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Proprioceptive training reduces headache burden and center of pressure path length in patients with cervicogenic headache: A randomized controlled trial

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ABSTRACT

Background: Cervicogenic headache (CGH) is frequently associated with altered cervical sensorimotor control, reduced range of motion and impaired postural stability. Prior work has shown that proprioceptive retraining with gaze direction recognition (GDR) can reduce pain and improve postural stability in CGH and chronic neck pain. *Purpose:* To examine whether adding a GDR-based proprioceptive training to standard physiotherapy reduces headache frequency and duration and improves postural balance (COP path length) in CGH patients. *Methods:* Thirty-eight participants with CGH (aged 35–49 years) were randomly assigned to receive either standard physiotherapy (Control, $n = 19$) or physiotherapy plus

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GDR proprioceptive training (Treatment, $n = 19$) for 8 weeks (3 sessions/week). Outcomes measured pre- and post-intervention included headache frequency (attacks/month), headache duration (hours/attack), and center-of-pressure (COP) path length during quiet standing. *Results:* Multivariate analyses revealed significant effects of time and group × time interaction (Wilks' $\Lambda = 0.142$, $F\,(3,30) = 60.55$, $P < 0.001$; Wilks' $\Lambda = 0.193$, $F\,(3,30) = 41.77$, $P < 0.001$), indicating greater improvements in the treatment group. Follow-up ANOVAs showed significant time and interaction effects for COP path length ($F\,(1,32) = 186.0$, $P < 0.001$; $F\,(1,32) = 130.0$, $P < 0.001$), headache duration ($F\,(1,32) = 16.0$, $P = 0.00035$; $F\,(1,32) = 7.43$, $P = 0.010$), and headache frequency ($F\,(1,32) = 11.7$, $P = 0.002$; $F\,(1,32) = 7.61$, $P = 0.010$). Groups did not differ at baseline. *Conclusion:* Adding GDR-based proprioceptive training to standard physiotherapy produced greater improvements in headache burden and markedly improved postural balance compared with standard physiotherapy alone.

KEYWORDS

cervicogenic headache, headache burden, postural balance, proprioception, eye movements

1. INTRODUCTION

Cervicogenic headache represents a relatively prevalent condition, accounting for approximately 1–4% of individuals experiencing headaches [1]. This disorder predominantly manifests as unilateral pain that remains consistent on one side, with a notably higher incidence observed in women [2, 3]. The pain typically begins in the cervical region and extends anteriorly toward the ocular, frontal, and temporal areas [4]. The duration of episodes can be variable, or patients may experience ongoing pain with fluctuating intensity that is exacerbated by cervical movements. The pain intensity ranges from moderate to severe but is generally not described as excruciating or pulsating, and its duration can be quite variable [5].

Cervicogenic headache is recognized by the International Classification of Headache Disorders (ICHD) as a secondary headache that develops from cervical spine disorders, especially those affecting the upper neck [6]. Several cervical structures are frequently implicated as sources of CGH, including the facet joints, intervertebral discs, ligaments, and muscles [7].

The upper cervical spine contains a high concentration of proprioceptive receptors that provide the central nervous system with information regarding neck position [8]. Consequently, impaired proprioceptive function in the cervical spine has been identified as a significant contributor to sensorimotor control disturbances in patients presenting with neck pain [9]. Cervical pain and muscular fatigue can modify the afferent input from proprioceptors in the neck, resulting in compromised postural stability [10, 11]. Cervical pain/fatigue alters mechanoreceptor/spindle sensitivity in upper cervical ligaments/muscles, disrupting afferent signals to vestibular nuclei and causing sensorimotor errors evidenced by increased joint position error (JPE) in CGH [12, 13].

Emerging evidence indicates that individuals with cervicogenic headache often exhibit balance impairments that are attributable, at least in part, to altered cervical proprioceptive feedback and associated sensorimotor dysfunction. In experimental postural control assessments, patients with CGH or related cervical pain conditions show greater postural sway—particularly in anteroposterior (AP) and mediolateral (ML) directions—when sensory information is challenged (e.g., standing on a foam surface with eyes closed) compared with asymptomatic controls [14, 15]. These findings are consistent with the hypothesis that faulty cervical afferent input, resulting from altered mechanoreceptor and muscle spindle sensitivity in the upper cervical region, degrades somatosensory contributions to balance control and leads to observable sensorimotor deficits [16]. Notably, performance differences are most pronounced under conditions that diminish visual and reliable somatosensory input, suggesting a disproportionate reliance on impaired cervical proprioception in CGH patients during postural regulation. Such impairments increase the susceptibility of these individuals to postural instability and potential falls [16, 17]. This postural instability reflects a reduced ability to maintain the body's center of mass within its base of support, particularly when sensory inputs are unreliable. Impaired cervical proprioception disrupts the integration of sensory information required for timely postural adjustments, leading to increased sway and delayed corrective responses. Consequently, CGH patients are more prone to balance loss in daily activities, particularly in low-light or uneven environments, which increases fall risk, underscoring the functional impact of cervical sensorimotor deficits and the importance of interventions to restore cervical proprioception and postural control [12, 14, 18].

Consequently, comprehensive postural evaluations and specific therapeutic interventions—including exercises to enhance proprioception and vestibular system function - are essential components of effective treatment for this patient population [18].

Proprioceptive training is a therapeutic approach designed to enhance proprioceptive function. This intervention emphasizes the utilization of somatosensory signals, particularly proprioceptive and tactile inputs, while minimizing reliance on other sensory modalities such as vision. The primary objective of this training is to enhance or restore sensorimotor function [19–21].

The gaze direction recognition (GDR) task is a type of proprioceptive training — in which participants observe another person's neck rotation from behind and attempt to identify gaze direction — is a motor imagery/visuospatial task designed to engage cervical sensorimotor networks and has been shown in pilot trials to improve pain and cervical ROM in chronic neck pain populations [22]. Recent randomized trials including proprioceptive protocols combining GDR and related sensorimotor exercises report improvements in postural stability and pain in people with CGH [23].

Despite these promising results, little is known about whether such training reduces headache burden - specifically headache frequency and duration - or leads to meaningful improvements in quantitative postural-sway measures such as COP path length. COP path length reflects the cumulative displacement of the body's center of mass during quiet standing and is a sensitive indicator of postural stability and sensorimotor efficiency, with longer path lengths indicating greater reliance on corrective postural adjustments and reduced balance control. As balance control is fundamentally a process of dynamic sensorimotor integration [24], and COP path length provides a quantitative index of how effectively visual, vestibular, and cervical proprioceptive inputs are integrated to maintain upright stance. In headache populations, dysfunction within overlapping vestibular, somatosensory, and pain-processing networks has been implicated in both balance impairments and symptom provocation [25]. Reductions in COP path length following intervention may therefore reflect improved multisensory integration and more efficient postural strategies, characterized by decreased sway variability and reduced need for compensatory corrections. Clinically, improved COP control may indicate greater postural robustness under sensory challenge, potentially lowering susceptibility to sensorimotor conflicts - such as those arising during head movements or visual perturbations—that have been proposed as triggers for headache episodes [26, 27]. Consequently, changes in COP path length may serve not only as an objective marker of postural improvement but also as a functional surrogate for enhanced sensorimotor stability relevant to headache management.

The aim of the present randomized controlled trial was therefore to determine whether adding a GDR-based proprioceptive training to standard physiotherapy reduces headache frequency and duration and improves COP path length in adults with CGH. We hypothesized that participants receiving the combined intervention would experience greater reductions in headache frequency and duration and greater improvements in COP path length than those receiving standard physiotherapy alone.

2. MATERIALS AND METHODS

2.1. Study design and ethics

This was a randomized, assessor-blinded, parallel-group controlled trial. The study took place over a 14-month period from July 2024 through September 2025. The study protocol was approved by the institutional ethics committee from Faculty of Physical Therapy, Cairo University with reference number P.T.REC/012/003409. The trial was registered on ClinicalTrials.gov (Registration Number: NCT07271004). All participants provided written informed consent prior to inclusion in our study.

2.2. Participants

Participants were recruited from outpatient clinics and met our diagnostic criteria for CGH according to ICHD-3 [1]. Inclusion criteria, exclusion criteria, and baseline screening procedures were applied as in prior related trials (age 35–49, no vestibular disease, no prior cervical surgery, etc.).

Randomization was performed using sealed opaque envelopes by an independent person. Each envelope contained a letter that assigned the participant to either the control group (CN) or the treatment group (TG). Assessors were blinded to group allocation (Fig. 1).

2.3. Interventions

Both groups received a standardized physiotherapy program (heat, TENS, ultrasound as indicated, mobility and strengthening exercises) delivered three times per week for 8 weeks, each session lasted for 60 min.

Control group (CG) underwent a selected physical therapy rehabilitation program (SPT). Each patient started the treatment session with a 20-min application of a hot pack to the neck and shoulder region to achieve muscle relaxation. Then the application of transcutaneous electrical nerve stimulation (TENS) to the cervical area for another 20 min (frequency = 50 Hz, pulse width = 100 μs). Next, ultrasound therapy was applied to the affected cervical muscles for 5 min at an intensity of 1–1.5 W/cm^2 in continuous mode. The standardized physiotherapy program was selected to reflect commonly applied, evidence-based conservative management for cervicogenic headache and chronic neck pain, as recommended in clinical guidelines and previous

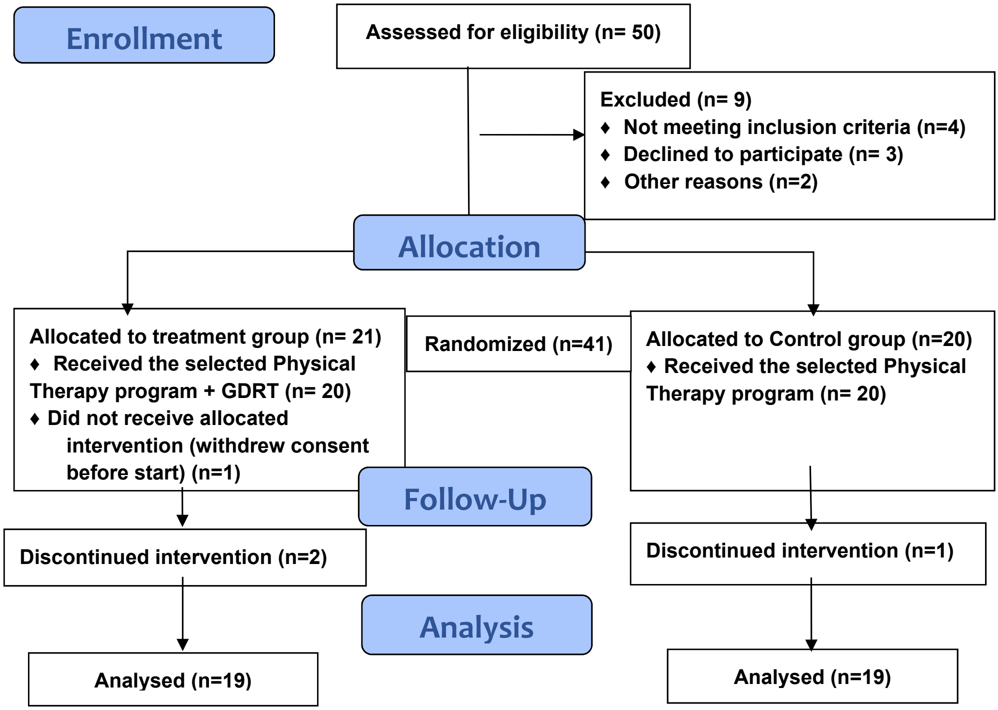

Fig. 1. Consort 2010 flow diagram

randomized controlled trials. Multimodal physiotherapy approaches combining pain-modulating modalities with therapeutic exercise have demonstrated effectiveness in reducing pain and improving cervical function in this population [28, 29]. The therapeutic exercise component targeted cervical mobility, postural alignment, and neuromuscular control. Active range-of-motion exercises were performed in flexion, extension, rotation, and lateral flexion to maintain joint mobility and stimulate cervical mechanoreceptors. Isometric neck muscle contractions were included to enhance deep cervical muscle activation and improve sensorimotor control, which is known to influence cervical proprioceptive input and joint position sense [30, 31]. These exercises were prescribed to support both mechanical function and afferent feedback from the upper cervical spine. The exercise program included three daily sessions, each consisting of 10 repetitions per movement. This combined treatment approach aimed to reduce pain, increase cervical mobility, and enhance overall functional ability in individuals with cervicogenic headache [30, 31] (see Supplementary material).

The treatment group (TG) additionally received a 10-min GDR proprioceptive training task per session (observation-from-behind of head/neck rotation, mental simulation, and block-recognition responses) with progressive difficulty across sessions. The GDR protocol followed published procedures used in previous GDR studies and in our previous trials [23, 32].

2.3.1. GDR exercise protocol. The experimental setup consisted of a rectangular table (1800 × 400 mm) positioned approximately 75 cm in front of the investigator, with six sequentially numbered blocks evenly spaced across its surface. All blocks remained visible to the participant throughout the task. The investigator directed their gaze toward randomly selected blocks by performing coordinated eye movements and cervical rotation, with each directional change initiated following a standardized cue from a research assistant. Once a block was selected, the investigator maintained a fixed gaze on the target until the participant responded.

Participants were seated in a supported chair with their feet flat on the floor and were positioned behind the investigator to allow clear observation of head and neck movements. They were instructed to keep the trunk stationary throughout the task and to mentally simulate performing the same cervical rotation as the investigator. Specifically, participants were asked to imagine rotating their own neck to follow the investigator's gaze while focusing on the associated neck muscle activity. Based on this internal simulation, participants verbally identified the number of the block they believed the investigator was viewing, responding as quickly and accurately as possible [33].

Task difficulty was progressively increased over the eight-week intervention period by reducing the time interval between trials and gradually minimizing verbal guidance. An assistant therapist monitored each session to ensure correct posture and provided immediate correction if compensatory trunk or body movements were observed. Trials were repeated if postural alignment was not maintained.

Participants did not receive immediate feedback regarding response accuracy during the task. A research assistant recorded both response accuracy and reaction time for each trial. Each complete GDR assessment consisted of 30 consecutive trials and required approximately 10 min to complete. Participants were explicitly instructed to remain still during the assessment, with movement limited to cervical rotation only [32, 33] (Fig. 2).

Fig. 2. Gaze direction recognition protocol provided for treatment group, therapist standing in front and patient from behind with 6 boxes on a table

2.4. Outcomes and measurement

Primary outcomes for this analysis were:

- **Headache frequency *(d/mo)*:** number of headache episodes per month, based on headache diary records.
- **Headache duration *(hr/wk)*:** mean hours per headache attack, based on headache diary records.
- **COP path length:** center-of-pressure path length during quiet standing (single task) was evaluated using the HUMAC Balance System (CSMi, Stoughton, MA, USA) [34]. The HUMAC balance system is reliable and valid to assess postural stability [35]. During the test, patients were instructed to minimize the movement of a purple dot displayed on the monitor (standardized instructions and trial duration), which represented the movement of their body's center of pressure (COP). Participants received continuous visual feedback and were asked to keep the dot as stable as possible. Three trials were conducted for 30 s each, and the total COP path length (in cm) from the best trial was used for analysis. Assessments were made at baseline (pre-intervention) and immediately post-intervention (within one week of the final session; Fig. 3).

2.5. Statistical analysis

A repeated-measures multivariate analysis of variance (MANOVA) was conducted with group (Control, Treatment) as the between-subjects factor and time (pre, post) as the within-subjects factor. Significant multivariate effects were followed by univariate repeated-measures ANOVAs for each dependent variable. Effect sizes are reported as partial eta-squared (η^2_p). Sample size determination was performed using G*Power software through a priori power analysis, focusing

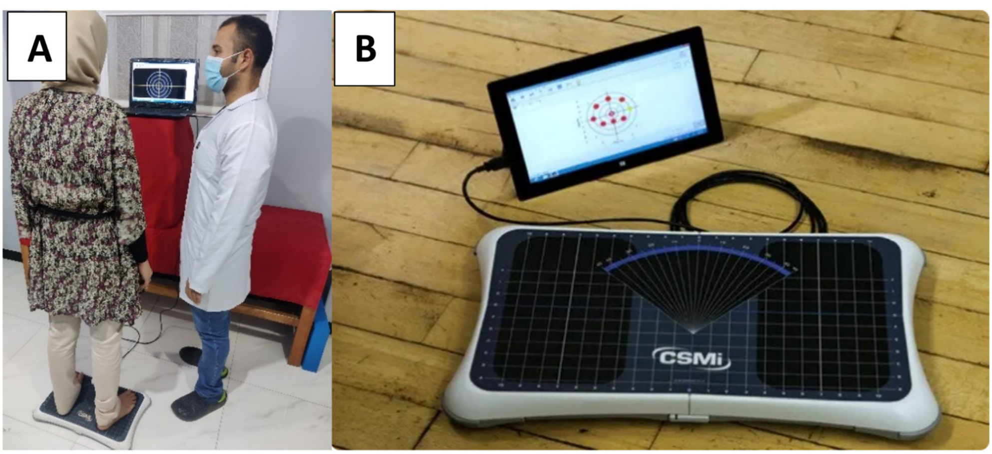

Fig. 3. Assessment of COP path length (cm) using the HUMAC Balance System (A) Participant performing the standing balance test while receiving visual feedback on a monitor to keep stable as much she can. (B) The HUMAC Balance System setup showing the balance platform and display interface used to record center of pressure (COP) path length (cm)

on the expected Group by Time interaction effect. Assuming a medium effect size ($f = 0.25$) and statistical power of 80%, the analysis revealed that 17 participants would be required in each group to identify statistically significant differences. Accounting for an anticipated dropout rate of 20%, the study was designed to recruit a minimum of 20 participants per group. Significance level was set at $\alpha = 0.05$. Analyses were performed using IBM SPSS Statistics (version 25).

3. RESULTS

3.1. Participant flow and baseline characteristics

Thirty-eight participants completed baseline and post-intervention assessments (Control $n = 19$; Treatment $n = 19$). Groups were comparable at baseline with no statistically significant differences in demographic or clinical characteristics (age, sex, baseline headache frequency/duration, COP measures) (Table 1).

3.2. Multivariate analysis

The repeated-measures MANOVA indicated no significant main effect of group on the combined dependent variables at baseline (Wilks' $\Lambda = 0.978$, F (3,30) = 0.22, $P = 0.879$), but there was a significant main effect of time (Wilks' $\Lambda = 0.142$, F (3,30) = 60.55, $P < 0.001$) and a significant group × time interaction (Wilks' $\Lambda = 0.193$, F (3,30) = 41.77, $P < 0.001$), indicating that overall scores changed over time and that patterns of change differed between groups.

3.3. Follow-up univariate ANOVAs

COP path length: No main effect of group (F (1,32) = 0.68, $P = 0.416$, $\eta^2_p = 0.021$), but a large effect of time (F (1,32) = 186.0, $P < 0.001$, $\eta^2_p = 0.853$) and a very large group × time interaction (F (1,32) = 130.0, $P < 0.001$, $\eta^2_p = 0.802$), indicating marked post-treatment improvement in COP path length for the Treatment group relative to Control.

Headache duration: No main effect of group (F (1,32) = 0.087, $P = 0.769$, $\eta^2_p = 0.003$), but a significant effect of time (F (1,32) = 16.0, $P = 0.00035$, $\eta^2_p = 0.333$) and a significant group × time interaction (F (1,32) = 7.43, $P = 0.010$, $\eta^2_p = 0.189$), indicating greater reductions in average attack duration in the Treatment group.

Table 1. Baseline demographic and clinical characteristics of control and treatment groups

Variable	Control (N = 19)[1]	Treatment (N = 19)[1]	P-value[2]
Sex			0.3
F	12 (65%)	9 (47%)	
M	7 (35%)	10 (53%)	
Age (years)	40.8 (4.3)	39.4 (4.1)	0.4
BMI (kg m^{-2})	24.6 (0.7)	24.2 (0.8)	0.12
Headache frequency (days/month)	5.0 (1.5)	6.5 (2.9)	0.085
Headache duration (hours/day)	12.4 (4.9)	14.7 (4.8)	0.2
COP path length (cm)	35.7 (5.9)	37.0 (6.0)	0.5

[1]n (%); Mean (SD).
[2]Pearson's Chi-squared test; Wilcoxon rank sum test.

Headache frequency: No main effect of group (F (1,32) = 0.007, P = 0.935, η^2_p = 0.0002), while time was significant (F (1,32) = 11.7, P = 0.002, η^2_p = 0.267) and the group × time interaction was significant (F (1,32) = 7.61, P = 0.010, η^2_p = 0.192), indicating a greater reduction in monthly headache count for the Treatment group.

In sum, although there were no baseline group differences, all outcomes improved over time and the Treatment group improved more than the Control group, with moderate to large effect sizes (especially for COP path length) (Table 2, Fig. 4).

4. DISCUSSION

The current study examined how proprioceptive and sensorimotor training, which included gaze direction recognition (GDR) exercises, affected postural balance and headache metrics in cervicogenic headache (CGH) patients. The findings demonstrated significant improvements in center of pressure (COP) path length, headache duration, and headache frequency in the treatment group compared with the control group receiving conventional physical therapy. These findings indicate that improving cervical sensorimotor control through combined visual and proprioceptive training can lead to meaningful gains in terms of headache symptoms and postural balance.

Table 2. Pre- and post-treatment changes in headache outcomes: within- and between-group comparisons

Pre- and post-treatment results

Group	Pre-treatment Mean ± SD	Post-treatment Mean ± SD	MD	% Change	*P* value (within)
Frequency (*d/mo*)					
CG	5.03 ± 1.47	4.68 ± 1.32	−0.35	−7%	0.461
TG	6.47 ± 2.94	3.17 ± 1.71	−3.3	−51%	0.003
MD	1.44	−1.51			
P (between)	0.083	0.007			
Duration (*hr/wk*)					
CG	12.42 ± 4.9	11.19 ± 4.94	−1.24	−9.9%	0.365
TG	14.68 ± 4.82	8.16 ± 4.04	−6.52	−44.4%	<0.001
MD	2.26	−3.02			
P (between)	0.184	0.06			
COP (cm)					
CG	35.72 ± 5.89	35.18 ± 5.73	−0.55	−1.5%	<0.001
TG	36.98 ± 5.96	30.86 ± 4.06	−6.12	−16.5%	<0.001
MD	1.26	−4.32			
P (between)	0.541	0.017			

CG: Control Group (standard physiotherapy); TG: Treatment Group (physiotherapy + GDR proprioceptive training); d/mo: days per month (headache frequency); hr/wk: hours per week (headache duration); COP: center-of-pressure path length (cm, best 30s trial); MD: mean difference (post-pre). Data are mean ± SD. Bold $P < 0.05$ indicate significant effects.

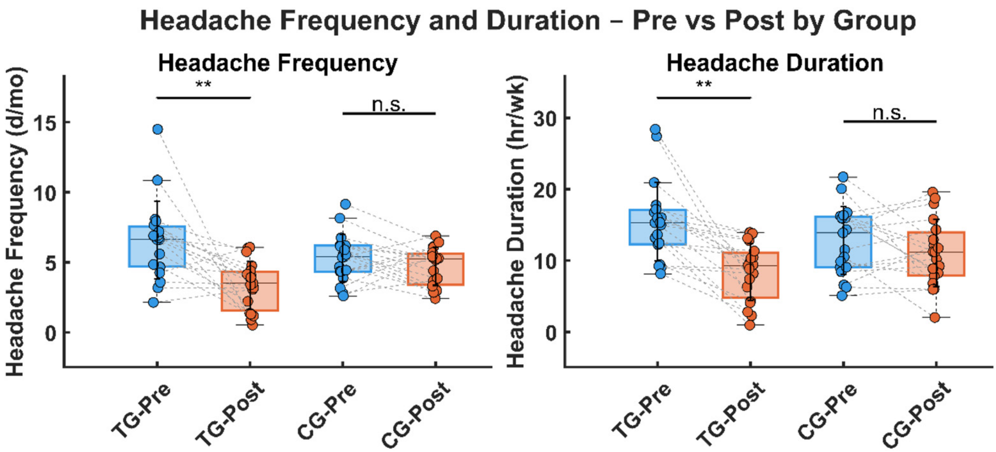

Fig. 4. Headache frequency and duration comparison before and after treatment for treatment and control group

4.1. Headache frequency and duration

The study showed a significant decrease in both the number and length of headaches for participants who, in addition to standard physiotherapy, received proprioceptive training based on gaze direction recognition (GDR), while the control group undergoing only standard physiotherapy for cervical dysfunctions had only slight, statistically insignificant variations (frequency: 51% vs 7% reduction; $\eta^2_p = 0.192$, $P = 0.010$; duration: $\eta^2_p = 0.189$, $P = 0.010$). Because of these moderate effect sizes, the observed improvements were both statistically significant and very likely to be of clinical interest. Thus, it suggests that GDR contributes the extra benefit over conventional physiotherapy in cervicogenic headache (CGH) therapy.

Cervicogenic headache is tightly linked to changes in cervical afferent input and poor sensorimotor integration. Thus, it is postulated that enhancing the precision of proprioceptive signaling would decrease the nociceptive input to the trigeminocervical complex and ultimately, lessen headache burden [27, 28].

Our results are consistent with those of systematic reviews which demonstrate that physiotherapy programs focused on cervical motor control and sensorimotor retraining efficaciously lower headache frequency and disability in CGH patients [25, 26, 29]. Nevertheless, most previous interventions comprise several aspects, which make it difficult to discern the exact sensorimotor features of the intervention; this current research focuses solely on the effects of GDR and thus simply a short visuospatial-proprioceptive task independently reduces headache burden [12].

By challenging cervical proprioception while limiting passive modalities, GDR probably facilitates a higher level of precision of afferent feedback and breaks the cycle of sensorimotor patterns that trigger headache which have been repressed using maladaptive ones. This targeted training can be combined with CGH rehabilitation thus providing a symptom drive mechanism-based relief, which is accompanied by even greater reductions in frequency and duration than the standard care alone [23].

4.2. Postural balance

This study revealed a significant decrease in center-of-pressure (COP) path length after adding GDR-based proprioceptive training, which is indicative of enhanced postural stability in individuals suffering from cervicogenic headache (very large interaction: $\eta^2_p = 0.802$, $P < 0.001$). However, only slight changes were evident in those receiving just standard physiotherapy. Thus, these results adequately argue that cervical sensorimotor training has the potential to significantly improve postural control in such patients.

This is supported by the fact that earlier works have identified balance deficits as well as other neck-related problems in patients with cervicogenic headache, particularly when sensory integration is challenged (e.g. deprived vision or unstable surfaces) [14, 16, 36]. Sensorimotor and proprioceptive training interventions have been shown to improve balance performance and cervical function in patients with neck pain, suggesting that targeting cervical afferent input may positively influence postural regulation [21, 37, 38]. Our findings are consistent with this body of evidence and extend it by demonstrating significant improvements in a quantitative postural-sway measure (COP path length) following a focused GDR-based intervention.

Importantly, the amount of change reported in the treatment group was greater than that observed for the control group thus indicating that visual - cervical sensorimotor retraining offers patients an extra beneficial factor compared to conventional physiotherapy alone. Similar postural stability improvements after GDR-based or sensorimotor exercises have been previously reported in cervicogenic headache and chronic neck pain patients [22, 23]. However, unlike other multimodal interventions, the GDR task addresses actives sensorimotor processing with intentional focus rather than passive treatment components and this could explain why it is beneficial for balance performance.

In line with the current results, Soliman et al. (2025) have shown that a targeted cervical sensorimotor control program which includes gaze-direction recognition exercises, joint repositioning exercises and stabilizer pressure biofeedback provided significantly greater positive contributions to dynamic balance, pain and disability among patients with cervicogenic headache when used in conjunction with conventional physiotherapy. This RCT further supports the concept that addition of sensorimotor components to standard treatment provides benefits for functional outcomes in CGH and supports that interventions targeting cervical afferent feedback and postural control can produce clinically meaningful changes, with improvements in both balance and headache-related symptoms [39].

Besides that, we did not check for cervical proprioceptive deficits (e.g., joint position error) before the intervention, thus the limitation that the improvement in postural control after GDR-based sensorimotor training can be mainly attributed to restoration of proprioception. To confirm the mechanisms, future studies should measure cervical proprioceptive deficits before and after the intervention.

Besides that, incorporating GDR-based sensorimotor training in rehabilitation regimens may help improve postural control in patients with cervicogenic headaches, as indicated by these findings. Further research is necessary to elucidate the link between proprioceptive function, sensorimotor training, and balance improvements by using direct measures of cervical proprioception.

4.3. Neurophysiological interpretation

The neurophysiological pathways through which the intervention of gaze direction recognition training (GDRT) could affect postural balance and headache outcomes could be associated with changes in cervical sensorimotor integration, and not directly related to biomechanical changes. The intervention of GDRT consists of repeated tasks that require the recognition of the direction of the head in relation to the surrounding space. This has been associated with the activation of cervical afferents and higher-order sensorimotor integration systems [13, 33], which play a critical role in the accurate representation of the body and the regulation of postural balance. [39].

The upper cervical spine's abundant mechanoreceptors establish neural connections to vestibular nuclei, cerebellar regions, and spinal pathways, where proprioceptive information integrates with visual and vestibular signals to coordinate postural responses [11]. Through repetitive gaze direction practice, the accuracy of proprioceptive signaling appears to improve, diminishing reliance on compensatory strategies from visual or vestibular systems [40]. This is supported by our finding that the largest group differences emerged during soft-surface eyes-closed conditions, which maximally challenge proprioception while limiting other sensory inputs.

Improvements in proprioceptive accuracy may also help reduce inappropriate neural transmission to the trigeminocervical nucleus, the site where cervical and trigeminal nerve pathways intersect at the upper cervical spine (C1–C3) [1]. When cervical afferent input becomes dysfunctional, it can trigger activation of this nucleus, producing headache pain that is perceived in areas supplied by the trigeminal nerve [41]. By restoring more accurate cervical proprioceptive signals, GDRT may decrease sensitization processes within the trigeminocervical system, leading to fewer and shorter headache episodes [42, 43]. Furthermore, enhanced motor coordination likely promotes more effective activation of the deep cervical stabilizer muscles, reducing mechanical loading on structures sensitive to pain [21].

These changes could be associated with changes in the processing of cervical afferent information and not directly associated with changes in the strength of the muscles and the biomechanical changes in the joints. Further studies that include direct assessments of cervical proprioception, muscle activation patterns, and central sensorimotor processing (e.g., joint position sense testing, electromyography, or neuroimaging) need to be conducted to confirm the proposed changes in the proposed neurophysiological pathways through which the intervention of GDRT could affect the neural pathways associated with headache.

4.4. Clinical implications

From a clinical point of view, the results of this study imply that the addition of cervical sensorimotor exercises, such as gaze direction recognition training (GDRT), could have a beneficial effect on the rehabilitation of patients suffering from cervicogenic headache when used in conjunction with conventional physiotherapy. Physiotherapy programs for cervicogenic headache typically focus on the alleviation of pain, mobility, and strengthening exercises; however, research has shown that cervical sensorimotor function and afferent input disorders are a significant problem in this group and may contribute to headache and other symptoms [9, 10, 44].

Interventions designed to target cervical sensorimotor function have been shown to have a positive effect on balance, neck function, and pain in patients with neck pain and cervicogenic headache [22, 23, 42, 45, 46]. The present study adds to this evidence by demonstrating that a brief, task-specific proprioceptive intervention can produce additional improvements in postural stability and headache outcomes beyond standard care.

It should be noted that the current study did not evaluate long-term outcomes; therefore, no conclusions can be drawn regarding symptom recurrence or sustained effects over time. Nonetheless, given that GDRT is a non-invasive, low-intensity exercise-based intervention, it may represent a feasible and low-risk addition to rehabilitation programs for patients who require alternatives or complements to pharmacological or manual therapy approaches. Future studies incorporating longer follow-up periods are needed to determine whether sensorimotor-based interventions confer lasting clinical benefits.

4.5. Limitations and future directions

However, some limitations of the study must also be pointed out. Firstly, although statistically significant effects were observed, more research with larger sample sizes must be conducted to establish the generalizability and robustness of these effects across different cervicogenic headache patients.

Secondly, since no long-term follow-up was conducted, no conclusions can be drawn regarding the long-term effects and maintenance of improvements observed for headache outcomes and postural control.

Lastly, although improvements were demonstrated for postural balance and headache frequency and duration, cervical proprioception was not directly examined and measured as an outcome. Therefore, although sensorimotor pathways are proposed, they are based on inference rather than objective data. Direct examination and measurement of cervical proprioception, muscle activation, and sensorimotor integration must be included to further clarify these pathways and their underlying effects and improvements following GDR-based sensorimotor training.

5. CONCLUSION

Overall, the present findings indicate that the addition of gaze direction recognition–based sensorimotor training to standard physiotherapy was associated with greater improvements in postural stability and reductions in headache frequency and duration in individuals with cervicogenic headache compared with standard physiotherapy alone. The present study suggests that interventions targeting cervical sensorimotor function may have a beneficial effect in individuals with cervicogenic headache. The lack of direct assessment of cervical proprioception, however, means that it is difficult to ascertain whether the effects found in this study were due to functional improvements rather than underlying mechanistic changes. Further research is necessary to confirm the present study's findings and their long-term clinical implications.

Author contributions: M.E., and M.R. conceived and conducted the measurements. F.S., M.E., and M.R. analyzed the results and M.R., A.A.H. and M.E. interpreted them. S.R. and M.E.

drafted the manuscript, and M.R., A.A.H. and F.S. supervised the entire project. All authors reviewed the manuscript.

Ethical considerations: The ethics committee of Cairo University approved this study (P.T.REC/012/003409) which was conducted in accordance with the latest version of the Declaration of Helsinki.

Conflict of interest: The authors have no conflicts of interest to report.

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SUPPLEMENTARY MATERIAL

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