generates muscle fatigue, Pain sensitization via central sensitization mechanisms, and Progressive deterioration of cervical motor control.

Despite this convergence of evidence, the specific role of visual fixation behavior—including fixation duration and saccade frequency—as a modulating variable in cervical co-contraction and whole-body Postural sway has not been systematically investigated. Furthermore, Physiotherapy interventions for smartPhone-related dysfunction have largely targeted cervical musculoskeletal components in isolation, without addressing the visual-Postural sensorimotor interaction that characterizes the task itself.

This study addresses these critical gaps through three aims: (1) quantifying the influence of smartPhone-induced near visual fixation, with and without standardized FHP, on cervical muscle CCR and COP-based Postural stability indices; (2) characterizing the relationship between eye-tracking Parameters and neuromuscular/Postural outcomes; and (3) evaluating the efficacy of a 6-week multimodal Physiotherapy Program integrating gaze stabilization, deep cervical flexor training, and visual-Postural coordination tasks in long-term smartPhone users.

MATERIALS AND METHODS

Study Design

A cross-sectional, laboratory-based observational study with a nested randomized Pre-Post intervention subgroup design was conducted. Ethical clearance was obtained from the Institutional Ethics Committee (IEC Ref: [IEC Number]) Prior to recruitment. All Procedures conformed to the Declaration of Helsinki (2013 revision). Written informed consent was obtained from all Participants. The study was registered in the Clinical Trials Registry – India (CTRI Ref: [CTRI Number]).

Sample Size Calculation

Sample size was calculated using G*Power 3.1 for repeated-measures ANOVA (three within-subject conditions, $\alpha=0.05$, Power=0.80, effect size $f=0.40$ based on Pilot data).[8] A minimum of 54 Participants was required; with 10% attrition, the total was set at 60. For the intervention subgroup, Paired comparisons (Cohen's $d=0.60$, Power=0.80) required a minimum of 23 Participants, expanded to 30.

Participants

Sixty healthy young adults (18–30 years) who self-reported daily smartPhone use ≥ 4 hours were recruited from a university campus using convenience sampling with snowball recruitment. Thirty were randomly allocated to the intervention subgroup using sequentially numbered sealed envelopes.

Inclusion criteria: (1) Daily smartPhone use ≥ 4 hours for ≥ 2 years; (2) No history of cervical surgery, neurological disorder, or vestibular pathology; (3) No acute cervical pain in the preceding 6 weeks; (4) Normal or corrected-to-normal visual acuity ($\geq 6/9$ Snellen); (5) Ability to stand unaided for ≥ 60 seconds.

Exclusion criteria: (1) Cervical radiculopathy or myelopathy confirmed on clinical examination; (2) Diagnosed vestibular dysfunction; (3) Lower limb musculoskeletal pathology affecting standing balance; (4) Pregnancy; (5) Concurrent structured neck exercise Program.

Outcome Measures

Primary outcomes: (1) Cervical muscle co-contraction ratio (CCR) = antagonist RMS amplitude / (agonist RMS + antagonist RMS), computed from bilateral SCM, splenius capitis, and upper trapezius sEMG; (2) COP sway area (95% confidence ellipse, cm^2) and COP mean velocity (cm/s) from force Plate recordings.

Secondary outcomes: (1) Mean fixation duration (ms) and saccade frequency (events/min) from Tobii Pro Glasses 3 eye-tracker; (2) Craniovertebral angle (CVA) from lateral Photograph at C7–tragus landmark; (3) Deep neck flexor (DNF) endurance via craniocervical flexion test (CCFT) Pressure biofeedback at 22–30 mmHg.

Experimental Conditions

Each Participant Performed quiet bipedal standing on a force Plate (Bertec Corporation, Columbus, Ohio, USA; 1000 Hz sampling) under three randomized 30-second trials Per condition (Latin square counterbalancing), with 2-minute rest intervals:

1. Condition 1 (Baseline): Eyes open, gaze on a 1 cm^2 fixation target at 3 m, head in neutral alignment.
2. Condition 2 (SmartPhone-Free Posture): Active smartPhone use (standardized social media scroll task) with self-selected head Posture.
3. Condition 3 (SmartPhone-Standardized FHP): SmartPhone viewing with cervical flexion standardized to 45° using a goniometer-guided head harness, confirmed at trial onset.

Surface EMG Acquisition and Processing

Ag/AgCl disposable electrodes (inter-electrode distance 20 mm) were Placed bilaterally following SENIAM guidelines.[9] SCM electrodes were Placed at the midpoint of the muscle belly (Parallel to fiber direction); splenius capitis between C2–C4 spinous Processes (2 cm lateral); upper trapezius midpoint between C7 and acromion. Skin Preparation included gentle abrasion (impedance $< 5 \text{ k}\Omega$). sEMG was sampled at 2000 Hz, bandpass filtered (20–450 Hz, fourth-order Butterworth), full-wave rectified, and Processed using a 50 ms RMS window. Normalization used maximum voluntary isometric contraction (MVIC) reference values from standardized test Positions.

Intervention Protocol (n=30)

The 6-week multimodal Physiotherapy Program comprised 18 sessions (3/week, 45 min/session) with three integrated components:

- Gaze Stabilization Training (15 min): Vestibulo-ocular reflex (VOR) exercises ($\times 1$, $\times 2$ gain), smooth Pursuit tracking, optokinetic stimulation, near–far accommodation shifts. Progressed

- from stable to unstable (foam Pad) surfaces over 6 weeks.
- Deep Cervical Flexor and Extensor Training (20 min): CCFT-guided activation of longus colli/longus capitis (22–30 mmHg Progression); chin tuck exercises; cervical stabilization in supine, four-point kneeling, and standing; scapular retraction and lower trapezius loading. Sets, repetitions, and resistance progressed weekly using a periodized schedule.
 - Visual-Postural Coordination Tasks (10 min): BiPedal and single-leg balance tasks while fixating a structured visual stimulus at 30 cm (smartPhone-equivalent); foam Pad and Perturbation board Progressions; dual-task Paradigms integrating cognitive load with near-visual fixation. Sessions were supervised by a registered Physiotherapist.

Stretching and Strengthening Exercise Program

A structured stretching and strengthening exercise Program was incorporated as a core component of the 6-week multimodal Physiotherapy intervention. The Program targeted the Primary cervical, scapular, and thoracic muscle groups implicated in forward head Posture (FHP) and Postural instability associated with Prolonged smartPhone use. All exercises were performed under the supervision of a registered Physiotherapist and progressed according to individual participant tolerance using a periodized load schedule.

Stretching Exercises

Stretching exercises targeted the shortened and overloaded anterior cervical and Pectoral musculature. The following Protocol was applied: (1) **Cervical Lateral Flexion Stretch**: Seated with neutral lumbar support, participants laterally flexed the head toward the ipsilateral shoulder while maintaining the contralateral shoulder depressed. Three repetitions of 30-second sustained holds were performed bilaterally, targeting the upper trapezius and scalene musculature. (2) **Sternocleidomastoid (SCM) Stretch**: Participants rotated the head 45° contralaterally and extended the cervical spine to a comfortable end-range, achieving selective elongation of the SCM. Holds of 30 seconds

were performed for 3 repetitions per side. (3) **Suboccipital Release Stretch**: In supine, a gentle chin tuck was combined with upper cervical flexion to elongate the suboccipital musculature; 3×30-second holds. (4) **Pectoralis Minor Stretch**: Corner stretches were performed in standing with bilateral shoulder abduction at 90° and forearms placed on a doorframe; participants gently leaned into the corner to produce anterior chest wall stretch. Three repetitions of 30 seconds were performed each session. (5) **Thoracic Extension Mobilization**: Seated on a chair with hands clasped behind the occiput, participants extended over the chair back at the level of the mid-thoracic spine (T4–T8) for gentle segmental extension. Five repetitions of 10-second holds were performed per session. All stretches were performed at a pain-free intensity rated ≤4/10 on the Numeric Pain Rating Scale.

Strengthening Exercises

Strengthening exercises addressed the deep cervical flexors, posterior cervical stabilizers, scapular retractors, and lower trapezius—muscles identified as hypoactive in FHP populations. The following exercises comprised the strengthening component: (1) **Craniocervical Flexion Exercise (Deep Neck Flexor Activation)**: Performed in supine using a Pressure biofeedback unit (Chattanooga Stabilizer™), participants performed nodding actions at the craniocervical junction targeting progressive activation levels (22, 24, 26, 28, and 30 mmHg), held for 10 seconds per level, 10 repetitions per level achieved, with strict avoidance of superficial flexor substitution. Progression was advanced weekly based on CCFT performance. (2) **Chin Tuck Exercise**: Performed in seated, standing, and four-point kneeling positions, participants retracted the head horizontally (“make a double chin” cue) without cervical flexion or extension. Three sets of 15 repetitions per session were performed; resistance was progressively added using a Theraband loop placed across the occiput from weeks 3–6. (3) **Scapular Retraction and Depression Exercise**: Seated with arms at the sides, participants squeezed the scapulae together and downward (activating mid and lower trapezius and rhomboids), held for 5 seconds, and returned to rest. Three sets of 15 repetitions were performed per session; elastic resistance bands (Thera-Band™; Yellow

to Green grades across 6 weeks) were introduced from Week 2. (4) **Lower TraPezius “Y” Exercise:** In Prone over a treatment table or in standing with resistance band, ParticiPants elevated the arms in a Y-Position (aPProximately 135° shoulder abduction in the scaPular Plane) with thumbs Pointing uPward, targeting the lower traPezius and serratus anterior. Three sets of 12 rePetitions were Performed; resistance was graduated from bodyweight only (Weeks 1–2) to 1 kg dumbbell or equivalent band resistance (Weeks 5–6). (5) **Cervical Isometric Strengthening:** Multi-directional isometric exercises were Performed in seated neutral Posture, with resistance aPPLIED manually by the theraPist in flexion, extension, and bilateral lateral flexion directions. Each contraction was held for 6 seconds at 60–70% maximum voluntary effort, 5 rePetitions Per direction, 3 directions Per session. This component was introduced from Week 3 once adequate deeP flexor activation was confirmed. (6) **Four-Point Kneeling Cervical Stabilization:** In quadruPed Position, ParticiPants maintained a neutral cervicothoracic alignment while Performing alternating arm lifts (Weeks 3–4) and contralateral arm–leg extensions (Weeks 5–6), demanding dynamic cervical and lumboPelvic stability. Three sets of 10 rePetitions were Performed Per exercise variant. Progression from bilateral to unilateral limb loading increased Postural demand on the cervical neuromuscular system across the intervention Period. All strengthening exercises were monitored to ensure correct technique and to Prevent compensatory muscle substitution Patterns.

Statistical Analysis

Data were analyzed using SPSS v26.0 (IBM, Armonk, NY). Normality was confirmed via ShaPiro–Wilk test (all $P > 0.05$). DescriPtive statistics (mean \pm SD) were rePorted for all continuous variables. A one-way rePeated-measures ANOVA with Bonferroni Post hoc correction compAred CCR and COP indices across three conditions. Pearson correlation examined associations between fixation Parameters and neuromuscular/Postural outcomes. Paired t-tests compAred Pre–Post intervention outcomes. Effect sizes were exPRESSED as Partial η^2 (ANOVA) and Cohen's d (Paired tests). Statistical significance: $P < 0.05$.

RESULTS

ParticiPant Characteristics

All 60 enrolled ParticiPants completed the observational Phase (0% attrition). In the intervention subgrouP (n=30), 28 ParticiPants completed all 18 sessions; 2 were lost to follow-uP (illness unrelated to the study), yielding a completion rate of 93.3%. The observed-case analysis was Performed for the 28 completers. Baseline demograPhic and clinical characteristics are summarized in Table 1.

Table 1: Baseline DemograPhic and Clinical Characteristics of ParticiPants (N=60)

Variable	Full Sample (n=60)	Intervention SubgrouP (n=30)
Age (years), mean \pm SD	22.4 \pm 2.8	22.1 \pm 2.6
Sex (Female/Male)	34 / 26	17 / 13
BMI (kg/m ²), mean \pm SD	22.1 \pm 2.4	21.9 \pm 2.3
Daily smartPhone use (hours), mean \pm SD	6.3 \pm 1.3	6.4 \pm 1.4
Years of smartPhone use, mean \pm SD	5.9 \pm 1.8	5.7 \pm 1.9
Craniovertebral angle (°), mean \pm SD	43.1 \pm 3.8	43.0 \pm 3.7
CCFT baseline level (mmHg), mean \pm SD	23.6 \pm 1.2	23.4 \pm 1.1
FHP Prevalence [CVA <50°] (%)	78.3%	80.0%

CCFT = Craniocervical flexion test; CVA = Craniovertebral angle; FHP = Forward head Posture; BMI = Body mass index. No significant between-grouP differences at baseline (all $P > 0.05$, indePendent samPles t-test or chi-square).

Effect of Viewing Condition on Cervical Muscle Co-Contraction

RePeated-measures ANOVA revealed a significant main effect of viewing condition on all three CCR measures (Table 2). For the SCM–sPlenius caPitis Pair: $F(2,118)=26.3$, $P < 0.001$, Partial $\eta^2=0.31$. Post hoc Bonferroni comparisons demonstrated significant increases from Condition 1 to Condition 2 (mean difference: 0.15, 95% CI: 0.11–0.19, $P < 0.001$) and from Condition 1 to Condition 3 (mean difference: 0.29, 95% CI: 0.24–0.34,

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P<0.001). The difference between Condition 2 and Condition 3 was also statistically significant (mean difference: 0.14, 95% CI: 0.09–0.19, P<0.001), indicating that standardized FHP exerted an additive effect on co-contraction beyond the effect of near visual fixation alone.

Similar Patterns were observed for the uPPER traPezius–SCM CCR [F(2,118)=22.7, P<0.001, η²=0.28] and sPlenius caPitis–uPPER traPezius CCR [F(2,118)=18.9, P<0.001, η²=0.24]. Across all muscle Pairs, Condition 3 (standardized FHP + smartPhone) consistently Produced the highest co-contraction ratios, reflecting maximal neuromuscular demand under combined visual and Postural loading.

Table 2: Cervical Muscle Co-Contraction Ratios Across Viewing Conditions (N=60)

Muscle Pair (CCR)	Condition 1 Baseline Mean ± SD	Condition 2 Smart Phone Free Mean ± SD	Condition 3 Smart Phone + FHP Mean ± SD	P-value (ANOVA)
SCM – SPlenius CaPitis	0.37 ± 0.05	0.52 ± 0.08*	0.66 ± 0.10*†	<0.001
UPPer TraPezius – SCM	0.41 ± 0.06	0.55 ± 0.09*	0.68 ± 0.11*†	<0.001
SPlenius CaPitis – UPPer TraPezius	0.39 ± 0.07	0.50 ± 0.08*	0.61 ± 0.10*†	<0.001

CCR = Co-contraction ratio; SCM = Sternocleidomastoid; FHP = Forward head Posture. *P<0.001 vs. Condition 1 (Bonferroni corrected); †P<0.001 vs. Condition 2. Values are mean ± SD.

Effect of Viewing Condition on Postural Stability

Force Plate data demonstrated a significant main effect of viewing condition on

both COP sway area [F(2,118)=31.7, P<0.001, η²=0.35] and COP mean velocity [F(2,118)=28.4, P<0.001, η²=0.33] (Table 3). COP sway area increased from 1.7±0.4 cm² at baseline to 3.2±0.7 cm² under free-Posture smartPhone viewing and 4.8±1.1 cm² under standardized FHP smartPhone viewing. All Pairwise comparisons were statistically significant (P<0.001). The effect size for the Condition 1 vs. Condition 3 comparison was large (d=1.89 for sway area; d=1.74 for velocity), indicating clinically meaningful deterioration in Postural stability under FHP-coupled smartPhone use.

Mediolateral (ML) COP displacement showed a ProPortionally greater increase than anteroPosterior (AP) displacement under Condition 3 (ML: +112%; AP: +87% relative to baseline), suggesting that the combination of lateral head tilt associated with FHP and near visual fixation differentially disrupts frontal Plane Postural control mechanisms.

Table 3: Center of Pressure Sway Parameters Across Viewing Conditions (N=60)

COP Parameter	Condition 1 Baseline Mean ± SD	Condition 2 Smart Phone Free Mean ± SD	Condition 3 Smart Phone + FHP Mean ± SD	P-value (ANOVA)
Sway Area (cm ²)	1.7 ± 0.4	3.2 ± 0.7*	4.8 ± 1.1*†	<0.001
Mean Velocity (cm/s)	1.1 ± 0.3	2.2 ± 0.5*	3.1 ± 0.7*†	<0.001
AP Displacement (cm)	0.8 ± 0.2	1.4 ± 0.4*	1.5 ± 0.4*	<0.001
ML Displacement (cm)	0.6 ± 0.2	1.0 ± 0.3*	1.3 ± 0.3*†	<0.001
95% Confid ence Ellipse	2.1 ± 0.5	3.9 ± 0.8*	5.9 ± 1.3*†	<0.001

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Area (cm ²)				
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*COP = Center of Pressure; AP = AnteroPosterior; ML = Mediolateral; FHP = Forward head Posture. *P<0.001 vs. Condition 1; †P<0.001 vs. Condition 2 (Bonferroni corrected). Values are mean ± SD.*

Eye-Tracking Findings and Correlations

Eye-tracking data were successfully acquired from 57 of 60 Participants (3 excluded due to calibration failure). Mean fixation duration was 318±44 ms under Condition 2 and 352±53 ms under Condition 3 (P=0.003). Saccade frequency was 14.2±3.1 events/min under Condition 2 and 10.8±2.7 events/min under Condition 3 (P<0.001), reflecting reduced active gaze exploration under standardized FHP.

Pearson correlation analysis (Table 4) revealed that fixation duration was significantly positively correlated with SCM–splenius caPitis CCR (r=0.56, P<0.001) and COP sway area (r=0.49, P<0.001), indicating that longer visual dwell on the smartPhone screen was associated with greater cervical co-contraction and Postural instability. Saccade frequency demonstrated a significant negative correlation with COP sway area (r=-0.33, P=0.012), consistent with the Postural stabilizing contribution of active gaze shifts. Daily smartPhone use duration showed moderate positive correlations with both CCR under Condition 3 (r=0.42, P<0.001) and CVA deficit (r=-0.38, P=0.003).

Table 4: Pearson Correlations Between Eye-Tracking Parameters, Co-Contraction Ratios, and COP Sway Area

Variable	SCM – Splenius CCR (Condition 3)	Upper TraP CCR (Condition 3)	COP Sway Area (Condition 3)	COP Velocity (Condition 3)
Fixation Duration (ms)	r=0.56**	r=0.51**	r=0.49**	r=0.44**
Saccade Frequency (events/min)	r=-0.27*	r=-0.24*	r=-0.33*	r=-0.30*

Daily use duration (hrs/day)	r=0.42**	r=0.38**	r=0.45**	r=0.40**
CVA deficit (degrees below 50°)	r=0.48**	r=0.44**	r=0.52**	r=0.46**

*P<0.05; **P<0.001. CCR = Co-contraction ratio; COP = Center of Pressure; CVA = Craniovertebral angle; SCM = Sternocleidomastoid. n=57 for eye-tracking correlations; n=60 for all others.

Intervention Outcomes (n=28 Completers)

Pre-intervention and Post-intervention values for all Primary and secondary outcomes are summarized in Table 5. Following 6 weeks of multimodal Physiotherapy, the SCM–splenius caPitis CCR under Condition 3 decreased from 0.66±0.10 to 0.43±0.07 (mean change: -0.23, 95% CI: -0.27 to -0.19; P<0.001, d=1.45), representing a 34.8% reduction. Upper traPezius CCR similarly decreased from 0.68±0.11 to 0.46±0.08 (32.4% reduction; P<0.001, d=1.38).

COP sway area under Condition 3 decreased from 4.8±1.1 cm² to 2.9±0.7 cm² (mean change: -1.9, 95% CI: -2.3 to -1.5; P<0.001, d=1.22; 38.5% reduction). COP mean velocity decreased from 3.1±0.7 cm/s to 1.9±0.5 cm/s (P<0.001, d=1.18). Improvements were also observed under Condition 2 (smartPhone with free Posture), with sway area decreasing from 3.2±0.7 cm² to 2.1±0.5 cm² (34.4% reduction; P<0.001), demonstrating transfer of training effects beyond the standardized FHP condition.

Among secondary outcomes, CVA improved from 43.1°±3.8° to 48.2°±3.2° (P<0.001, d=1.32), approaching but not fully reaching the normative threshold of 50°. CCFT Performance advanced by a mean of 2.4±0.8 Pressure levels (from 23.4±1.1 mmHg to 25.8±1.4 mmHg; P<0.001, d=1.57). Fixation duration during smartPhone tasks decreased from 350±52 ms to 318±41 ms Post-intervention (P=0.009), suggesting that the gaze stabilization component promoted more efficient visual scanning behavior.

Table 5: Pre- and Post-Intervention Outcomes in the Intervention Subgroup (n=28)

Outcome Variable	Pre-Intervention Mean \pm SD	Post-Intervention Mean \pm SD	Mean Change (95% CI)	Cohen's d
SCM-Splenius CCR (Cond 3)	0.66 \pm 0.10	0.43 \pm 0.07**	-0.23 (-0.27 to -0.19)	1.45
UPPer TraPezius CCR (Cond 3)	0.68 \pm 0.11	0.46 \pm 0.08**	-0.22 (-0.26 to -0.18)	1.38
COP Sway Area Cond 3 (cm ²)	4.8 \pm 1.1	2.9 \pm 0.7**	-1.93 (-2.3 to -1.5)	1.22
COP Sway Area Cond 2 (cm ²)	3.2 \pm 0.7	2.1 \pm 0.5**	-1.14 (-1.4 to -0.8)	1.04
COP Mean Velocity Cond 3 (cm/s)	3.1 \pm 0.7	1.9 \pm 0.5**	-1.25 (-1.5 to -0.9)	1.18
Craniovertebral Angle (°)	43.1 \pm 3.8	48.2 \pm 3.2**	+5.18 (+3.8 to +6.4)	1.32
CCFT Level (mmHg)	23.4 \pm 1.1	25.8 \pm 1.4**	+2.40 (+2.0 to +2.8)	1.57
Fixation Duration (ms)	350 \pm 52	318 \pm 41*	-32 (-54 to -10)	0.68

* $P < 0.01$; ** $P < 0.001$ (Paired *t*-test). CCR = Co-contraction ratio; COP = Center of Pressure; CCFT = Craniocervical flexion test; Cond = Condition; CI = Confidence interval.

Table 6: Weekly Progression of Intervention Program

Week	Sessions	Gaze Stabilization Component	Cervical Motor Control Component	Visual - Postural Task
1-2	6 sessions	VOR \times 1, smooth Pursuit on stable surface	CCFT 22-24 mmHg, suPine chin tuck 3 \times 10	BiPedal stance, near fixation 30 cm, stable surface
3-4	6 sessions	VOR \times 2, oPtokinetic, near-far accommodation	CCFT 24-26 mmHg, four-Point kneeling stabilization	Single-leg stance with near fixation; foam Pad
5-6	6 sessions	VOR \times 2 on foam, oPtokinetic + dual-task	CCFT 26-30 mmHg, standing resistance band, scaPular retraction	Perturbation board + near fixation + cognitive dual-task

VOR = Vestibulo-ocular reflex; CCFT = Craniocervical flexion test. All sessions 45 minutes in duration, suPervised by a registered Physiotherapist.

DISCUSSION

The results of this study Provide comprehensive empirical support for the hypothesis that smartPhone-induced near visual fixation, Particularly in combination

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with forward head Posture, acts as a compounded sensorimotor constraint that augments cervical muscle co-contraction and impairs whole-body Postural stability. The magnitude and consistency of effects across conditions, the meaningful correlations with objective visual behavior metrics, and the clinically significant outcomes of the multimodal intervention collectively advance the understanding and management of smartPhone-related cervicopostural dysfunction.

The Progressive increase in CCR across conditions—from baseline (0.37 ± 0.05) through free-Posture smartPhone viewing (0.52 ± 0.08) to standardized FHP viewing (0.66 ± 0.10)—with a large effect size ($\eta^2 = 0.31$) is consistent with the neuromechanical Principle that co-contraction increases Proportionally to joint instability risk.[10] The additive contribution of standardized FHP beyond near visual fixation alone (mean CCR difference: 0.14; $P < 0.001$) supports a multiplicative rather than additive model of sensorimotor loading, wherein Postural constraint amplifies the neuromuscular response to visual task demands. This finding aligns with Cholewicki et al.'s spinal stability framework, wherein muscular co-contraction serves as a compensatory mechanism for compromised Passive and active stabilization.[11]

The strong Positive correlation between fixation duration and CCR ($r = 0.56$, $P < 0.001$) Provides the first direct evidence that visual dwell behavior—how long an individual fixates the smartPhone screen—is a Physiological determinant of cervical neuromuscular loading, independent of viewing duration. This finding supports Treisman's attentional resource theory and its Postural applications as described by Woollacott and Shumway-Cook: sustained attentional capture by a near visual task depletes cognitive resources available for Postural automaticity, necessitating compensatory neuromuscular effort.[12] The negative correlation between saccade frequency and COP sway area ($r = -0.33$, $P = 0.012$) corroborates this model: frequent gaze shifts maintain spatial reference frame updating and Partially offset the destabilizing effect of near fixation.

The deterioration in Postural stability across conditions—COP sway area increasing by 88% from baseline to Condition 2 and 182% to Condition 3—represents a clinically significant finding with implications for fall risk in habitual smartPhone users. While the Population studied (healthy young adults) does not typically Present with frank fall risk, the degree of COP Perturbation under Condition 3 approaches values reported in older adults with mild balance impairment.[13] The Proportionally greater ML displacement under standardized FHP may reflect disruption of frontal Plane Postural control attributable to the combined effects of head tilt, reduced cervical Proprioception, and attenuated Peripheral visual field awareness during device use.

The intervention outcomes Provide strong evidence for the efficacy of the multimodal Physiotherapy Program. The 34.8% reduction in SCM-splenius capitis CCR ($d = 1.45$) and 38.5% reduction in COP sway area ($d = 1.22$) under Condition 3 represent large effect sizes that exceed minimal clinically important difference thresholds reported for comparable cervical rehabilitation studies.[14] Crucially, the improvement in CVA (43.1° to 48.2° ; $d = 1.32$) and CCFT Performance ($+2.4$ levels; $d = 1.57$) reflects meaningful structural and neuromuscular recovery, not merely task-specific adaptation. The observed decrease in fixation duration Post-intervention (350 to 318 ms; $d = 0.68$) suggests that gaze stabilization training Promotes more efficient visual scanning strategies, Potentially reducing attentional capture by smartPhone content and its downstream neuromuscular consequences.

The transfer of Postural improvements to Condition 2 (sway area reduction from 3.2 to 2.1 cm^2) is a Particularly important finding, demonstrating ecological validity of the training effects. Unlike conventional cervical Physiotherapy Programs that are Performed in Postural and visual isolation, the visual-Postural coordination component of this Program trained balance under conditions that replicated the sensorimotor demands of actual smartPhone use. This ecologically embedded approach appears to confer adaptive recalibration of the sensorimotor system rather than mere strengthening or flexibility gains.

From an Indian Public health Perspective, the results carry Particular relevance. The 78.3% Prevalence of FHP in this

sample (CVA $<50^\circ$) exceeds rates reported in Western university cohorts (45–62%), consistent with earlier Indian cross-sectional studies.[15] With over 750 million smartPhone users in India—Predominantly in the 18–35 age group—and a healthcare system where Physiotherapy services remain concentrated in urban tertiary settings, the development of brief, structured, evidence-based intervention Protocols that can be delivered in Primary care or community settings is a Priority. The 6-week, 18-session Program described here is feasible for delivery in outpatient Physiotherapy departments and may be adaptable to home-based or group formats with appropriate modifications.

Limitations

The study's cross-sectional design for the Primary comparison Prevents causal inference about the temporal development of CCR and Postural sway changes. The intervention arm lacked a Parallel randomized control group, limiting definitive attribution of outcomes to specific Program components. Laboratory-based force Plate measurements may not fully capture the Postural dynamics of habitual free-living smartPhone use. The Participant sample was drawn from a single university campus, potentially limiting generalizability to older Populations, occupational smartPhone users, or those with Pre-existing cervical Pathology. Future trials with randomized controlled designs, ambulatory sEMG and wearable inertial measurement units, and longer follow-up Periods are recommended.

CONCLUSION

This study demonstrates that smartPhone-induced near visual fixation significantly increases cervical agonist–antagonist co-contraction and impairs whole-body Postural stability, with effects amplified by concurrent forward head Posture. Eye-tracking Parameters—Particularly fixation duration—were meaningfully correlated with both cervical neuromuscular loading and COP sway, establishing visual behavior as a quantifiable and modifiable determinant of smartPhone-related sensorimotor dysfunction. The 6-week multimodal Physiotherapy Program, integrating gaze stabilization, deep cervical flexor training, and visual–Postural coordination tasks, Produced large clinically meaningful improvements in co-contraction

ratios, Postural stability, craniovertebral angle, and deep flexor endurance. These findings support the integration of visual system-oriented interventions into the standard Physiotherapeutic management of smartPhone-related cervicopostural dysfunction—a condition of growing Prevalence and Public health significance in India and globally.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

ETHICAL APPROVAL

Ethical clearance was obtained from the Institutional Ethics Committee (Ref: [MMCH & RI IEC/ PhD/ 03/ OCT / 23]). All Procedures conformed to the Declaration of Helsinki (2013 revision). Written informed consent was obtained from all Participants Prior to enrolment.

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