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EFFECTS OF PROPRIOCEPTIVE NEUROMUSCULAR FACILITATION COMBINED WITH REAL-TIME SMARTPHONE ERGONOMIC MONITORING ON PAIN, CERVICAL RANGE OF MOTION, DISABILITY, AND FORWARD HEAD POSTURE IN PHYSIOTHERAPISTS WITH TEXT NECK SYNDROME: A RANDOMIZED CONTROLLED TRIAL

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Abstract

Text Neck Syndrome (TNS) results from sustained postural asymmetry due to the use of handheld devices. Physiotherapists are at an increased risk of developing TNS from personal and professional smartphone use. Although various interventions exist to manage TNS, to the authors' knowledge, no published trial has examined a combined neuromuscular and real-time behavioral-feedback approach in physiotherapists with TNS.

Aims: *The aim of this study was to evaluate the impact of real-time smartphone ergonomic monitoring on the implementation of the Proprioceptive Neuromuscular Facilitation (PNF) technique on pain, cervical range of motion (ROM), disability and forward head posture in physiotherapists with TNS.*

Design: *This study was an assessor-blinded parallel-group randomized controlled trial, conducted in accordance with the CONSORT 2010 statement.*

Methods: *Sixty-six physiotherapists were recruited. Inclusion criteria was a craniovertebral angle (CVA) < 50°, Numeric Pain Rating Scale (NPRS) ≥ 3 and Neck Disability Index (NDI) ≥ 10. Participants were randomized to Group A (n = 33) to receive PNF combined with a smartphone ergonomic monitoring application, or to Group B (n = 33) to receive PNF only. PNF was delivered 3 times a week for 8 weeks. Groups were assessed by the same outcome assessors who were blind to group allocation. Primary outcomes were pain and cervical ROM assessed by a goniometer. The secondary outcomes were NDI and CVA (photographic analysis).*

Outcomes were assessed at baseline, 4 weeks and 8 weeks. Analyses of variance (ANOVA) were performed to assess within-group change and independent samples t-tests to assess between group changes ($p < 0.05$).

Results: *Sixty-three participants (Group A, $n = 31$; Group B, $n = 32$) completed the trial and were analyzed according to the protocol. Within-group analyses demonstrated significant improvements of all nine outcomes ($p < .001$). At week eight, Group A demonstrated more improvement than Group B in pain (NPRS 2.33 ± 1.49 vs. 3.94 ± 1.57; $p < .001$, $d = -1.05$), neck disability (NDI 12.44 ± 3.33 vs. 17.06 ± 5.55; $p < .001$, $d = -1.01$), craniovertebral angle (49.93° ± 3.08 vs. 46.88° ± 3.23; $p < .001$, $d = 0.97$), cervical extension ($p = .010$, $d = 0.68$), left lateral flexion ($p = .012$, $d = 0.65$), and left rotation ($p = .002$, $d = 0.82$). Differences in flexion, right lateral flexion and right rotation, favored Group A, and were not significant. Because cervical flexion differed between groups at baseline ($p = .038$), supplementary baseline-adjusted analyses were added; after adjustment, differences favored Group A in all six movement directions.*

Conclusion: *The addition of real-time smartphone ergonomic monitoring to a traditional PNF protocol improved pain, disability, and craniovertebral angle and a range of cervical movements in a group of physiotherapists with Text Neck Syndrome more than PNF alone. The results encouraged the author to combine Continuous Behavioral Feedback and Neuromuscular Rehabilitation for the management of occupational TNS.*

Ethics approval: *IRB, The Superior University, Lahore (Ref. IRB/FAHS/REHAB/04/26/MS/RS-4020).*

Introduction

The repetitive use of digital devices such as smartphones is a growing health concern as it can lead to musculoskeletal disorders, most notably cervical pain, also known as "Text Neck Syndrome" (TNS). Four out of five users, and especially younger users, keep their phone within reach all but a few hours each day, and the worldwide smartphone user population is estimated to have reached 3.6 billion in 2020 and continues to increase (1). The musculoskeletal consequences of repetitive digital device use disproportionally affects the neck and upper back, and has been associated with poor sleep and social withdrawal as well as other behavioral and psychological consequences (2).

The forward head and neck position, which is common when using a digital device, has been analyzed by Hansraj, who concluded that the weight of the head, which on average is approximately 5 kg, can increase to nearly 27 kg when the head is forward by approximately 60° as is common when looking at a handheld digital device. Hansraj's research demonstrated a nearly 6-fold increase in the load on the cervical spine (3). TNS describes the muscular and soft tissue injuries and imbalances as well as the degenerative changes of the cervical spine that occur due to repetitive digital device use. In terms of clinical presentation, TNS is characterized by chronic, upper neck and upper back pain, muscular fatigue and imbalance, and, in more advanced cases, neurological symptoms (i.e. disc herniation, arm/leg pain, numbness, and tingling, as well as headaches). The unmanaged physical symptoms of TNS often progress to the point that they coincide with the psychosocial symptoms of excessive device dependence (4). This is especially problematic for physiotherapists, as they are frontline healthcare workers, and prolonged documentary work (i.e. required literature reviews and electronically documented communications with other healthcare workers and patients), increases their already elevated risks. Compared to

other healthcare workers, physiotherapists report some of the highest levels of neck-related disability. Prolonged, awkward postures are the primary risk factor for the development of upper body muscular disabilities in physiotherapists (5). From a public health perspective, this creates a double burden. Work-related musculoskeletal disorders were reported in approximately two-thirds of practicing physiotherapists in a Croatian study (compared to approximately one-third of physiotherapy students). Although this musculoskeletal strain affects the physiotherapists' capacity to provide hands-on care, it also has a negative impact on patients (6).

Proprioceptive Neuromuscular Facilitation (PNF) is a rehabilitation method based on the neurophysiology of movement using synergistic, multi-planar diagonal movement patterns to stimulate the muscle, tendon and joint proprioceptors (7). Established PNF techniques have been effective in treating a variety of cervical dysfunctions and a number of randomized trials have shown PNF techniques to be equivalent or superior to alternative stretching and manual-mobilization techniques (see Section 1.2). Sustained poor posture, such as forward head and shoulder posture, in Text Neck Syndrome (TNS) results in impaired cervical proprioception which leads to positional errors, delays deep flexor activation, and creates muscular imbalance which all contribute to pain and stiffness (8). PNF facilitation techniques, when combined with stretching and relaxation techniques, provide a rational, grounded approach to address the muscular imbalances and proprioceptive deficiencies contributing to TNS (9).

A limitation of clinic-based PNF is that the gains made during treatment can fade after patients return to their regular daily activities. Using a smartphone to perform activities of daily living can often bring patients into a forward-flexed posture, the same posture that probably caused their symptoms in the first place, and negate the postural and neuromuscular gains made during treatment (10). Addressing this particular limitation can be achieved through real-time postural control technologies. These technologies, available through smart devices and/or smart clothing, can be programmed to provide a warning or feedback if a postural threshold is sustained for a given period of time (11). The biofeedback has the potential to empower patients to change their posture and to enhance their self-regulation of posture. Previous work shows that when used in combination with physiotherapy, postural biofeedback can enhance self-regulation of posture (12).

Physiotherapists are a good population to test the combined approach for a couple of reasons. First, they are not likely to change their occupational device use behaviors by means of a clinic-based intervention. Second, physiotherapists have significant knowledge of rehabilitation technologies (13). This may enable them to engage with a structured monitoring protocol. Text Neck Syndrome is one of many ways that excessive device use may impact the neck. It is important to consider device-use related pain and discomfort of the neck from a population health perspective because it is one of the leading causes of disability worldwide (14). The burden is only growing due to changes in the working population. In addition to this increased population burden, there are significant and mature literature bodies in both proprioceptive neuromuscular facilitation (PNF) for neck pain and the use of wearable and/or app-based technology for postural monitoring (15). However, to the authors' knowledge, no published trial has combined these approaches or evaluated them in physiotherapists with Text Neck Syndrome. A previous PNF trial in Text Neck Syndrome examined PNF added to an exercise programme in 38 participants (25).

1.1 Study Rationale

This study aims to resolve the clinical difficulty of how to maintain postural correction out of the clinic with continued smartphone use. There are a number of clinical uses for the application of PNF for postural and cervical pain disorders, however, these benefits are lost over time due to lack of reinforcement outside the clinic during patients' normal daily activities (16). Physiotherapists are high smartphone users and literate users, who,

given the nature of their work, interact meaningfully with patients during treatment, and therefore, may benefit most from the application of real-time ergonomic feedback to enhance their rehabilitation and monitoring practice (12). This study aims to provide occupational health recommendations for physiotherapy practice, and to evaluate whether the use of feedback technology within the context of a Text Neck Syndrome rehabilitation program enhances outcomes in comparison to PNF Therapy alone (17).

1.2 Existing Evidence

Maicki conducted a randomized, double-blind clinical trial where they compared Physiotherapy using PNF against manual therapy in 93 women (45-65 years) with chronic cervical pain and radiological evidence of cervical osteoarthritis (45). The outcome measures chosen to evaluate the efficacy of the interventions were the Oswestry Disability Index, cervical range of motion, and the Visual Analog Scale (at 2 weeks and 3 months post-intervention). At both time periods, the authors reported PNF as being significantly better than manual therapy. Suresh, Venkatesan and Babu, in their randomized clinical study, compared PNF with cranio-cervical flexor training in chronic mechanical neck pain and reported improvement in pain, disability and active cervical range of motion, with similar benefit from the two approaches (46). Not every comparative trial has favored PNF over alternative manual techniques. Ashfaq et al. conducted a single-blinded randomized trial with 90 participants with mechanical neck pain. They compared PNF with routine therapy, passive vertebral mobilization with routine therapy, and routine therapy only. Assessment was done using the Neck Disability Index, before and after 4 weeks of treatment. Results showed that passive vertebral mobilization with routine therapy showed significant improvement in neck disability when compared to PNF with routine therapy (23). The authors of the study suggested that the specific manual and/or neuromuscular technique layered with base exercise program may impact the outcome strength, and thus isolating the contribution of PNF in this study was appropriate (24).

One randomized trial specifically evaluated structured facilitation techniques in a Text-Neck-Syndrome population similar to a smartphone user (47). This single-blinded study, done at a physiotherapy department in Faisalabad, Pakistan, compared two stretching-and-facilitation interventions (elongation longitudinaux avec décoaptation ostéo-articulaire and post-facilitation stretching) with 40 smartphone users aged 18-35 with Neck Disability Index scores of 10 and above due to Text Neck Syndrome. The intervention was carried out over 6 weeks, with 18 sessions in total. Both interventions led to a considerable reduction in pain and disability due to Text Neck Syndrome. Taken together, PNF has been associated with improvements in pain, disability and cervical range of motion in mechanical neck pain and in smartphone users with Text Neck Syndrome, and physiotherapists are at high risk of neck-related musculoskeletal disorders. Real-time postural monitoring has been proposed to extend the effects of clinic-based postural correction to the settings in which the postural load occurs. To the authors' knowledge, no published trial has combined PNF with real-time smartphone ergonomic monitoring or evaluated this combination in physiotherapists with Text Neck Syndrome. The present trial was designed to address this gap.

1.3 Objectives

The primary objectives are to investigate the influence of integrating real-time smartphone ergonomic monitoring (Group A) and standard PNF (Group B) on the Numeric Pain Rating Scale (NPRS) scores of physiotherapists with Text Neck Syndrome. It also aims to assess the influence of the two groups on active cervical range of motion in flexion, extension, right and left lateral flexion and right and left rotation, through goniometry.

The secondary objectives include evaluating and comparing the effects of the two protocols on disability associated with neck-related conditions as measured by the Neck Disability Index (NDI), and evaluating and comparing the effects of the

two protocols on forward head posture as assessed by craniovertebral angle (CVA) through standardized photographic analysis. Additionally, it aims to compare within- and between-group change at baseline, 4 weeks, and 8 weeks to access whether real-time ergonomic monitoring amplifies the prolonged effect of PNF.

1.4 Operational Definitions

TNS (Text Neck Syndrome): A clinical condition which presents with neck pain and stiffness caused by repetitive, prolonged forward head flexion to use handheld/personal electronic devices with a craniovertebral angle (CVA) less than 50° (ie. forward head flexion) on photographic analysis; cervical radiculopathy and myelopathy were excluded (Section 2.3) (39).

PNF (Proprioceptive Neuromuscular Facilitation): A stretching and strengthening technique based on the neurophysiology of the musculature including contract relax, hold relax, and/or rhythmic stabilization that is performed by a physiotherapist (40).

Ergonomic smartphone monitoring (RTSM): A mobile health application used to monitor head posture and give real-time feedback prompting postural correction (41).

forward head posture (FHP): A deviation in which the head is positioned in front of the body's vertical reference line. This is measured by determining the craniovertebral angle, which is the angle between a horizontal line through C7 and a line joining C7 to the tragus of the ear. This angle is considered abnormal if it is <50 degrees (42).

Neck Disability Index (NDI): A self-reported 10-item measure in which each item describes a neck pain related activity or disability. Each item is rated on a scale of 0-5, 0 being no disability, and 5 being unable to perform the activity due to neck pain. The total score is the sum of each item, and a total score of 50 indicates the individual is completely disabled by neck pain (43).

1.5 Hypotheses

Null hypothesis (H0): There is no significant difference in pain intensity, cervical range of motion, neck disability, and forward head posture between the two groups of physiotherapists (one receiving real-time smartphone ergonomic monitoring and the other not).

Alternate hypothesis (H1): The group of physiotherapists that received PNF and real-time smartphone ergonomic monitoring will experience a significant decrease in pain intensity, improvement in cervical range of motion, decrease in disability and a change in forward head posture when compared to the group that received PNF alone.

Methodology

2.1 Trial Design

This was a randomized, assessor-blinded trial where the participants were randomized to two groups. The trial was designed in accordance with the CONSORT 2010 statement. The entire trial process from start to finish took eight months.

2.2 Setting and Participants

Participants were recruited from physiotherapy departments and rehabilitation clinics in Lahore, Pakistan via purposive sampling.

2.3 Inclusion and Exclusion Criteria

The inclusion criteria were: age 22 to 45 years; confirmed diagnosis of Text Neck Syndrome; craniovertebral angle<50°, cervical pain ≥3 on a Numeric Pain Rating Scale; daily smart device use ≥ 4 hours per day for 6 months; Neck Disability Index of ≥ 10; and signed informed consent and willingness to comply with all study requirements. The exclusion criteria were: history of cervical spine surgery, fracture or malignancy; and evidence of cervical radiculopathy or myelopathy.

2.4 Sample Size

Sample size was calculated using G*Power (version 3.1) for the group-by-time interaction in a repeated-measures design (two groups, three measurements; medium effect size, Cohen's f =

0.25, equivalent to d = 0.5; power = 0.80; significance level = 0.05; correlation among repeated measures = 0.5; nonsphericity correction ε = 1) (44). This indicated a minimum total of 28 participants. The study targeted 30 participants per group (N = 60); allowing for a 10% dropout rate, the final target was 66 (n = 33 per group). For a conventional two-sided independent-samples t-test at a single time point (d = 0.5, α = 0.05, power = 0.80), 64 participants per group would be required, so comparisons between groups at individual time points may have been underpowered (see Limitations).

2.5 Randomization, Allocation Concealment, and Blinding

The authors used computer-generated randomization with a block size of 4. Allocation concealment was achieved by the use of sequentially numbered, sealed, opaque envelopes, which were opened only after the baseline assessment. The study adopted an assessor-blinded design. The outcome assessor was blinded to group allocation, however, the treating physiotherapist and the participants could not be blinded to group allocation due to the nature of the intervention. Sequence generation, envelope preparation, enrolment and group assignment were all performed by the first author (HR), who also delivered all treatment; outcomes were assessed by a blinded assessor. Because blocks of four do not divide 66 evenly, the final block was incomplete; how it was handled was not recorded. The study protocol is available from the corresponding author on request.

2.6 Interventions

Both the study groups were trained with a standardized PNF protocol and were asked to perform the exercises 3 times a week for 8 weeks (30 min each session). The protocol comprised of PNF stretching and strengthening techniques (hold-relax for the cervical extensors and contract-relax for the cervical lateral flexors) applied to the sternocleidomastoid and upper trapezius muscles. Each technique used 3 repetitions from the first session, with a 5-second contraction followed by a 3-second relaxation; the number of repetitions and sets was increased progressively over the 8 weeks. The resistance applied and the exact number of sets in each week were not recorded. All sessions were delivered and supervised by the first author (HR), a physiotherapist.

The group A (experimental) was further instructed to use the smartphone ergonomic monitoring application (PostureScreen) for 8 weeks to monitor head posture and receive feedback prompting postural correction. The application's alert threshold, feedback mode and daily exposure were not recorded and are therefore not reported. Group B (control) was trained with the PNF protocol only.

2.7 Outcome Measures and Data Collection Tools

Numeric Pain Rating Scale (NPRS): Used to measure the intensity of cervical pain, where 0 indicates no pain and 10 indicates the worst possible pain. Measure active range of motion (ROM) in the neck in flexion, extension, lateral flexion (left and right), and rotation (right and left) using a universal goniometer, starting from a neutral position with participant seated up-right. Neck Disability Index (NDI): A self-report questionnaire on impact of neck pain on daily activities, work, recreation, driving, sleeping, pain, concentration, reading, headaches, lifting and personal care, scored from 0 to 50. Craniovertebral Angle (CVA): Using Lateral view Digital images, standardized by the researcher, and measured using PostureScreen software. CVA was defined as the angle between a horizontal line through the spinous process of the seventh cervical vertebra (C7) and a line joining C7 to the tragus of the ear; a smaller angle indicates greater forward head posture, and a CVA below 50° was used as the cut-off.

All the aforementioned assessments were conducted at baseline and at 4 and 8 weeks by a blinded assessor. NPRS and cervical ROM were the primary outcome measures, while NDI and CVA were the secondary outcome measures.

2.8 Data Collection Procedure

- Recruitment: Physiotherapists aged 22 to 45 years, working in physiotherapy/rehabilitation departments in Lahore, were screened for inclusion/exclusion criteria (bad CVA, pain score, smartphone use, NDI score).
- Enrollment and baseline assessment: Eligible participants underwent baseline assessment of pain, cervical ROM, NDI, CVA by the blinded assessor.
- Randomization and allocation: Participants were allocated to either Group A or Group B using computer-generated block randomization and sealed opaque envelopes.
- Treatment: Both groups were treated with the same PNF protocol three times per week for 8 weeks. Group A used the ergonomic monitoring app for the duration of the study.
- Follow-up assessment: Reassessment of outcome measures was done by the blinded assessor at weeks 4 and 8. The treating physiotherapist recorded intervention logs, attendance registers and session logs on a daily basis; the usage data of the application by Group A was logged at 4 weeks.

2.9 Statistical Analysis

Data were analyzed using SPSS version 27, on a per-protocol basis. Descriptive statistics were performed to determine the mean, standard deviation, frequency, and percentages of the sample. The Shapiro-Wilk test was conducted to test the distributional normality of the baseline pain, disability, cervical flexion and craniovertebral angle scores; all the baseline measures did not deviate significantly from the normality ($p > .05$), indicating that parametric tests were justified to be used. Change within each group across the three time points was analyzed using one-way repeated-measures ANOVA (Friedman test for non-normally distributed data), with Bonferroni correction for pairwise comparisons. For between group differences and effect size at each time point, the independent samples t-test (Mann-Whitney U test for non-normally distributed data) was performed. Within-group repeated-measures ANOVAs had 2 and 60 degrees of freedom in Group A and 2 and 62 in Group B; sphericity was assessed with Mauchly's test and, where violated (8 of 18 analyses), the Greenhouse-Geisser correction was applied, after which all within-group effects remained significant ($p < .001$). Effect sizes are Cohen's d (mean difference divided by the pooled standard deviation). Because cervical flexion differed between groups at baseline, supplementary analyses were added: between-group differences at weeks 4 and 8 were estimated with 95% confidence intervals in original units, both unadjusted and adjusted for the baseline value of the same outcome (analysis of covariance), and the group-by-time interaction was tested with linear mixed models including a random participant intercept. These supplementary analyses were not prespecified. No formal adjustment for multiplicity across outcomes was planned, so findings for secondary and movement-specific outcomes are interpreted as exploratory. Analyses included the 63 participants who completed follow-up; outcome data were not available for the three participants who did not complete the trial. p value < 0.05 was considered as the level of significance for all the analyses.

2.10 Ethical Considerations

The study was conducted and approved by the Institutional Review Board of The Superior University, Lahore (Ref. IRB/FAHS/REHAB/04/26/MS/RS-4020), before participant recruitment and data collection. The study was conducted in line with the principles of beneficence and non-maleficence. Prior to enrollment, the purpose, procedures, potential risks, and the right to withdraw at any point in time without a penalty was explained to participants and written informed consents were taken. Any negative effect was recorded as an adverse effect and the intervention was adjusted as needed. Data collected from the participants were anonymized and accessible only to the research team for the duration of data collection, analyses and reporting.

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Results

3.1 Participant Flow and Baseline Characteristics

Eighty physiotherapists were assessed for eligibility; 14 were excluded (9 did not meet inclusion criteria, 5 declined participation), and 66 were enrolled and randomized (Group A, n = 33; Group B, n = 33). Three participants were lost to follow-up (Group A: n = 2, personal reasons and relocation; Group B: n = 1, personal reasons), leaving 63 participants (Group A, n = 31; Group B, n = 32) for per-protocol analysis (Figure 1).

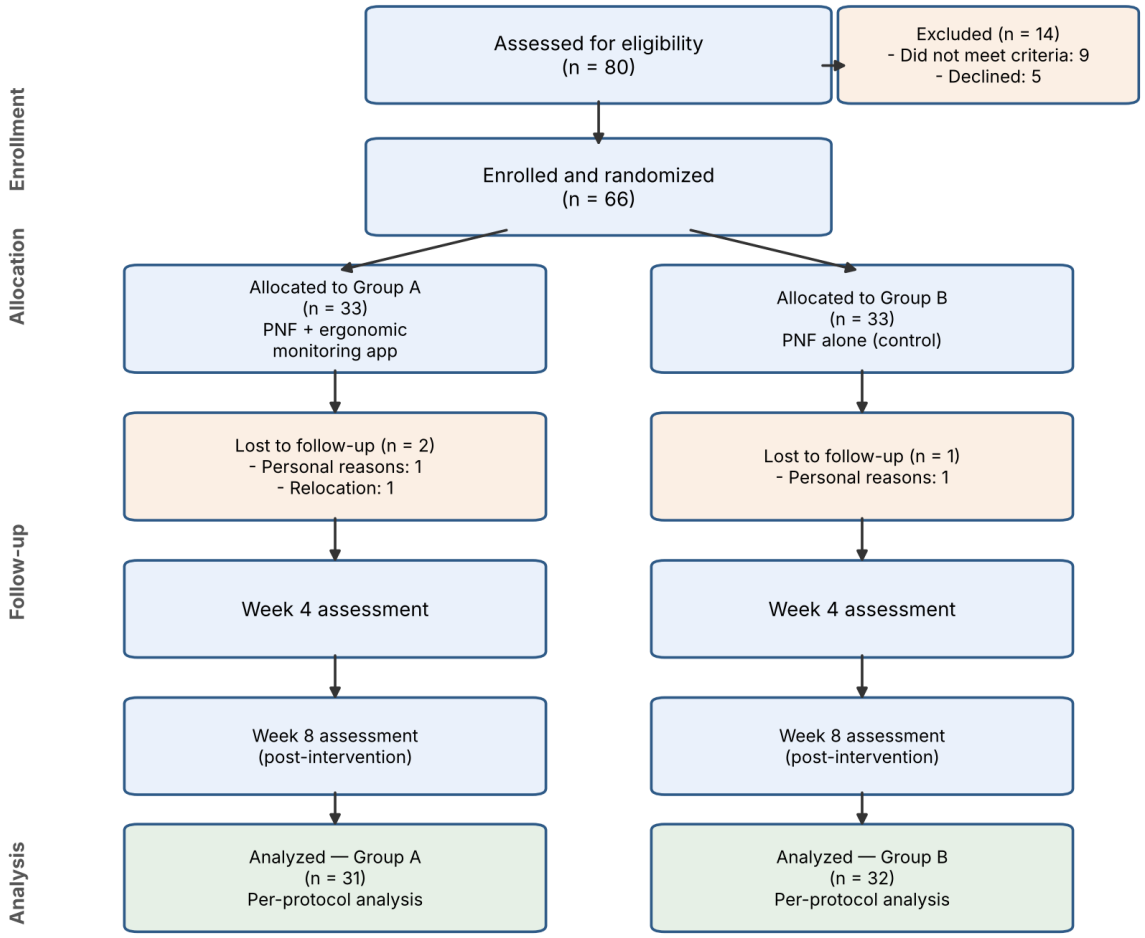


Figure 1. CONSORT flow diagram of participant recruitment, allocation, follow-up, and analysis.

Groups were comparable at baseline across all demographic variables. Mean age was 28.48 ± 4.20 years in Group A and 29.78 ± 4.03 years in Group B. Group A comprised 67.7% female and 32.3% male participants, and Group B comprised 56.3% female and 43.8% male participants (p = .497). Mean years of clinical experience were 4.80 ± 2.94 (Group A) and 4.59 ± 2.74 (Group B) (p = .774), and mean daily smartphone use was 5.87 ± 1.28 hours (Group A) and 6.21 ± 1.62 hours (Group B) (p = .352); individual values confirmed that every participant reported at least 4 hours of daily device use (minimum 4.0 hours; Table 1).

Table 1. Baseline demographic characteristics

Variable	Group A (n = 31)	Group B (n = 32)	p-value
Age (years), mean ± SD	28.48 ± 4.20	29.78 ± 4.03	0.233
Gender, female/male, n	21 / 10	18 / 14	0.497
Years of clinical experience, mean ± SD	4.80 ± 2.94	4.59 ± 2.74	0.774
Daily smartphone use (h), mean ± SD	5.87 ± 1.28	6.21 ± 1.62	0.352

3.2 Pain Intensity (NPRS)

Pain scores declined significantly over 8 weeks in both groups (Group A: $F = 124.34$, $p < .001$; Group B: $F = 51.45$, $p < .001$). No between-group difference was present at baseline ($p = .780$). Group A reported significantly lower pain than Group B from week 4 onward (week 4: $p = .005$, $d = -0.73$; week 8: $p < .001$, $d = -1.05$), with mean NPRS falling from 5.75 ± 1.16 to 2.33 ± 1.49 in Group A versus 5.84 ± 1.52 to 3.94 ± 1.57 in Group B (Table 2, Figure 2).

Table 2. Pain intensity (NPRS) by group and time point

Time point	Group A, mean ± SD	Group B, mean ± SD	Between-group p	Cohen's d
Baseline	5.75 ± 1.16	5.84 ± 1.52	0.780	-0.07
Week 4	3.65 ± 1.49	4.88 ± 1.84	0.005	-0.73
Week 8	2.33 ± 1.49	3.94 ± 1.57	<0.001	-1.05

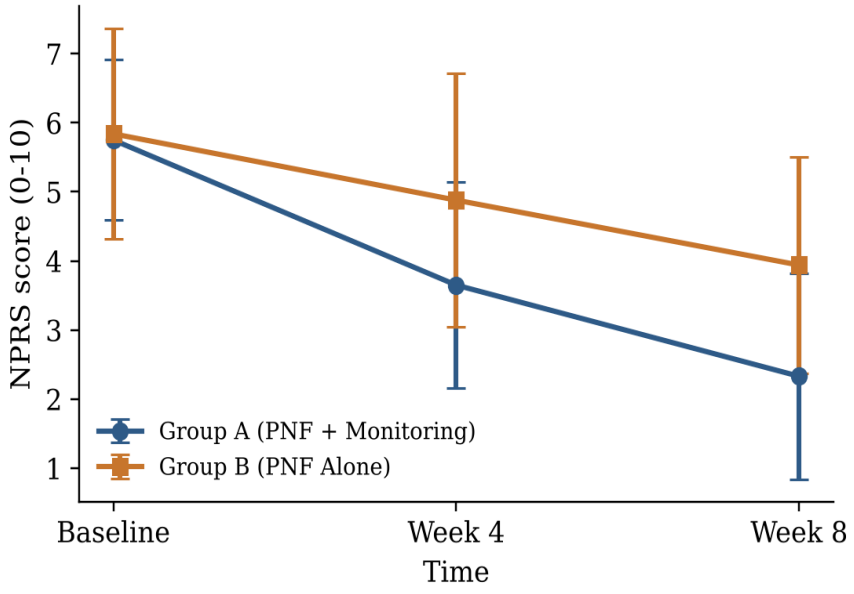


Figure 2. Pain intensity (NPRS) over time by group (mean ± SD).

3.3 Cervical Range of Motion

All six directions of cervical ROM improved significantly within both groups across the 8-week period (within-group repeated-measures ANOVA, all $p < .001$). The magnitude of improvement was consistently larger in Group A. At week 8, between-group differences reached statistical significance in favor of Group A for extension ($p = .010$, $d = 0.68$), left lateral flexion ($p = .012$, $d = 0.65$), and left rotation ($p = .002$, $d = 0.82$). Numerically larger gains were observed in Group A for flexion, right lateral flexion, and right rotation, but these did not reach statistical significance in the unadjusted comparison (Table 3, Figure 3). After adjustment for baseline values, between-group differences favored Group A in all six directions (Table 6).

Table 3. Cervical range of motion (degrees) by movement, group, and time point

Movement	Group A baseline	Group A week 8	Group B baseline	Group B week 8	Week-8 p
Flexion	43.75 ± 7.39	52.74 ± 8.24	47.35 ± 5.97	50.99 ± 6.30	0.351
Extension	42.47 ± 6.20	49.85 ± 7.11	42.96 ± 4.58	45.72 ± 4.97	0.010
Lateral flexion, right	36.78 ± 4.44	43.04 ± 4.42	38.71 ± 6.02	40.96 ± 6.88	0.158
Lateral flexion, left	37.27 ± 2.88	42.99 ± 4.43	37.30 ± 4.44	39.94 ± 4.95	0.012
Rotation, right	74.16 ± 6.85	81.90 ± 7.18	74.94 ± 8.15	78.44 ± 8.90	0.094
Rotation, left	76.69 ± 8.11	84.15 ± 7.82	74.46 ± 6.08	78.44 ± 6.07	0.002

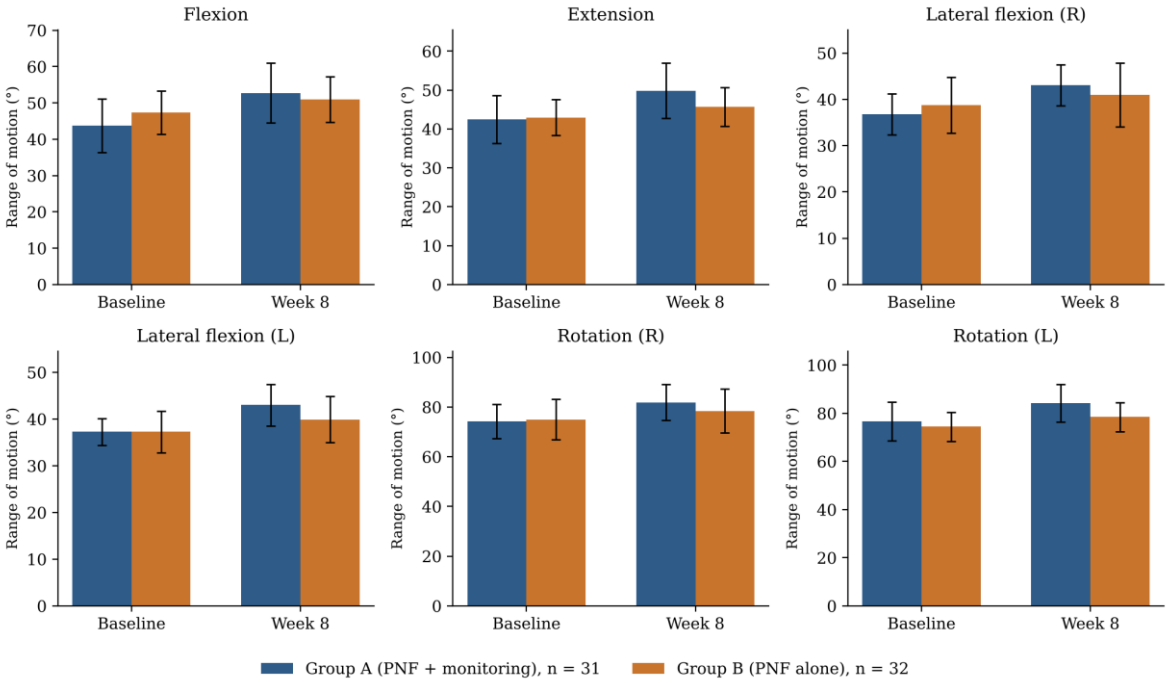


Figure 3. Cervical range of motion (degrees) by movement, baseline vs. week 8, by group (mean ± SD).

3.4 Neck Disability Index

Neck-related disability improved significantly within both groups (Group A: $F = 115.12$, $p < .001$; Group B: $F = 30.91$, $p < .001$). Mean NDI fell from 20.71 ± 4.61 to 12.44 ± 3.33 in Group A and from 20.91 ± 6.37 to 17.06 ± 5.55 in Group B. The between-group difference at week 8 was statistically significant and large in magnitude ($p < .001$, $d = -1.01$) (Figure 4).

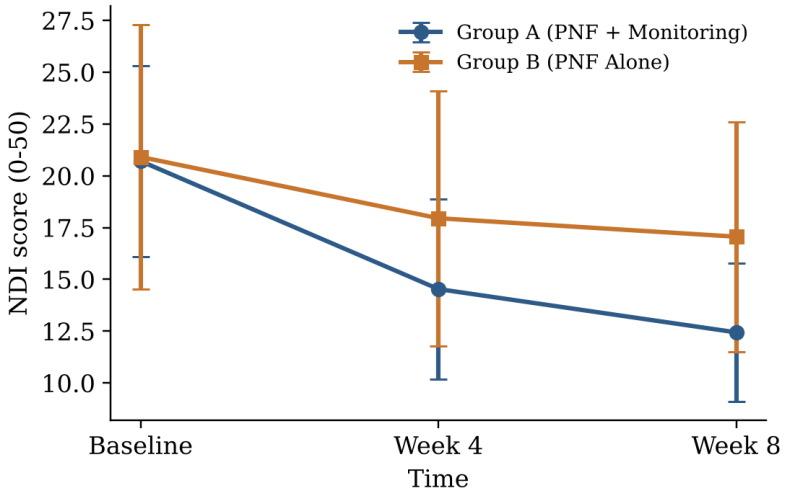


Figure 4. Neck Disability Index over time by group (mean ± SD).

3.5 Craniovertebral Angle

CVA increased significantly in both groups, indicating reduced forward head posture (Group A: $F = 164.16$, $p < .001$; Group B: $F = 16.33$, $p < .001$). By week 8, Group A averaged 49.93° ± 3.08 compared with 46.88° ± 3.23 in Group B, a statistically significant and large between-group difference ($p < .001$, $d = 0.97$) (Figure 5).

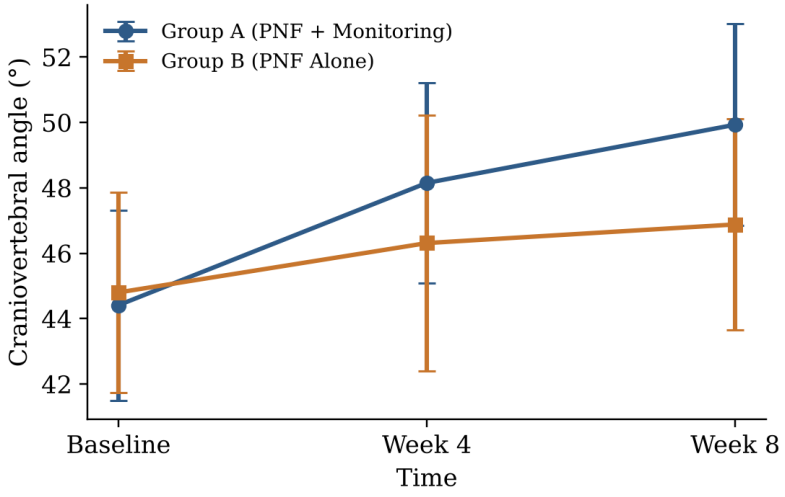


Figure 5. Craniovertebral angle over time by group (mean ± SD).

3.6 Summary of Between-Group Comparisons

Cervical flexion differed between the groups at baseline ($p = .038$; Table 5); no other outcome differed significantly at baseline. By week 8, Group A showed statistically significant advantages over Group B for pain intensity, cervical extension, left

lateral flexion, left rotation, neck disability, and craniovertebral angle, with effect sizes ranging from medium to large (Table 4, Figure 6). Differences for flexion, right lateral flexion, and right rotation favored Group A numerically but did not reach statistical significance.

Table 4. Between-group comparison of all outcomes at week 4 and week 8

Outcome	Time point	p-value	Cohen's d
Pain intensity (NPRS, 0-10)	Week 4	0.005	-0.73
Pain intensity (NPRS, 0-10)	Week 8	<0.001	-1.05
Flexion (°)	Week 4	0.923	-0.02
Flexion (°)	Week 8	0.351	0.24
Extension (°)	Week 4	0.205	0.33
Extension (°)	Week 8	0.010	0.68
Lateral flexion, right (°)	Week 4	0.666	0.11
Lateral flexion, right (°)	Week 8	0.158	0.36
Lateral flexion, left (°)	Week 4	0.024	0.58
Lateral flexion, left (°)	Week 8	0.012	0.65
Rotation, right (°)	Week 4	0.234	0.30
Rotation, right (°)	Week 8	0.094	0.43
Rotation, left (°)	Week 4	0.015	0.63
Rotation, left (°)	Week 8	0.002	0.82
Neck Disability Index (0-50)	Week 4	0.013	-0.64
Neck Disability Index (0-50)	Week 8	<0.001	-1.01
Craniovertebral angle (°)	Week 4	0.041	0.52
Craniovertebral angle (°)	Week 8	<0.001	0.97

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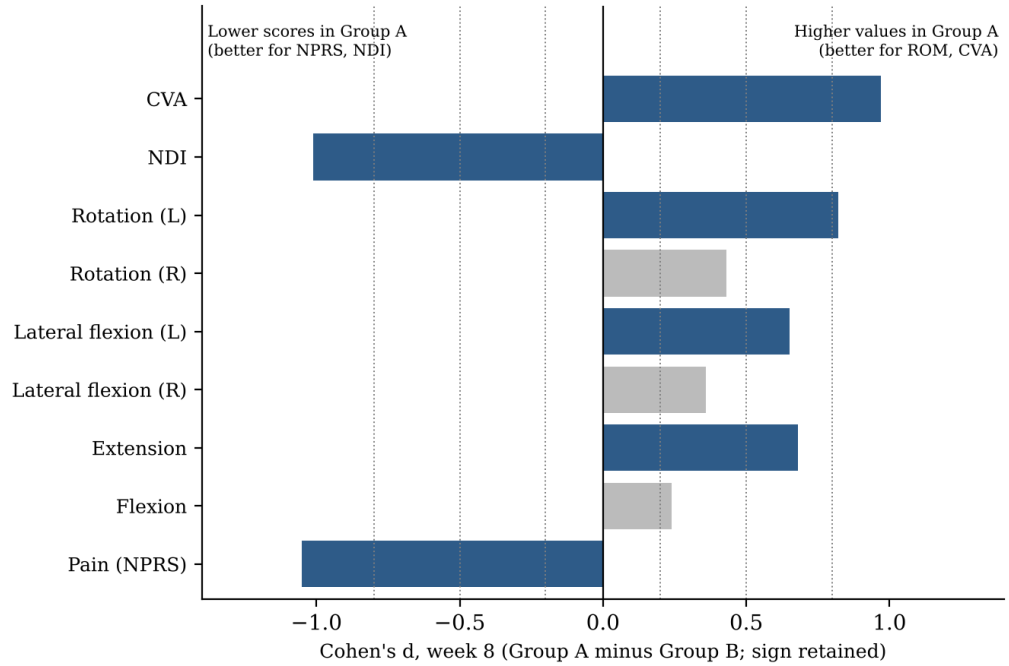


Figure 6. Between-group effect sizes (Cohen's d, Group A minus Group B, sign retained) at week 8. Negative values for NPRS and NDI indicate lower (better) scores in Group A; positive values for ROM and CVA indicate higher (better) values in Group A. Blue bars denote differences significant in the unadjusted comparison (p < .05); grey bars were not significant.

3.7 Baseline Comparability and Supplementary Analyses

Baseline values are presented in Table 5. Cervical flexion differed between the groups at baseline (Group A 43.75 ± 7.39°, Group B 47.35 ± 5.97°; p = .038), whereas no other outcome differed significantly (all p > .05). Non-significant baseline tests cannot by themselves confirm balanced randomization. One participant in each group had a baseline craniovertebral angle of 50° or above (51.9° and 50.2°) and was retained in the analysis.

Table 5. Baseline values by group (mean ± SD) and between-group p-values (Welch independent-samples t-test)

Outcome	Group A (n = 31)	Group B (n = 32)	p-value
Pain intensity (NPRS, 0-10)	5.75 ± 1.16	5.84 ± 1.52	0.780
Flexion (°)	43.75 ± 7.39	47.35 ± 5.97	0.038
Extension (°)	42.47 ± 6.20	42.96 ± 4.58	0.726
Lateral flexion, right (°)	36.78 ± 4.44	38.71 ± 6.02	0.152
Lateral flexion, left (°)	37.27 ± 2.88	37.30 ± 4.44	0.975
Rotation, right (°)	74.16 ± 6.85	74.94 ± 8.15	0.682
Rotation, left (°)	76.69 ± 8.11	74.46 ± 6.08	0.223

Outcome	Group A (n = 31)	Group B (n = 32)	p-value
Neck Disability Index (0-50)	20.71 ± 4.61	20.91 ± 6.37	0.883
Craniovertebral angle (°)	44.41 ± 2.91	44.80 ± 3.07	0.613

Table 6 presents between-group differences (Group A minus Group B) in original units with 95% confidence intervals, unadjusted and adjusted for the baseline value of the same outcome. After adjustment, differences favored Group A for all nine outcomes at both time points (all adjusted $p < .001$; negative differences for pain and NDI indicate lower, better scores in Group A). This included cervical flexion at week 8 (adjusted difference 5.33°, 95% CI 3.76 to 6.91), and right lateral flexion and right rotation, which were not significant in the unadjusted comparison. The group-by-time interaction was significant for every outcome (likelihood-ratio test, all $p < .001$). These analyses were not prespecified and are supplementary; the clinical importance of the differences was not assessed against a prespecified threshold.

Table 6. Between-group differences (Group A minus Group B) with 95% confidence intervals, unadjusted and baseline-adjusted

Outcome	Time point	Unadjusted difference (95% CI)	Baseline-adjusted difference (95% CI)
Pain intensity (NPRS, 0-10)	Week 4	-1.23 (-2.07 to -0.39)	-1.13 (-1.60 to -0.66)
Pain intensity (NPRS, 0-10)	Week 8	-1.61 (-2.39 to -0.84)	-1.53 (-2.06 to -1.01)
Flexion (°)	Week 4	-0.19 (-4.05 to 3.68)	3.63 (2.19 to 5.08)
Flexion (°)	Week 8	1.74 (-1.97 to 5.45)	5.33 (3.76 to 6.91)
Extension (°)	Week 4	2.06 (-1.16 to 5.28)	2.58 (1.32 to 3.85)
Extension (°)	Week 8	4.13 (1.03 to 7.24)	4.61 (3.08 to 6.14)
Lateral flexion, right (°)	Week 4	0.64 (-2.33 to 3.62)	2.61 (1.35 to 3.87)
Lateral flexion, right (°)	Week 8	2.08 (-0.83 to 4.99)	3.99 (2.70 to 5.28)
Lateral flexion, left (°)	Week 4	2.29 (0.32 to 4.27)	2.32 (1.40 to 3.24)
Lateral flexion, left (°)	Week 8	3.05 (0.69 to 5.42)	3.08 (1.89 to 4.28)
Rotation, right (°)	Week 4	2.35 (-1.56 to 6.26)	3.11 (1.83 to 4.40)
Rotation, right (°)	Week 8	3.46 (-0.61 to 7.53)	4.24 (2.75 to 5.73)
Rotation, left (°)	Week 4	4.55 (0.92 to 8.17)	2.44 (1.18 to 3.70)
Rotation, left (°)	Week 8	5.71 (2.17 to 9.26)	3.72 (2.26 to 5.18)
Neck Disability Index (0-50)	Week 4	-3.42 (-6.11 to -0.74)	-3.25 (-4.58 to -1.92)
Neck Disability Index (0-50)	Week 8	-4.62 (-6.92 to -2.31)	-4.48 (-5.78 to -3.18)
Craniovertebral angle (°)	Week 4	1.84 (0.08 to 3.61)	2.24 (1.40 to 3.08)
Craniovertebral angle (°)	Week 8	3.05 (1.46 to 4.64)	3.38 (2.49 to 4.28)

Discussion

The effects of combining the PNF protocol with the real-time smartphone ergonomic monitor were greater than that of the PNF protocol alone on pain, neck disability, craniovertebral angle and various planes of cervical ROM of physiotherapists with Text Neck Syndrome. The results indicated that both the intervention and control groups showed statistically significant within group improvement on all outcome measures; although, because both groups received PNF and there was no PNF-free comparison group, these within-group changes cannot by themselves establish the efficacy of PNF. The randomized comparison estimates the incremental effect of adding real-time monitoring, and the improvement was greater when PNF was combined with the real-time postural feedback. As such, the null hypothesis described in section 1.5 was rejected for the outcomes with significant between-group differences (pain, disability, craniovertebral angle, cervical extension, left lateral flexion, and left rotation), but not for cervical flexion, right lateral flexion, or right rotation in the primary unadjusted analysis. Supplementary baseline-adjusted analyses (Table 6) showed significant differences in all six directions; because these analyses were not prespecified, they are interpreted cautiously.

The results of this study are in line with the existing literature on the use of PNF to manage mechanical neck pain and chronic neck pain. In a study by Maicki, PNF was found to be more effective than manual therapy in improving pain, cervical ROM and neck disability of women with chronic neck pain at 2 weeks and 3 months of follow up (45). Suresh et al., in their study, compared PNF with cranio-cervical flexor training and reported similar benefit from both approaches on pain, disability and active cervical ROM in patients with chronic mechanical neck pain (46). The current study further extends the above literature to text neck syndrome of physiotherapists and to integrating a technology-based behavioral approach along with PNF to address text neck syndrome. In the present trial the combination showed greater benefit than PNF alone on some, but not all, outcomes. These findings are in alignment with an earlier trial in smartphone users with text neck syndrome that examined structured, clinic-based stretching and facilitation techniques and reported reductions in pain and disability (47).

One interesting discrepancy is reported by Ashfaq et al. who found that in the treatment of mechanical neck pain, passive vertebral mobilization plus routine therapy produced greater reduction in neck pain disability compared to PNF plus routine therapy (23). It is possible that this discrepancy is due to the different comparator conditions in the two studies. Ashfaq compared PNF with passive vertebral mobilization (each added to routine therapy), while the present study compared PNF plus real-time ergonomic monitoring with PNF alone. The two studies therefore address different clinical questions. It is possible that the combination of neuromuscular technique, exercise dose, and behavioral modification influenced the outcome of this study.

Outcomes from the smartphone application and accompanying ergonomic monitoring system paralleled evidence from systematic reviews regarding the incorporation of wearables and apps into therapy practices. Those reviews identified postural biofeedback as an adjunct to, and not a replacement for, individualized physiotherapy in improving postural control and motor self-regulation. Outcomes further align with occupational rehabilitation theories regarding the necessity to modify behavior and the environment in which the individual works to fully address the causes of impairment. Outcomes from smartphone applications further complement evidence from Titcomb et al. showing brief postural education and corrective exercises improved craniovertebral angle. Possible mechanisms, which were not measured in this trial, include the following: the PNF technique, hold-relax, for postural correction in Group A, may have engaged autogenic and reciprocal inhibition and improved cervical range of motion, joint position sense and deep cervical flexor activation, all of which are negatively affected by

sustained forward head posture. The additional benefit observed in Group A may be related to the behavioral component, but the design cannot separate it from the effects of extra attention, expectation or prompting, and the monitoring dose was not recorded.

The findings should be considered within the broader occupational and public health context. Relative neck-related disability of physiotherapists compared to other health professionals (4-6), combined with the global burden of neck pain (48), and the existing evidence of smartphone/device usage and its association with neck and upper limb musculoskeletal load (3, 20-24), justify the need for similar occupational-based interventions to that studied here.

4.1 Clinical implications

These results suggest that, to reduce neck-related disability of physiotherapists, occupational health programs might benefit from including structured rehabilitation programs based on PNF and continuous, technology mediated postural feedback, especially if they also include clinic based neuromuscular interventions, considering the under recognized neck-related disability of this working population; confirmation in larger, longer trials is needed. The week-8 between-group differences in pain (1.61 points) and disability (4.62 points) were statistically significant, but their clinical importance was not assessed against a prespecified threshold, and a mean craniovertebral angle of 49.93° does not show that all participants reached normal posture.

4.2 Limitations

- Assessor-blinded Design. Only the outcome assessor was blind to group assignment.
- Reliance on self-reported measures and subject to reporting bias.
- Short term follow-up of 8 weeks. The durability of the gains and particularly whether Group A's advantage persisted after monitoring stopped is unknown.
- Recruitment was restricted to physiotherapy and rehabilitation services in one City of Pakistan (Lahore).
- Usage data of the smartphone app was recorded only at 4 weeks, therefore, it was not possible to assess variability in feedback engagement and its relationship to outcome.
- Analysis population. Analyses were restricted to the 63 of 66 randomized participants who completed follow-up; outcome data were unavailable for the three non-completers, so no intention-to-treat analysis could be performed.
- Baseline imbalance and post hoc analyses. Cervical flexion differed between groups at baseline ($p = .038$). Baseline-adjusted and group-by-time analyses were added post hoc and are supplementary; no formal multiplicity adjustment across outcomes was planned, so secondary and movement-specific findings are exploratory.
- Eligibility. One participant in each group had a baseline craniovertebral angle of 50° or above (51.9° and 50.2°) and was retained in the analysis.
- Comparator. Both groups received PNF, so the trial estimates the incremental effect of the monitoring package; it did not include a sham or attention-control condition, and the contributions of additional attention, expectation and behavioral prompting cannot be separated from the monitoring itself.
- Intervention fidelity. The settings of the monitoring application (alert threshold, feedback mode) and daily exposure were not recorded, and app usage was logged only at week 4, so the dose of the monitoring component cannot be described precisely.
- Allocation and delivery by one investigator. The same investigator generated the allocation sequence, prepared the envelopes, enrolled participants, assigned groups and delivered all treatment, which weakens the independence of allocation concealment; PNF resistance and weekly set numbers were not recorded.
- Sample size. The sample was smaller than required for a conventional two-sided t-test comparison between groups at a single time point (64 per group), so individual between-group and movement-specific comparisons may have been underpowered.

4.3 Recommendations for Future Research

- Use of a sham or attention-control monitoring application to disentangle the unique effects of postural feedback from general attention effects.
- Use of objective outcome measures (e.g. surface electromyography of the cervical flexors, inertial motion sensors) in addition to self-report measures.
- Extended follow-up to assess the effects of treatment beyond the active monitoring period (e.g. 3 and 6 months after the intervention).
- Multi-site recruitment to enhance external validity.
- Continuous, as opposed to periodic, tracking of application adherence to assess the dose-response relationship.

4.4 Conclusion

In physiotherapists with Text Neck Syndrome, PNF with smartphone ergonomic monitoring showed significantly greater reductions in pain intensity and disability, and greater increases in craniovertebral angle and in selected cervical ROM directions (all six directions after baseline adjustment), compared to PNF alone at the end of the 8-week intervention. Although PNF alone was effective in improving all the measured outcomes, adding real-time postural monitoring was associated with greater improvement than PNF alone over the 8-week intervention; whether the benefit persists after monitoring stops was not assessed.

Declarations

Ethics approval and consent to participate: The study protocol was approved by the Institutional Review Board of The Superior University, Lahore, Pakistan (Ref. IRB/FAHS/REHAB/04/26/MS/RS-4020). Written informed consent was obtained from all participants.

Consent for publication: Not applicable; no identifiable individual data are reported.

Availability of data and materials: The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests: The authors declare that they have no competing interests.

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