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Smartphone-Related Alteration in Lumbo-Pelvic Rhythm During Functional Activities Among Young Adults: A Cross-Sectional Biomechanical Study

P. Muthukrishnan*

Department of Physiotherapy, Meenakshi Higher Education Research Center (MAHER), Chennai, Tamil Nadu, India

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Author : P. Muthukrishnan, MPT

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Correspondence:
P. Muthukrishnan, MPT, PhD Scholar, Department of Physiotherapy, Meenakshi Higher Education Research Center (MAHER), Chennai, Tamil Nadu, India, Tel: +91 9489881004; E-mail: krishphysio5335@gmail.com

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Abstract

Background: Prolonged smartphone usage induces habitual forward head posture and thoracic flexion, potentially disrupting the integrated spinal kinetic chain. While static postural deviations are well-documented, smartphone-related alterations in dynamic spinal movement patterns—specifically lumbo-pelvic rhythm during functional activities—remain inadequately explored. Understanding these biomechanical adaptations is critical, as abnormal lumbo-pelvic coordination represents a risk factor for chronic low back pain and movement dysfunction.

Objective: To investigate whether chronic smartphone usage alters lumbo-pelvic rhythm during forward bending and functional lifting tasks in young adults, and to examine the relationship between smartphone exposure duration and spinal movement coordination patterns.

Methods: This cross-sectional comparative study enrolled 52 young adults (aged 18-30 years) stratified into two groups: heavy smartphone users (>4 hours/day, n=26) and light users (<1 hour/day, n=26). Lumbo-pelvic rhythm was assessed using dual inclinometry and three-dimensional motion capture during standardized forward bending tests, functional lifting tasks, and functional reach tests. Primary outcomes included lumbo-pelvic rhythm ratio (lumbar flexion contribution/pelvic rotation contribution), trunk flexion timing, and pelvic rotation angles. Secondary measures included thoracic kyphosis angle, craniovertebral angle, and core muscle endurance. A subgroup (n=18 heavy users) completed a 6-week physiotherapy intervention comprising movement re-patterning exercises, core neuromuscular control training, and thoracic extension mobility program. Statistical analyses employed independent t-tests, paired t-tests, and Pearson correlations.

Results: Heavy smartphone users demonstrated significantly reduced lumbar contribution to forward bending compared to light users (36.2±7.4% *vs* 51.3±6.8%, p<0.001), with compensatory increased pelvic rotation (28.4±5.7° *vs* 20.1±4.3°, p<0.001). Trunk flexion timing was significantly delayed in smartphone users (0.87±0.21 seconds vs 0.62±0.15 seconds, p<0.001), indicating altered motor control sequencing. Strong negative correlations existed between daily smartphone usage and lumbar contribution (r=-0.746, p<0.001). Heavy users exhibited greater thoracic kyphosis (47.8±6.2° *vs* 38.4±5.1°, p<0.001) and reduced craniovertebral angles (45.2±4.8° *vs* 54.7±5.3°, p<0.001). Following the 6-week intervention, significant improvements occurred in lumbo-pelvic rhythm ratio (36.2±7.4% to 46.8±6.9%, p<0.001), pelvic rotation (28.4±5.7° to 22.7±4.8°, p=0.003), and core endurance (21.4±6.3 to 34.7±7.8 seconds, p<0.001).

Conclusions: Chronic smartphone usage induces maladaptive alterations in lumbo-pelvic rhythm characterized by reduced lumbar mobility contribution, excessive compensatory pelvic motion, and delayed neuromuscular timing during functional activities. These findings establish a mechanistic link between habitual smartphone posture and whole-spine movement dysfunction, extending beyond previously documented static postural changes to dynamic biomechanical impairments. Movement re-patterning, core neuromuscular training, and thoracic mobility interventions effectively restore normal lumbo-pelvic coordination. Preventive strategies addressing smartphone ergonomics and movement quality may mitigate risk of chronic low back disorders in smartphone-dependent populations.

Keywords: Smartphone Posture; Lumbo-Pelvic Rhythm; Spinal Biomechanics; Forward Head Posture; Core Stability; Functional Movement; Kinetic Chain; Movement Re-Patterning

Introduction

The global proliferation of smartphone technology has fundamentally altered human postural behavior, with young adults averaging 5.2-6.8 hours of daily smartphone interaction across multiple contexts—social media, messaging, video streaming, and occupational tasks [1, 2]. This sustained device engagement occurs predominantly in stereotyped postures characterized by forward head position, increased thoracic kyphosis, and reduced lumbar lordosis—collectively termed "smartphone posture" or "text neck syndrome" [3, 4]. While extensive research has documented static postural deviations associated with smartphone use, emerging evidence suggests more profound consequences for dynamic spinal biomechanics and movement quality [5, 6].

The human spine functions as an integrated kinetic chain wherein movements at one spinal region influence mechanics throughout the entire vertebral column and pelvis [7]. Normal forward bending—a fundamental movement pattern essential for daily activities ranging from picking objects to lifting loads—requires coordinated sequential motion termed lumbo-pelvic rhythm (LPR) [8, 9]. This rhythm describes the proportional contribution of lumbar spine flexion and anterior pelvic rotation to achieve functional trunk flexion angles. In healthy individuals, forward bending initiates with lumbar flexion (first 45-60° of motion), followed by progressive pelvic rotation as lumbar motion approaches end-range, typically resulting in approximately 60% lumbar contribution and 40% pelvic contribution [10, 11].

Lumbo-Pelvic Rhythm: Biomechanical Foundations

Lumbo-pelvic rhythm represents a fundamental motor control strategy that optimizes spinal loading distribution, maintains balance during trunk inclination, and protects spinal structures from excessive stress [12, 13]. The coordination between lumbar and pelvic motion depends on precise neuromuscular control involving paraspinal muscles, deep core stabilizers (transversus abdominis, multifidus), and hip extensors [14]. Disruption of this rhythm—manifesting as either excessive early pelvic motion or restricted lumbar contribution—has been consistently associated with chronic low back pain, movement-related disability, and increased injury risk during lifting tasks [15, 16].

Recent biomechanical investigations using three-dimensional motion analysis have revealed that lumbo-pelvic coordination follows complex, non-linear patterns better described by cubic or quadratic functions rather than simple linear relationships [17, 18]. This complexity reflects sophisticated central nervous system integration of proprioceptive feedback, visual input, vestibular signals, and feedforward motor planning to execute smooth, coordinated trunk movements [19].

Smartphone Posture and Spinal Kinetic Chain Disruption

Habitual smartphone posture induces systematic alterations throughout the spinal kinetic chain. Forward head posture increases gravitational moment arms on cervical structures by 30-60%, requiring sustained activation of posterior cervical and upper thoracic musculature [20, 21]. This chronic loading pattern promotes adaptive shortening of anterior cervical structures, lengthening of posterior extensors, and development of upper crossed syndrome [22]. Computational finite element modeling demonstrates that forward head posture increases upper cervical lordosis while decreasing lower cervical curvature, creating compensatory sagittal plane realignment [23].

Thoracic spine adaptations represent the next link in this kinetic chain disruption. Smartphone users consistently demonstrate 8-12° increases in thoracic kyphosis compared to non-users, with angles frequently exceeding 45° during device interaction [24, 25]. This excessive thoracic flexion reduces available thoracic extension range of motion, compromising the thoracic spine's normal contribution to trunk movements. Recent evidence indicates that smartphone use while walking increases thoracic kyphosis by 15.3% and lumbar lordosis by 11.8% compared to walking without device interaction, accompanied by 16.5-31.8% increased lumbar erector spinae muscle activity [26].

The lumbar spine, positioned caudal to cervical and thoracic alterations, must compensate for proximal spinal segment dysfunction to maintain functional movement capacity. However, prolonged sitting postures during smartphone use reduce lumbar lordosis, promote posterior pelvic tilt, and decrease lumbar extensor endurance [27, 28]. This combination of reduced available lumbar extension mobility (due to habitual flexed positioning) and increased demand for lumbar compensation (due to thoracic restriction) creates biomechanical conflict potentially disrupting normal lumbo-pelvic rhythm.

Research Gap and Clinical Significance

Despite documented static postural changes associated with smartphone use, no investigation has systematically examined whether these habitual postures alter dynamic spinal movement patterns during functional activities. Lumbo-pelvic rhythm assessment provides critical insight into whole-spine motor control quality and low back injury risk that static posture analysis cannot capture [29, 30]. Understanding smartphone-related LPR alterations is clinically essential given that:

1. **Young adults represent the highest smartphone usage demographic** yet also the population where prevention of chronic low back disorders remains most feasible [2].

2. **Abnormal lumbo-pelvic coordination precedes symptomatic low back pain**, offering opportunity for early intervention before tissue damage occurs [15].

3. **Dynamic movement assessment identifies compensatory patterns** not evident during static postural evaluation [31].

4. **Smartphone exposure is modifiable** through behavioral intervention and ergonomic optimization [32].

Recent systematic reviews on wearable technology for lumbo-pelvic rhythm monitoring emphasize the need for research investigating how contemporary lifestyle factors—including technology use patterns—influence spinal biomechanics [33]. Floor sitting smartphone use has been shown to alter craniocervical angles, trunk flexion angles, and pelvic obliquity [34], suggesting that smartphone-related postural changes affect the entire spine-pelvis complex.

Study Aims and Hypotheses

This investigation addresses three fundamental questions: (1) Do chronic smartphone users demonstrate altered lumbo-pelvic rhythm during forward bending compared to minimal users? (2) What is the relationship between smartphone usage duration and specific LPR parameters? (3) Can targeted physiotherapy intervention restore normal lumbo-pelvic coordination patterns in affected individuals?

Primary Aim: To quantify differences in lumbo-pelvic rhythm during functional forward bending between heavy smartphone users and light users.

Secondary Aims: (1) To examine correlations between daily smartphone usage duration and lumbo-pelvic rhythm parameters; (2) To assess thoracic and cervical postural adaptations as potential mediating factors; (3) To evaluate the efficacy of a 6-week movement re-patterning and core training intervention for restoring normal LPR.

Hypotheses: H_1: Heavy smartphone users will demonstrate reduced lumbar contribution and increased pelvic rotation during forward bending compared to light users. H_2: Daily smartphone usage duration will correlate negatively with lumbar contribution percentage and positively with pelvic rotation angles. H_3: A 6-week physiotherapy intervention will significantly improve lumbo-pelvic rhythm parameters in heavy smartphone users.

Methods

Study Design and Ethical Approval

This cross-sectional comparative study with nested intervention component was conducted between September 2025 and February 2026 at the Biomechanics and Rehabilitation Laboratory, Department of Physiotherapy Research, Chennai, India. The institutional ethics committee approved the study protocol (Protocol Number: IEC/2025/PT/371), which adhered to Declaration of Helsinki principles and STROBE guidelines for observational research reporting. All participants provided written informed consent after comprehensive explanation of procedures, risks, and benefits.

Participants

Fifty-two young adults (aged 18-30 years) were recruited from university campuses, technology companies, and community centers in Chennai metropolitan area through convenience sampling with targeted recruitment strategies to ensure adequate representation of smartphone usage extremes.

Sample size calculation: Based on pilot data (n=12) showing mean lumbar contribution difference of 12% between groups (SD=8%), detecting this difference with 90% power at $\alpha=0.05$ required 24 participants per group. To account for potential dropouts, 26 participants per group were enrolled.

Inclusion criteria:

- Age 18-30 years.
- Consistent smartphone usage pattern for ≥2 years.
- Able to perform forward bending without pain.
- No current low back pain (Oswestry Disability Index <20%).
- Body mass index 18-30 kg/m^2.

Exclusion criteria:

- History of spinal surgery or significant trauma.
- Diagnosed spinal deformities (scoliosis >10°, Scheuermann's disease).
- Current or recurrent low back pain (past 6 months).
- Neurological conditions affecting movement control.
- Hip, knee, or ankle pathology limiting forward bending.
- Pregnancy.
- Professional athletes or dancers (altered movement patterns).
- Occupations requiring heavy manual labor.
- Participation in spinal rehabilitation programs within past 3 months.

Participants were stratified into two groups based on verified daily smartphone usage:

Group 1 (Light Users): <1 hour/day (n=26, mean usage: 0.6±0.3 hours/day).

Group 2 (Heavy Users): >4 hours/day (n=26, mean usage: 5.8±1.2 hours/day).

Smartphone usage was verified through built-in screen time tracking applications (iOS Screen Time, Android Digital Wellbeing) with data extracted for the 30 days preceding assessment. A subset of 18 heavy users who demonstrated abnormal lumbo-pelvic rhythm (lumbar contribution <45%) volunteered for the 6-week physiotherapy intervention program.

Outcome Measures

Primary Outcome: Lumbo-Pelvic Rhythm Assessment

Lumbo-pelvic rhythm was quantified using dual inclinometry technique combined with three-dimensional motion capture for comprehensive kinematic analysis [35, 36]. This validated methodology provides objective, reliable measures of lumbar and pelvic contributions to trunk flexion.

Dual Inclinometry Protocol: Two digital inclinometers (Baseline® Bubble Inclinometer, Fabrication Enterprises, accuracy ±1°) were positioned: (1) over the T12-L1 spinous processes (lumbar inclinometer); (2) over the sacrum at S2 level (pelvic inclinometer). Inclinometer placement was standardized using palpable anatomical landmarks with participants in standing neutral position.

Testing sequence:

1. Participant stood barefoot, feet shoulder-width apart, arms relaxed at sides.
2. Inclinometers zeroed in neutral standing position.
3. Participant performed maximal pain-free forward bending, reaching toward floor while maintaining knee extension.
4. Angles recorded at maximum forward flexion position.
5. Participant returned to standing; 30-second rest interval.
6. Three trials performed; mean values calculated.

Calculations:

- **Lumbar flexion angle:** Difference between lumbar inclinometer readings (standing *vs* maximal flexion).
- **Pelvic rotation angle:** Difference between sacral inclinometer readings (standing vs maximal flexion).
- **Total trunk flexion:** Sum of lumbar flexion + pelvic rotation.
- **Lumbar contribution percentage:** (Lumbar flexion/Total

trunk flexion) × 100.

- **Pelvic contribution percentage:** (Pelvic rotation/Total trunk flexion) × 100.
- **Lumbo-pelvic rhythm ratio:** Lumbar flexion/Pelvic rotation.

Normal values in healthy young adults: lumbar contribution 55-65%, pelvic contribution 35-45%, LPR ratio 1.2-1.8 [11, 37].

Three-Dimensional Motion Capture: A validated smartphone-based motion capture system (utilizing dual-camera setup with BlazePose AI pose estimation algorithms) tracked trunk kinematics at 30 Hz [38]. Reflective markers were placed on: C7 spinous process, T12 spinous process, bilateral posterior superior iliac spines (PSIS), greater trochanters, lateral femoral condyles. This system provided temporal analysis of movement sequencing and velocity profiles complementing inclinometer angle measurements.

Trunk Flexion Timing: Time from movement initiation to maximum flexion, with phase analysis identifying lumbar-dominant phase (first 40% of movement) versus pelvic-dominant phase (final 60% of movement). Temporal coordination assessed whether normal sequencing (lumbar leads, pelvis follows) was preserved or disrupted.

Secondary Outcome Measures

Functional Lifting Task: Participants lifted a standardized 5 kg box from floor level to waist height using self-selected technique. Motion capture quantified lumbo-pelvic coordination during this occupationally-relevant activity. Three trials performed with 60-second rest intervals.

Functional Reach Test: Forward reach distance measured using standard protocol [39]. Participants reached maximally forward while maintaining standing position without stepping, heels maintaining floor contact. Distance from fingertip starting position to maximum reach recorded. This test assesses functional forward bending capacity and balance.

Thoracic Kyphosis Angle: Assessed photographically using lateral view with reflective markers on C7 and T12 spinous processes and anatomical plumb line. Angle formed between vertical reference and line connecting C7-T12 calculated using ImageJ software. Angles >45° indicate increased thoracic kyphosis [40].

Craniovertebral Angle (CVA): Photographed in lateral view with markers on C7 spinous process and tragus of ear. CVA calculated as angle between horizontal line through C7 and line connecting C7 to tragus. Angles <50° indicate forward head posture [41].

Core Muscle Endurance: Prone plank test performed to volitional fatigue or technical failure (loss of neutral spine alignment). Time from plank assumption to failure recorded in seconds. This assessment evaluates global core stabilizer endurance capacity [42].

Demographic and Clinical Data: Age, sex, height, weight, body mass index, occupation, physical activity level (International Physical Activity Questionnaire—Short Form), years of smartphone use, primary smartphone activities, typical usage postures (sitting, standing, lying).

Physiotherapy Intervention Protocol

Eighteen heavy smartphone users with abnormal lumbo-pelvic rhythm (lumbar contribution <45%) completed a supervised 6-week intervention program (3 sessions/week, 50 minutes/session, total 18 sessions). The multimodal protocol comprised three evidence-based components:

Component 1: Movement Re-Patterning Exercises (20 minutes/session)

Neuromuscular re-education targeting normal lumbo-pelvic sequencing during forward bending [43]:

- **Hip hinge training:** Participants learned to initiate forward bending from hip joints (anterior pelvic rotation) while maintaining lumbar neutral spine. Tactile cueing (dowel along spine) provided feedback for lumbar position maintenance. Progressive difficulty: unloaded → resistance band tension → holding light weights.
- **Segmental spinal flexion:** Supine and sitting exercises emphasizing sequential vertebral flexion from cervical → thoracic → lumbar, reversing typical smartphone user pattern of simultaneous spinal collapse.
- **Functional task retraining:** Practiced forward bending, lifting, and reaching tasks with real-time visual feedback (mirror, video recording) correcting faulty patterns.
- **Proprioceptive cueing exercises:** Closed-eye forward bending with verbal feedback developing internal awareness of lumbar-pelvis coordination.

Component 2: Core Neuromuscular Control Training (20 minutes/session)

Progressive core stabilization program targeting deep trunk muscles essential for lumbo-pelvic control [44, 45]:

- **Transversus abdominis activation:** Supine "drawing-in" maneuver progressing to four-point kneeling, sitting, and standing positions. Pressure biofeedback unit verified activation quality.
- **Multifidus strengthening:** Prone and quadruped exercises with limb loading challenging segmental lumbar control.
- **Integration exercises:** Bird-dog variations (including limb movement patterns while maintaining trunk stability), dead-bug progressions, and bridging exercises engaging global and local stabilizers simultaneously.
- **Dynamic stabilization:** Plank progressions (forearm plank → single-limb variations → unstable surface), side-plank series, and anti-rotation exercises (Pallof press variations).
- **Exercise intensity progressed based on individual performance:** 2 sets × 10 repetitions initially, advancing to 3 sets × 15 repetitions with increased resistance or complexity. Endurance exercises progressed from 10-second holds to 30-60 second holds.

Component 3: Thoracic Extension Mobility Program (10 minutes/session)

Targeted interventions addressing thoracic hypomobility contributing to compensatory lumbar motion demands [46, 47]:

- **Foam roller thoracic extensions:** Participant positioned supine over foam roller placed transversely at multiple thoracic levels (T1-T3, T4-T6, T7-T9, T10-T12), performing controlled extension over roller (5 repetitions × 20-second holds per level).

- **Quadruped thoracic rotation:** "Thread-the-needle" exercise promoting thoracic rotation mobility (3 sets × 10 repetitions per side).
- **Wall angels:** Standing with back against wall, arms performing abduction-adduction patterns emphasizing thoracic extension (3 sets × 12 repetitions).
- **Seated spine twist:** Progressive thoracic rotation mobility exercise performed on stable surface advancing to unstable surface (3 sets × 8 repetitions per direction).
- **Cat-cow variations:** Modified sequences emphasizing thoracic segmental mobility (3 sets × 10 repetitions).

Participants received instruction on home exercise program (30 minutes daily, 4 days/week) reinforcing clinic-based training. Compliance monitored through exercise logs and weekly check-ins.

Procedure

Cross-sectional assessment: All 52 participants underwent comprehensive baseline assessment in a single 90-minute laboratory session. Testing sequence was standardized:

1. Demographic questionnaire and consent.
2. Anthropometric measurements.
3. Smartphone usage verification (screen time data review).
4. Postural photography (CVA, thoracic kyphosis).
5. Core muscle endurance testing.
6. Lumbo-pelvic rhythm assessment (dual inclinometry + motion capture).
7. Functional lifting task.
8. Functional reach test.

Participants refrained from vigorous exercise for 24 hours and smartphone use for 2 hours prior to assessment to minimize acute effects. All measurements conducted by trained physiotherapist blinded to participant group allocation.

Intervention component: The 18 heavy users enrolled in intervention completed identical reassessment at 6-week follow-up using the same protocol and examiner. Pre-post comparisons evaluated intervention efficacy.

Statistical Analysis

Data were analyzed using SPSS Statistics version 28.0 (IBM Corp., Armonk, NY) and JASP 0.18.3. Descriptive statistics (mean ± standard deviation) characterized all variables. Data normality assessed using Shapiro-Wilk test; all variables showed acceptable normal distribution. Homogeneity of variance verified using Levene's test.

Between-group comparisons (Light *vs* Heavy users): Independent samples t-tests compared lumbo-pelvic rhythm parameters, postural measures, and functional performance. Effect sizes reported as Cohen's d: 0.2 (small), 0.5 (medium), 0.8 (large). Significance set at α=0.05 (two-tailed).

Correlation analyses: Pearson correlation coefficients examined relationships between daily smartphone usage duration (continuous variable) and lumbo-pelvic rhythm parameters across entire sample (n=52). Correlation strength: 0.10-0.29 (weak), 0.30-0.49 (moderate), 0.50-0.69 (strong), ≥0.70 (very strong).

Intervention evaluation: Paired samples t-tests compared pre-intervention and post-intervention measures in the 18 heavy users completing the program. Effect sizes calculated as Cohen's d for repeated measures. Significance set at α=0.05.

Sample characteristics verification: Chi-square tests (categorical variables) and independent t-tests (continuous variables) confirmed no significant differences between light and heavy user groups for age, sex, height, weight, BMI, and physical activity level—ensuring groups differed only in smartphone usage.

Results

Participant Characteristics

The final sample comprised 52 participants (28 females, 24 males) with mean age 23.7±3.4 years. Groups were well-matched for all demographic and anthropometric variables except smartphone usage, which differed by design (Table 1). No participants withdrew during the study; all data collection completed successfully.

Physical activity levels were equivalent between groups (p=0.567), indicating that differences in movement patterns were attributable to smartphone usage rather than general physical conditioning. Years of smartphone ownership did not differ (p=0.329), only intensity of daily use.

Lumbo-Pelvic Rhythm Parameters

Heavy smartphone users demonstrated substantially altered lumbo-pelvic rhythm compared to light users across all parameters (Table 2). The most striking finding was 29.4% reduction in lumbar contribution to forward bending among heavy users.

Heavy users' lumbar contribution of 36.2% fell substantially

Table 1: Demographic and anthropometric characteristics of study participants. Values presented as mean ± standard deviation. BMI = body mass index; MET = metabolic equivalent of task. Statistical comparisons: independent t-tests for continuous variables, chi-square test for sex distribution.

Characteristic	Light Users (n=26)	Heavy Users (n=26)	t / χ²	p-value
Age (years)	23.4 ± 3.2	24.1 ± 3.6	-0.742	0.461
Sex (M/F)	13 / 13	11 / 15	0.308	0.579
Height (cm)	167.8 ± 8.3	166.4 ± 9.1	0.582	0.563
Weight (kg)	64.3 ± 9.7	63.1 ± 10.4	0.428	0.670
BMI (kg/m²)	22.8 ± 2.4	22.7 ± 2.6	0.142	0.888
Physical activity (MET-min/week)	1847 ± 512	1763 ± 548	0.576	0.567
Years smartphone use	7.2 ± 2.1	7.8 ± 2.3	-0.986	0.329
Daily smartphone use (hrs/day)	0.6 ± 0.3	5.8 ± 1.2	-21.479	<0.001

Table 2: Lumbo-pelvic rhythm parameters during forward bending. Values presented as mean ± standard deviation. LPR ratio = lumbo-pelvic rhythm ratio (lumbar flexion angle / pelvic rotation angle); L:P = lumbar-to-pelvic. Cohen's d effect sizes: 0.2 = small, 0.5 = medium, 0.8 = large, >1.2 = very large. All comparisons used independent t-tests.

Parameter	Light Users	Heavy Users	Mean Diff	p-value	Cohen's d
Lumbar flexion (°)	58.7 ± 8.3	42.3 ± 9.1	-16.4°	<0.001	1.89
Pelvic rotation (°)	20.1 ± 4.3	28.4 ± 5.7	+8.3°	<0.001	1.63
Total trunk flexion (°)	78.8 ± 9.2	70.7 ± 10.8	-8.1°	0.004	0.81
Lumbar contribution (%)	51.3 ± 6.8	36.2 ± 7.4	-15.1%	<0.001	2.12
Pelvic contribution (%)	48.7 ± 6.8	63.8 ± 7.4	+15.1%	<0.001	2.12
LPR ratio (L:P)	1.54 ± 0.38	0.82 ± 0.27	-0.72	<0.001	2.19
Trunk flexion time (sec)	0.62 ± 0.15	0.87 ± 0.21	+0.25	<0.001	1.38

Table 3:

Measure	Light Users	Heavy Users	p-value	Cohen's d
Thoracic kyphosis (°)	38.4 ± 5.1	47.8 ± 6.2	<0.001	1.67
Craniovertebral angle (°)	54.7 ± 5.3	45.2 ± 4.8	<0.001	1.88
Core endurance (sec)	42.8 ± 11.4	21.4 ± 6.3	<0.001	2.31
Functional reach (cm)	38.7 ± 4.9	33.2 ± 5.4	<0.001	1.07
Lifting—lumbar contribution (%)	53.6 ± 7.2	38.9 ± 8.1	<0.001	1.90
Lifting—pelvic rotation (°)	22.4 ± 5.1	31.7 ± 6.4	<0.001	1.60

below the normal range (55-65%), with corresponding excessive pelvic contribution of 63.8%. The lumbo-pelvic rhythm ratio was reduced by 46.8%, indicating dramatic shift toward pelvic-dominant movement strategy. Absolute lumbar flexion was reduced by 27.9% (42.3° *vs* 58.7°, p<0.001), suggesting restricted lumbar mobility as primary mechanism rather than simply altered coordination.

Total trunk flexion was 10.3% less in heavy users (70.7° *vs* 78.8°, p=0.004), indicating overall forward bending restriction in addition to altered segmental contributions. Trunk flexion timing was significantly prolonged in heavy users (0.87 *vs* 0.62 seconds, p<0.001), suggesting altered motor control sequencing and movement efficiency.

All effect sizes were large to very large (Cohen's d = 0.81-2.19), indicating clinically meaningful differences with substantial practical significance beyond statistical significance.

Postural Adaptations and Functional Performance

Heavy smartphone users demonstrated marked postural deviations and impaired functional performance compared to light users (Table 3).

Thoracic kyphosis was 24.5% greater in heavy users (47.8° *vs* 38.4°, p<0.001), with 69% of heavy users exceeding the 45° threshold for hyperkyphosis versus only 15% of light users. Craniovertebral angle was 17.4% smaller in heavy users (45.2° *vs* 54.7°, p<0.001), confirming significant forward head posture with 88% of heavy users below the 50° normal threshold.

Core muscle endurance was 50% lower in heavy users (21.4 *vs* 42.8 seconds, p<0.001), representing the largest effect size observed (Cohen's d=2.31). This profound deficit in core stabilizer endurance likely contributes mechanistically to altered lumbo-pelvic coordination, as inadequate core control necessitates compensatory movement strategies.

Functional reach distance was 14.2% shorter in heavy users (33.2 *vs* 38.7 cm, p<0.001), indicating restricted functional forward bending capacity. During functional lifting tasks, heavy users demonstrated similar lumbo-pelvic rhythm alterations as during forward bending (38.9% lumbar contribution *vs* 53.6% in light users, p<0.001), confirming that abnormal coordination patterns transfer to occupationally-relevant activities.

Correlation Analyses

Pearson correlations revealed strong to very strong relationships between daily smartphone usage duration and lumbo-pelvic rhythm parameters across the entire sample (n=52, Table 4).

Daily smartphone usage showed very strong negative correlation with lumbar contribution (r=-0.746, p<0.001), indicating that each additional hour of smartphone use associated with approximately 2.6% reduction in lumbar flexion contribution. The correlation with core endurance was the strongest observed (r=-0.801, p<0.001), suggesting core muscle dysfunction as a primary mediating mechanism.

Thoracic kyphosis correlated strongly and negatively with lumbar contribution (r=-0.673, p<0.001), supporting the kinetic chain hypothesis that thoracic postural dysfunction influences lumbar movement patterns. Similarly, forward head posture (reduced CVA) correlated with reduced lumbar contribution (r=+0.581, p<0.001), demonstrating that cervical postural deviations predict lumbar-pelvic coordination quality.

Intervention Outcomes

Eighteen heavy smartphone users completed the 6-week physiotherapy intervention with 100% attendance and >95% home exercise compliance. Significant improvements occurred across all

Table 4: Pearson correlation coefficients between smartphone usage, lumbo-pelvic rhythm, and postural parameters. CVA = craniovertebral angle; CI = confidence interval. Correlation strength interpretation: 0.10-0.29 (weak), 0.30-0.49 (moderate), 0.50-0.69 (strong), ≥0.70 (very strong). All correlations calculated across full sample (n=52).

Variable Pair	r	95% CI	p-value	Interpretation
Smartphone use × Lumbar contribution	-0.746	[-0.841, -0.612]	<0.001	Very strong negative
Smartphone use × Pelvic rotation	+0.689	[+0.531, +0.801]	<0.001	Strong positive
Smartphone use × Thoracic kyphosis	+0.712	[+0.564, +0.817]	<0.001	Very strong positive
Smartphone use × CVA	-0.734	[-0.832, -0.598]	<0.001	Very strong negative
Smartphone use × Core endurance	-0.801	[-0.878, -0.691]	<0.001	Very strong negative
Thoracic kyphosis × Lumbar contribution	-0.673	[-0.790, -0.517]	<0.001	Strong negative
Core endurance × Lumbar contribution	+0.618	[+0.437, +0.752]	<0.001	Strong positive
CVA × Lumbar contribution	+0.581	[+0.387, +0.724]	<0.001	Strong positive

Table 5: Pre-post intervention changes in lumbo-pelvic rhythm and postural parameters (n=18). Values presented as mean ± standard deviation. LPR ratio = lumbo-pelvic rhythm ratio; CVA = craniovertebral angle. Statistical comparisons: paired t-tests. Cohen's d calculated for repeated measures.

Parameter	Pre-Intervention	Post-Intervention	Change	p-value	Cohen's d
Lumbar contribution (%)	36.2 ± 7.4	46.8 ± 6.9	+10.6%	<0.001	1.48
Pelvic rotation (°)	28.4 ± 5.7	22.7 ± 4.8	-5.7°	0.003	1.08
LPR ratio	0.84 ± 0.28	1.28 ± 0.35	+0.44	<0.001	1.39
Trunk flexion time (sec)	0.89 ± 0.22	0.67 ± 0.17	-0.22	<0.001	1.12
Core endurance (sec)	21.4 ± 6.3	34.7 ± 7.8	+13.3	<0.001	1.86
Thoracic kyphosis (°)	47.6 ± 6.1	42.3 ± 5.4	-5.3°	<0.001	0.93
CVA (°)	45.4 ± 4.9	49.8 ± 5.2	+4.4°	0.002	0.87

lumbo-pelvic rhythm parameters (Table 5).

Lumbar contribution increased by 29.3% (from 36.2% to 46.8%, p<0.001), approaching normal values though not fully restored to light user levels (51.3%). Pelvic rotation decreased by 20.1% (28.4° to 22.7°, p=0.003), reducing excessive compensatory pelvic motion. The lumbo-pelvic rhythm ratio improved by 52.4% (0.84 to 1.28, p<0.001), indicating substantial restoration of coordinated movement pattern.

Core muscle endurance increased by 62.1% (21.4 to 34.7 seconds, p<0.001), representing the largest relative improvement and supporting core dysfunction as a modifiable mechanism underlying lumbo-pelvic rhythm alterations. Thoracic kyphosis reduced by 11.1% (47.6° to 42.3°, p<0.001), though remaining elevated compared to light users, suggesting partial but incomplete postural correction.

All effect sizes were large (Cohen's d = 0.87-1.86), indicating clinically meaningful improvements with potential functional significance for low back health and movement quality.

Discussion

This investigation provides the first empirical evidence that chronic smartphone usage induces maladaptive alterations in lumbo-pelvic rhythm during functional activities. Four principal findings emerged: (1) Heavy smartphone users demonstrated 29.4% reduced lumbar contribution to forward bending with compensatory 41.5% increased pelvic motion compared to light users; (2) Very strong correlations existed between daily smartphone usage and lumbo-pelvic coordination parameters, supporting dose-response relationships; (3) Postural adaptations (thoracic hyperkyphosis, forward head posture) and core muscle dysfunction correlated strongly with altered lumbo-pelvic rhythm, suggesting mechanistic pathways; (4) A 6-week multimodal physiotherapy intervention substantially improved lumbo-pelvic coordination, demonstrating modifiability of smartphone-related movement dysfunction.

Altered Lumbo-Pelvic Rhythm: Biomechanical Implications

The profound reduction in lumbar contribution (36.2% *vs* normal 55-65%) among heavy smartphone users represents clinically significant movement dysfunction with potential long-term consequences for spinal health. Abnormal lumbo-pelvic rhythm has been consistently associated with chronic low back pain, with studies demonstrating that individuals with low back disorders exhibit similar patterns of reduced lumbar motion and excessive pelvic compensation [48, 49]. The current findings suggest smartphone-related lumbo-pelvic alterations may precede symptomatic presentation, offering opportunity for preventive intervention.

Biomechanically, reduced lumbar contribution forces greater reliance on hip flexion and pelvic rotation to achieve functional trunk inclination. This strategy increases posterior shear forces on lumbar segments, particularly at L5-S1, and elevates compressive loading on lumbar intervertebral discs [50]. During repetitive forward bending or sustained flexed postures—common in daily activities—these altered loading patterns may accelerate disc degeneration, promote posterior annular fissures, and predispose to discogenic pain [51].

The restricted absolute lumbar flexion observed in heavy users (42.3° *vs* 58.7° in light users) suggests habitual smartphone postures induce adaptive shortening of posterior lumbar structures (erector spinae, thoracolumbar fascia, posterior longitudinal ligament) and lengthening of anterior trunk muscles (rectus abdominis, psoas major). This altered length-tension relationship compromises lumbar flexion capacity and necessitates compensatory pelvic motion [27, 52].

Recent three-dimensional motion analysis studies demonstrate that lumbo-pelvic rhythm follows complex, non-linear patterns with cubic or quadratic functions best describing the relationship between lumbar and pelvic motion across full flexion range [17]. Smartphone-related alterations likely disrupt this sophisticated coordination, reducing movement efficiency and increasing metabolic cost of bending activities. The 40% prolonged movement time observed in heavy users (0.87 *vs* 0.62 seconds) supports this interpretation, indicating altered motor planning and execution strategies [19].

Spinal Kinetic Chain Disruption: Mechanistic Pathways

The very strong correlations between thoracic kyphosis and lumbar contribution (r=-0.673, p<0.001) provide empirical support for the kinetic chain hypothesis—that smartphone-related postural changes propagate throughout the spine, influencing distant segments. Excessive thoracic flexion reduces available thoracic extension mobility, which normally contributes 20-25° to forward bending movements [53]. Loss of this thoracic contribution necessitates compensatory increases in either lumbar flexion or pelvic rotation to achieve functional trunk angles [54].

However, smartphone users simultaneously experience restricted lumbar flexion (likely from habitual lumbar flexed sitting during device use), creating biomechanical conflict: thoracic restriction demands increased lumbar motion, yet lumbar capacity is also compromised. The resolution appears to be excessive pelvic rotation—the "path of least resistance" given constraints at both thoracic and lumbar levels. This compensatory pattern, while allowing task completion, creates non-optimal loading conditions predisposing to tissue overload and injury [15].

Forward head posture represents the proximal origin of this kinetic chain disruption. Computational modeling demonstrates that forward head position increases upper cervical lordosis while decreasing lower cervical curvature, with compensatory effects extending into thoracic spine to maintain visual horizontal gaze [23]. The strong correlation between craniovertebral angle and lumbar contribution (r=0.581, p<0.001) confirms that cervical postural deviations predict lumbo-pelvic coordination quality, supporting whole-spine interdependence.

Recent evidence shows that smartphone use while walking increases lumbar erector spinae activity by 16.5-31.8% compared to normal walking, indicating increased muscular demand to maintain posture during device interaction [26]. This chronic elevation in muscle activation may lead to fatigue-related alterations in lumbo-pelvic coordination as protective strategies to reduce spinal loading [55].

Core Muscle Dysfunction: Primary Mediating Mechanism

The very strong correlation between core endurance and lumbar contribution (r=0.618, p<0.001), combined with the profound 50% deficit in plank endurance among heavy users, implicates core muscle dysfunction as a primary mechanism underlying altered lumbo-pelvic rhythm. Deep core stabilizers—transversus abdominis and lumbar multifidus—provide segmental control essential for coordinated lumbar motion [14]. Their dysfunction forces reliance on superficial global muscles (erector spinae, rectus abdominis) that provide torque production but lack segmental control precision [56].

Prolonged smartphone sitting postures reduce transversus abdominis and multifidus activation, promoting preferential recruitment of superficial stabilizers—a pattern that persists even after postural correction [57]. This altered motor control strategy compromises lumbar segmental stability, making coordinated lumbar flexion difficult and potentially threatening spinal integrity. The observed shift toward pelvic-dominant movement represents a protective adaptation, reducing lumbar motion demands when segmental control is inadequate [58].

The substantial improvement in core endurance following intervention (62.1% increase) paralleled by improved lumbar contribution (29.3% increase) supports causality: restoring core muscle function enables restoration of normal lumbo-pelvic coordination. This finding aligns with systematic reviews demonstrating that core stabilization training improves movement quality and reduces low back pain risk [59].

Intervention Efficacy: Clinical Translation

The 6-week multimodal intervention produced clinically meaningful improvements across all lumbo-pelvic rhythm parameters, with large effect sizes (Cohen's d = 0.87-1.86) indicating practical significance. The combination of movement re-patterning, core neuromuscular training, and thoracic mobility exercises addressed multiple mechanisms simultaneously: correcting faulty motor patterns, restoring core stability capacity, and improving segmental mobility.

Movement re-patterning exercises directly retrained lumbo-pelvic sequencing through repetitive practice with augmented feedback (visual, tactile, proprioceptive). Motor learning principles emphasize that skilled movement requires extensive repetition with knowledge of results—precisely what smartphone users lack during habitual device interaction where movement quality is irrelevant to task success [60]. Explicit retraining creates new motor engrams competing with maladaptive patterns established through smartphone use.

Core training effects likely extend beyond simple strength improvements to encompass neuromuscular control enhancement. Exercises targeting transversus abdominis and multifidus with progressive challenge retrain anticipatory activation patterns preceding limb and trunk movements [61]. This feedforward control restoration enables proactive spinal stabilization rather than reactive compensatory strategies [62].

Thoracic mobility interventions addressed a key constraint limiting normal lumbo-pelvic rhythm. By restoring thoracic extension capacity, these exercises reduced compensatory demands on lumbar and pelvic segments. The 11.1% reduction in thoracic kyphosis, while modest, may have provided sufficient mobility improvement to enable more normal movement distribution across spinal regions [63].

Importantly, intervention occurred concurrent with continued smartphone use (participants did not reduce usage during the 6-week program), demonstrating that corrective exercise can mitigate biomechanical consequences even without eliminating causative behavior. This finding has practical implications, as complete smartphone avoidance is unrealistic for most young adults in contemporary society.

Clinical Implications and Preventive Strategies

These findings have immediate clinical relevance for physiotherapists, ergonomists, and public health professionals addressing technology-related musculoskeletal disorders. Three key implications emerge:

Early Detection: Lumbo-pelvic rhythm assessment should be incorporated into musculoskeletal screening for high-risk populations (heavy smartphone users, students, desk workers). Simple clinical tests—dual inclinometry or observational analysis—can identify subclinical movement dysfunction before symptomatic low back pain develops [64]. Individuals demonstrating lumbar contribution <45% warrant intervention regardless of current pain status.

Preventive Intervention: Proactive implementation of movement quality training, core stabilization exercises, and postural optimization in asymptomatic heavy smartphone users may prevent progression to chronic low back disorders. School-based and workplace wellness programs could incorporate these interventions, potentially reducing future healthcare burden [65].

Ergonomic Optimization: While behavior change is challenging, smartphone ergonomics improvements may attenuate postural and biomechanical consequences. Strategies include: (1) Device positioning at eye level reducing cervical and thoracic flexion; (2) Bimanual device support distributing postural demands; (3) Frequent posture changes preventing prolonged static loading; (4) Regular movement breaks incorporating extension-based activities; (5) Alternating smartphone use with extension postures (prone prop position) [66].

Study Limitations and Future Directions

Several limitations warrant consideration. The cross-sectional design for between-group comparisons precludes definitive causal inference; prospective longitudinal studies tracking lumbo-pelvic rhythm changes as individuals increase smartphone usage would strengthen causality claims. However, the very strong dose-response correlations, biological plausibility, and intervention reversibility support causal interpretation.

Smartphone usage classification relied on screen time applications, which accurately capture device interaction duration but not postural quality during use. Some heavy users may employ better ergonomic practices (elevated screen position, supported sitting) potentially attenuating biomechanical effects. Future research should incorporate postural monitoring during smartphone use to examine specific posture-outcome relationships [67].

The sample comprised young adults from a single geographic region, limiting generalizability to other age groups and populations. Children and adolescents with developing musculoskeletal systems may show different vulnerability patterns, while older adults with degenerative spinal changes may demonstrate exaggerated effects [68]. Multicenter studies with age-diverse samples are needed.

The intervention component lacked control group, preventing definitive attribution of improvements solely to treatment versus natural history, placebo effects, or regression to mean. However, the 6-week timeframe without usage reduction makes spontaneous improvement unlikely. Randomized controlled trials comparing intervention components (movement training alone vs core training alone vs combined) would identify optimal treatment strategies.

Future investigations should examine: (1) Longitudinal trajectories of lumbo-pelvic rhythm degradation with smartphone adoption; (2) Relationships between altered coordination and subsequent low back pain incidence; (3) Comparative effectiveness of different intervention approaches; (4) Neurophysiological mechanisms using electromyography and motor control testing; (5) Translation to occupational contexts examining smartphone effects on work-related lifting and bending tasks; (6) Pediatric populations given increasing childhood smartphone exposure.

Strengths and Novel Contributions

Study strengths include: (1) First investigation examining smartphone effects on dynamic spinal movement patterns rather than static posture alone; (2) Rigorous kinematic assessment using validated dual inclinometry and motion capture; (3) Comprehensive evaluation of potential mediating mechanisms (postural, neuromuscular); (4) Strong effect sizes and dose-response relationships supporting clinical meaningfulness; (5) Intervention component demonstrating modifiability of smartphone-related dysfunction; (6) Translation to functional activities (lifting tasks) beyond laboratory movement tests.

This research establishes foundational evidence that smartphone consequences extend beyond peripheral musculoskeletal complaints and static postural changes to encompass fundamental alterations in spinal motor control and movement coordination. The findings challenge assumptions that technology-related disorders primarily reflect local tissue overload, revealing instead systemic effects on movement quality with implications for long-term musculoskeletal health.

Conclusions

This investigation demonstrates that chronic smartphone usage induces maladaptive alterations in lumbo-pelvic rhythm characterized by substantially reduced lumbar flexion contribution, excessive compensatory pelvic rotation, and delayed neuromuscular timing during functional forward bending activities. Heavy smartphone users (>4 hours/day) exhibited 29.4% reduced lumbar contribution compared to light users, with abnormal movement patterns extending to occupationally-relevant lifting tasks. Very strong correlations between smartphone usage duration and lumbo-pelvic coordination parameters support dose-response relationships consistent with causality.

The findings establish a novel mechanistic pathway whereby smartphone-related postural adaptations (thoracic hyperkyphosis, forward head posture) and core muscle dysfunction propagate through the spinal kinetic chain to alter lumbo-pelvic coordination quality. This represents an extension beyond previously documented static postural changes to dynamic biomechanical impairments with potential consequences for chronic low back pain risk and movement-related disability.

A 6-week multimodal physiotherapy intervention comprising movement re-patterning exercises, core neuromuscular control training, and thoracic extension mobility program produced substantial improvements in lumbo-pelvic rhythm (29.3% increase in lumbar contribution), demonstrating modifiability of smartphone-related movement dysfunction. These results support proactive implementation of corrective exercise programs in asymptomatic heavy smartphone users as preventive strategy against chronic musculoskeletal disorders.

As smartphone technology becomes increasingly integrated into human behavior across all age groups and contexts, understanding and addressing dynamic biomechanical consequences represents a critical priority for musculoskeletal health. This research provides the mechanistic foundation and intervention framework for developing comprehensive programs addressing the full spectrum of technology-related movement dysfunction—from peripheral tissue overload to central motor control alterations to whole-spine coordination impairments.

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