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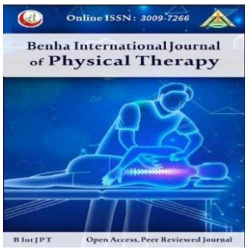

Original research

Effect of Forward Head Posture on Temporomandibular Joint Proprioception in Postmenopausal Women: An observational study.

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Abstract

Background: Forward head position (FHP) is a common postural variation that might harm cervical and craniofacial biomechanics. Age-related hormonal changes and anatomical abnormalities increase the susceptibility of postmenopausal women to postural variation and temporomandibular joint (TMJ) problems. **Purpose:** To determine joint position error (JPE) during mandibular motions to examine the effect of FHP on TMJ proprioceptive function in postmenopausal women. **Methods:** Postmenopausal women with and without FHP participated in an observational study. Under both open-eye and closed-eye situations, the accuracy of TMJ repositioning was evaluated in four mandibular movement directions: right and left lateral deviation, protrusion, and mouth opening. The groups' JPE levels were compared. **Results:** The FHP group's JPE was significantly higher than the controls' in every direction. The mouth opening error (mean ± SD) for the FHP group was 7.33 ± 3.96 mm for open eyes and 8.78 ± 4.95 mm for closed eyes, compared to 1.67 ± 1.06 mm and 2.52 ± 1.33 mm for the controls. The patterns of lateral deviation and protrusion were similar. Deficits in proprioception were more obvious when the eyes were closed. **Conclusion:** FHP significantly impairs TMJ proprioception in postmenopausal women. These findings underscore the importance of postural assessment and modification in managing temporomandibular disorders (TMD) in this population.

Keywords: Forward head posture, Joint position sense, Postmenopausal, Postural balance, Proprioception, Temporomandibular joint disorders.

INTRODUCTION:

Forward head posture (FHP) is one of the most prevalent musculoskeletal postural imbalances [1] in older women, as aging is associated with reduced cervical range of motion (ROM), increased thoracic kyphosis, and a higher prevalence of FHP [2]. These conditions encompass a range of cervical spine pathologies, headaches, temporomandibular dysfunction, visual disturbances, tinnitus, and altered activity in facial and cranial muscles, which can lead to decreased sleep quality [3-5]. FHP is characterized by the extension of the upper cervical spine, specifically, the C0 to C3 cervical segments, combined with the flexion of the lower cervical and upper thoracic segments. This posture results in an anterior displacement of the head's center of gravity relative to the typical axis of motion for flexion and extension of the vertebral column. Studies have shown that increased FHP may contribute to deficits in the cervical sagittal balance parameters, particularly in the cervical sagittal vertical alignment and C2-C7 Cobb's angle[3]. The sagittal C2-7 Cobb angle is the most commonly used method to evaluate cervical lordosis and kyphosis. It is obtained by drawing parallel lines extending from the lower end plates of C2 and C7. Then, perpendicular lines are drawn from the previous lines, and the angle of their intersection is equal to the Cobb angle[3,6,7].

Additionally, it has been suggested that increased thoracic kyphosis may contribute to the development of FHP. A higher incidence of FHP and an increased level of disability are associated with a decrease in the craniovertebral angle, which is the horizontal line traveling through the C7 spinous process and a line that connects the midpoint of the tragus of the ear to the skin overlying the C7 spinous process [3]. The development of FHP is attributed to various factors, including faulty shoulder, neck, and head posture while sleeping; extensive use of computers and mobile phones; and inadequate intake of essential nutrients like calcium. Furthermore, a slouched sitting posture may lead to posterior pelvic tilt, which decreases lumbar lordosis and increases thoracic kyphosis, thereby impacting the cervical spine and potentially contributing to the development of FHP [4,5,8]. FHP can result in significant health issues, including neck pain, headaches, and functional impairments [4, 8]. FHP has been shown to alter the position of the mandibular condyle, causing it to be displaced posteriorly with increased muscle activity of the masseter and digastric muscles, thereby exacerbating the mechanics of the temporomandibular joint (TMJ) [9, 10].

The temporomandibular disorders (TMD) encompass a spectrum of clinical conditions affecting the masticatory muscles, temporomandibular joint (TMJ) and surrounding structure characterized by symptoms including tenderness, exacerbated pain upon mouth opening, limited mouth opening, referred pain to the mandibular angle and neck, muscle fatigue, chronic facial and neck pain, sleep disturbance, and psychosocial distress [11, 12]. The exact causes of common temporomandibular disorders (TMD) are not entirely understood. However, several factors are believed to be associated with their development, including dental occlusion, emotional stress, joint hypermobility, trauma, microtrauma to the teeth, and hormonal changes [11, 12]. It is noted that joint disorders may be linked to hormonal fluctuations, as the presence of estrogen and progesterone receptors in the TMJ disc has been observed [13]. As a result, hormonal changes during menopause might increase women's susceptibility to musculoskeletal and joint diseases [14]. Additionally, muscle hyperactivity or the overuse of masticatory muscles has been suggested as a potential cause of TMD. Muscle overuse and painful TMD can create a "vicious cycle," in which each factor, muscle overuse and pain, reinforces the other [11, 15].

TMJ proprioception is informed by free nerve endings and proprioceptors in muscles and periodontal ligaments, which send sensory information about jaw position and movement to the central nervous system [16-18]. Regarding the influence of FHP on proprioception, a previous study concluded that FHP alters muscle length and negatively affects muscle spindle activity, thereby reducing the sense of joint position [16]. A few studies have looked into the association of FHP with TMD [9, 10, 19], but how FHP impacts TMJ proprioception, specifically in postmenopausal women, is still not well understood. Therefore, this study aims to determine the effect of FHP on TMJ proprioception in postmenopausal women, formulate more effective and tailored preventive and rehabilitative measures for this demographic. So, an appropriate assessment of TMJ proprioception in postmenopausal women with FHP was needed to plan not only rehabilitation but also pre-habilitation interventions to prevent TMJ disorders. Thus, this study was the first to determine the effect of FHP on TMJ proprioception in postmenopausal employees, informing preventive and rehabilitative strategies.

Study Design

The study was designed as an observational cross-sectional study. Before the commencement of the study, ethical approval was obtained from the Institutional Review Board at the Faculty of Physical Therapy, Cairo University (Approval No: P.T.REC/012/003297). The study adhered to the Guidelines of the Declaration of Helsinki on human research. The research was conducted from December 2023 to March 2024.

METHODS

Participants

The study sample consisted of 173 postmenopausal women. Of the 173 participants, 90 were postmenopausal women with forward head posture (FHP), and 83 were postmenopausal women without FHP. Participants were recruited from the Faculty of Physical Therapy at Cairo University and the Faculty of Physical Therapy at MISR University, comprising faculty and staff members. After explaining the study's nature, purpose, benefits, and their right to refuse or withdraw at any time, informed consent was obtained from each participant. Additionally, participants were informed of the confidentiality of any information collected.

Inclusion and Exclusion Criteria

To be included in the study, participants had to be between 50 and 60 years old with a body mass index (BMI) ranging from 25 to 28 kg/m². Participants were excluded if they exhibited any of the following conditions: (a) identified or acquired dental defects, dental prostheses, or conditions such as visual, voice, and hearing disabilities; (b) history of facial paralysis or orofacial, neck, or shoulder fractures or surgeries; or (c) fixed or mobile spinal deformities, headaches, migraines, or vestibular or neurological conditions that might impair proprioception [8, 9]. Participants were classified into two groups based on their craniovertebral angle (CVA). The FHP group consisted of 90 women with a CVA of less than 48°, while the control group consisted of 83 women with a CVA greater than 48° [3]. Twenty subjects were excluded from this study; five had oral problems, and fifteen had spinal deformities (Fig. 1). Additionally, both groups were investigated for the signs and symptoms of TMD using the Clinical Index classification-Fonseca.

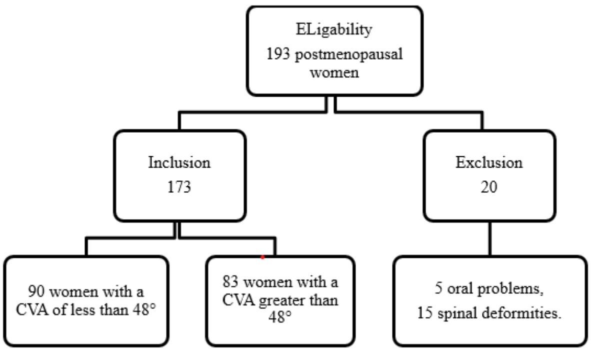

Fig. 1. Flowchart of the study

Outcome Measures

Craniovertebral Angle (CVA) Measurement

CVA is an accepted and validated approach for evaluating forward head posture in clinical and research contexts, which can distinguish between individuals with and without FHP [20, 21]. A Samsung ST65 camera (14.2 megapixels) was used to take a standing, lateral view photo of each participant (Fig. 2A). Since standing posture facilitates easier analysis of FHP, it was chosen over a sitting position [20]. The use of lateral-view photography, as assessed with Surgimap Spine, has been corroborated by multiple studies demonstrating elevated intra-rater and inter-rater reliability. Ethical limitations and exposure to ionizing radiation rendered CT and X-ray techniques impractical for our observational study, which takes a non-intrusive approach [21]. Participants were instructed to tie their hair back and wear disposable coveralls and sleeveless T-shirts. To ensure that the reflective markers were placed correctly, the researcher asked the participant to bend her head to identify the spinous process of C7. She then marked the most noticeable spinous process and the tragus of the ear. The camera was positioned 150 centimeters away from the participant, and a landmark was placed on the floor to ensure proper alignment in front of the camera, perpendicular to its plane of view. The women were instructed to stand upright with their visual axis horizontal to the floor, without external interference affecting their posture [22, 23]. To ensure consistency, three shots were taken at approximately 60-second intervals. The pictures were subsequently imported into the Surgimap Spine application to examine the CVA. The Surgimap Spine program is highly dependable for evaluating spine postural angles from digital images [24]. Specifically, studies have demonstrated that measures are pretty consistent, with inter-rater ICCs ranging from 0.93 to 0.98 and intra-rater ICCs ranging from 0.96 to 0.99 [24]. The CVA was obtained by drawing a line extending from the ear's tragus to C7 and a horizontal line that passed through C7 (fig. 2B). With a CVA cutoff of 48°, the average of the three readings was utilized for analysis; individuals with a CVA less than 48° were classified as having FHP, while those with a CVA more than 48° were classified as controls [20].

Fig. 2: Measurement of the Craniovertebral Angle; (A) A Samsung ST65 camera, (B) the Craniovertebral Angle

TMJ Repositioning Accuracy Measurement

An electronic digital caliper (Circle 300 mm × 0.05 × 1/128, Shanghai, China) provides a direct digital reading of the distance measured with great accuracy and precision **(Fig. 3).** It features a 0.05 mm reading inaccuracy. The calipers have two scales: one calibrated in inches (0 to 12 inches) and another in centimeters (30 cm), with a 10 mm graduation. Numerous clinical studies have demonstrated the accuracy of the caliper in measuring the range of motion of the mandible, as jaw movements are both traceable and quantifiable using the caliper to measure the full ROM of the TMJ in several directions: mouth opening, protrusion, and right and left lateral jaw movements **(Fig. 4).** The digital caliper method was selected due to its non-invasive and cost-effective nature, as well as its validation in prior TMJ studies with inter-rater ICCs of 0.9. This measurement method ensures accurate and reliable measurements of mandibular movements. Additionally, as we measured dynamic functional JPE, radiographic techniques are less suited for repeated, real-time assessments [25]. The following procedure was followed for each measurement. To measure mouth opening, the participant was instructed to open her mouth as wide as possible. The caliper distance between the maxillary central incisor's labioincisal edge and the opposing mandibular incisor [25, 26]. To measure protrusion, the participant was instructed to move the mandible anteriorly without making contact with any teeth while in the physiological resting position of the mandible (i.e., 3 mm between the maxillary and mandibular teeth). The caliper measured the horizontal distance between the maxillary and mandibular central incisors' incisal margins [25]. To measure lateral deviation**,** the participant was instructed to start from the physiological resting position and shift the mandible to the right and left as far as possible. The caliper measures the labioincisal embrasures of the maxillary central incisor and the labioincisal embrasure of the opposing mandibular incisor [25]. For each direction, the caliper measured the calipered range of motion (ROM), and the participant was trained to actively move her jaw from the starting position to the functional ROM. The test was conducted three times with eyes open and three times with eyes closed. The joint position error (JPE) was calculated as the absolute difference between the target and actual positions, and the average error was recorded for each condition [26, 27].

Fig. 3: An electronic digital caliper used for measuring the temporomandibular joint range of motion

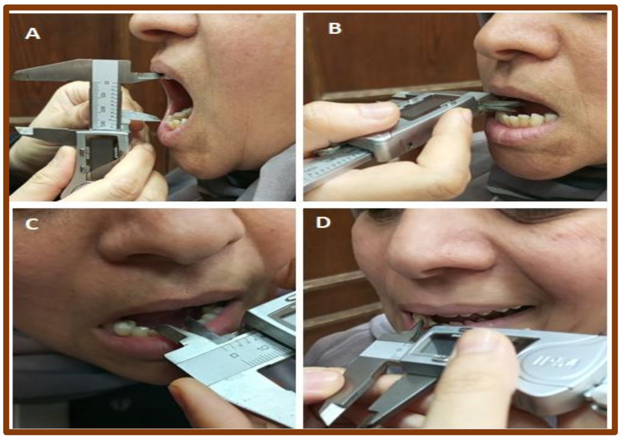

Fig. 4: Measurement of the temporomandibular joint repositioning accuracy in directions: (A) mouth vertical opening, (B) protrusion, (C) right lateral laterdeviation,n,n,n, and (D) left lateral deviation.

Clinical index classification: Fonseca (Signs and Symptoms Temporomandibular Disorders):

The Fonseca questionnaire is an internationally recognized tool specifically designed to evaluate the existence and intensity of temporomandibular disorders, having undergone standardization and validation processes with an Intraclass Correlation Coefficient (ICC) of 0.98 [28]. It consists of 10 questions that assess the presence and the severity of TMD symptoms, including pain, clicking or popping, limited opening, and joint locking. Each question may have a response of "yes," "sometimes," or "no," and each participant could only respond once. Scores interpretation was as follows: 0–15 indicated no TMDs, 20–40 indicated mild TMDs, 45–65 indicated moderate TMDs, and 70–100 indicated severe TMDs [28].

Statistical analysis:

Statistical analysis was conducted using the SPSS computer program (version 23 for Windows). The study included one independent variable, the tested group (between-subject factor), with two levels: the FHP group (A) and the control group (B). The dependent variables were the TMJ repositioning error for vertical opening, protrusion, and left and proper lateral movement with open- and closed-eye conditions. Data normality was verified using the Kolmogorov-Smirnov test. The statistical assumption of homogeneity of variance within and between groups was assessed using Mauchly's sphericity and Levene's test. A one-way between-subjects MANOVA was used to compare the variables of interest between the two groups with open- and closed-eye conditions.

RESULTS

The unpaired t-test statistical analysis revealed that the mean values of participants' age, height, body mass, and BMI did not differ significantly ($p > 0.05$) between the two groups (Table 1). Regarding TMD assessment using the clinical index classification, Fonseca found that between postmenopausal women with and without FHP, the chi-square test revealed a significant difference ($p < 0.0001$) between the two groups **(Table 2).**

Table 1: Demographic data for postmenopausal women with and without Forward Head Posture:

	FHP group (A)	Control group (B)	t-value	p-value
	mean ± SD	mean ± SD		
Age (years)	57.133± 4.20	57.518± 3.845	-0.627	0.532
Body mass (kg)	72.839± 7.265	71.195± 7.022	1.511	0.133
Height (cm)	162.62 ± 7.292	160.939± 6.843	1.561	0.120
BMI (kg/m²)	27.748± 1.424	27.337 ± 1.373	1.931	0.055

FHP: Forward Head Posture, BMI = Body Mass Index, *Significant at alpha level < 0.05. Data are represented as ± SD

Table 2: The frequency distribution and chi-square test value of clinical index classification—Fonseca between postmenopausal women with and without forward head posture:

	No TMDs	Mild TMDs	Moderate TMDs	Severe TMDs	Chi-Square Test value	p-value
FHP group (A)	0 (0%)	55 (61.11%)	25 (27.77%)	10 (11.11%)	173.000	0.0001*
Control group (B)	83 (100 %)	0 (0%)	0 (0%)	0 (0%)		

FHP: Forward Head Posture, TMDs: Temporomandibular joint disorders, *Significant at alpha level < 0.05. Data are represented as numbers and percentages.

All dependent variables, including repositioning error for TMJ vertical openness, protrusion, and right and left lateral deviation, were substantially impacted by the tested group, according to the one-way between-subjects MANOVA (F-value = 113.632, p-value < 0.0001, partial η2 = 0.863).

The subsequent multiple pairwise comparison tests revealed significant increases ($p < 0.05$) in the mean values of all measured variables (TMJ repositioning error in all directions of motion, both with open- and closed-eye conditions) in the FHP group compared with the control group **(Table 3).**

Table 3: Descriptive statistics and multiple pairwise comparison tests of all measured variables between postmenopausal women with and without Forward Head Posture:

TMJ repositioning error	FHP group (A)	Control group (B)	Mean difference (95% CI)	F-value	p-value
Mouth opening with an open eye	7.33± 3.96	1.672± 1.06	5.662 (4.564 to 6.760)	143.383	0.001*
Mouth opening with closed eyes	8.78± 4.95	2.52± 1.33	6.252 (5.143 to 7.361)	123.764	0.001*
Protrusion with opened eye	1.709± 1.00	0.543± 0.208	1.166 (0.943 to 1.389)	106.530	0.001*
Protrusion with closed eyes	2.98± 0.93	1.329± 0.488	1.659 (1.433 to 1.885)	210.039	0.001*
Right lateral motion with opened eye	2.76± 1.16	0.986± 0.22	1.774 (1.518 to 2.031)	186.494	0.001*
Right lateral motion with closed eyes	3.52± 0.97	1.33 ± 0.22	2.192 (1.976 to 2.409)	399.637	0.001*
Left lateral motion with opened eye	2.62± 1.18	0.645± 0.186	1.975 (1.715 to 2.236)	224.06	0.001*
Left lateral motion with closed eyes	3.54± 0.973	1.14± 0.42	2.409 (2.18 to 2.638)	432.646	0.001*

FHP: Forward Head Posture, CI: Confidence Interval, *Significant at alpha level < 0.05. Data are represented as ± SD.

DISCUSSION

The findings of this study reveal that FHP significantly impairs TMJ proprioception in postmenopausal women, as evidenced by increased joint position errors (JPE) across all mandibular movements. Under both open- and closed-eye conditions, the FHP group consistently demonstrated greater JPE than the control group, highlighting how altered cervical alignment compromises neuromuscular control for precise mandibular coordination.

The finding that postmenopausal women with FHP show greater TMJ JPE may be attributable to the menopausal transition's hormonal shifts, particularly the drop in estrogen levels. Estrogen is essential during the postmenopausal period because it aids in regulating collagen synthesis, which helps maintain the functional and structural integrity of the joints, preserves ligamentous elasticity, and increases the sensitivity of proprioceptors in connecting tissues [13, 29]. The reduction of estrogen during menopause leads to deterioration in joint stability and neuromuscular coordination, which is elicited by proprioceptive deficits resulting from mechanical dysfunctions such as FHP [13, 29, 30]. Research indicates that women tend to be more vulnerable to TMJ disorders after menopause. For example, one study found a substantial correlation between low estrogen levels and the prevalence of temporomandibular disorders (TMD) among postmenopausal women. Some other research pointed out that a lack of estrogen might lead to inflammatory changes in the TMJ, resulting in pain and dysfunction [13, 29].

FHP is often seen in postmenopausal females due to greater cervical spine ailments and changes in their posture. The degeneration of the cervical spine and posture alignment is increased in this group of women, mainly due to hormonal shifts along with the decline of other bodily factors related to menopause. The reduction of estrogen levels significantly impacts muscle mass and muscle strength. Estrogen is crucial in maintaining muscle mass; its deficiency leads to muscle wasting and a decrease in force production, which is associated with erectile changes, such as FHP. With ageing and changes in hormone levels, there is a continuous progression of cervical spine degeneration, characterized by a reduction in disc size and arthrosclerosis of the facet joints. There is a possibility that these conditions could change the alignment and biomechanics of cervical vertebrae and facilitate features of FHP [4, 6, 13, 29]. Sarcopenia, the loss of skeletal muscle mass and the associated bodily functions are highly exacerbated for women who are post-menopausal and in later ages due to the changes in hormones. Sarcopenia decreases muscle strength in the cervical and upper thoracic regions, thereby reducing the support provided to the head and neck skeleton, which can lead to FHP [8, 31]. Osteoporosis, the depletion of female hormones, leads to rapid bone demineralization. Compression fractures in the vertebrae, particularly in the thoracic spine, increase Kyphosis, which forces the head to move forward to maintain balance. Chronic pain and reduced mobility individuals who are post-menopausal women tend to suffer from chronic orthopedic pain, which results in adopting compensating body postures that relieve discomfort while struggling with treating FHP [8, 31]. Psychosocial factors, such as paying less attention to social relationships, can lead to mood changes, along with eruptions of self-depression and fatigue, which can result in poor posture disturbances ending in slumped shoulder posture, accompanied by a bent head [6].

FHP increases the physical strain placed on the cervical and upper thoracic musculature, resulting in shoulder and neck pain. The postural alteration can limit the expansion of the thorax and, therefore, lung volume. Changes in proprioception and vestibular systems caused by FHP increase the likelihood of falling. Driving or reading involves head and neck movements, which may become difficult to perform[5,6,8,9,32]. An integrated mechanical and endocrine imbalance, resulting from hormonal insufficiency and biomechanical misalignments, could increase the risk of sensorimotor dysfunction. In particular, the cervical misalignment that defines FHP alters the relevant neural structures and interacts with the hormonal context, weakening the vascular responsiveness of the joint receptors. It becomes evident that these mechanical and endocrine interactions from surface structures globally impair the brain's ability to integrate proprioceptive signals stemming from the TMJ, thus resulting in increased JPE during jaw movements. This explains why older women experiencing TMJ proprioceptive deficits from FHP have discernible difficulty stabilizing their head about their body [30-32].

The reduced TMJ proprioceptive acuity in postmenopausal women with FHP can be attributed, on the one hand, to cumulative dysfunctions from head postural misalignment. On the other hand, operating skeletal factors make sense of the mechanics. Poor habitual posture, neck dysfunctions, and activity restrictions are not acute outcomes of aging; however, the overlap of thoracic kyphosis and FHP tends to be more common in older individuals due to cumulative postural adaptations that occur over time. This gradual shift in postural control, particularly affected by repetitive strain and absence of movement, generates chronic compensatory alterations to head and neck positions, which aim to maintain a line of sight towards the ground. With the active head posture maintained over time, the vertebrae are forcibly ordered to achieve and maintain a position that facilitates functional head movement, which in turn longitudinally locks the spine into a symmetric, non-neutral position [33, 34]. Such alignment is needed to ensure a restful position for the TMJ, which might enhance the likely disturbed proprioceptive feedback and facilitate adaptive muscle synergies around the neck. In these women, further factors contribute to the mechanical restraints; shifts induced a lack of estrogen, the primary metabolic driver. It weakens the skeleton's deformability and tactile elements around the joints and lowers sensitivity around the proprioceptor devices of active matrices. It is essential for maintaining collagen structure and controlling motoneurons. Menopause significantly alters the mechanisms of severe feedback loops that sustain joint slackness in the absence of muscle activity and eroded proprioceptive signals [13, 29]. Strapping down the peripheral deviations and diffuse hormonal remodeling, which was superimposed and exacerbated by amplified summation, significantly impaired the TMJ's ability to interpret the signals sent through the monitoring systems integrated at the joint level. This might account for the remarkable increase in JPE noted in all mandibular movements in the postmenopausal women with FHP.

Another musculoskeletal explanation is that hyperkyphosis is a significant health risk commonly observed in older adults. An increase in the thoracic kyphosis angle has been linked to reduced mobility in older individuals. While FHP and hyperkyphosis are closely related mechanically and functionally, FHP can occur independently of hyperkyphosis in older adults. Some studies have shown that individuals experiencing head, neck, and shoulder pain typically have a smaller CVA, which indicates FHP compared to asymptomatic individuals. Another musculoskeletal explanation, cervical spine dysfunction, is a common musculoskeletal issue among the working-age population, which is a leading cause of disability [5, 35]. Pain can lead to postural changes and reduced range of motion, ultimately decreasing mobility in one or more vertebrae [2, 35].

CVA and Cobb's angle are two postural metrics used to evaluate FHP in older women. Like other body parts, posture also changes with age, and these measurements capture such changes. The CVA is typically between 48 ° and 55° in normal individuals [21, 36]. FHP is associated with a CVA of less than 48° [20], which is common among older women due to musculoskeletal aging, weakness of the cervical musculature, and other factors that facilitate sustaining horizontal gaze [3, 4]. Maximal vertebral rotation during thoracic kyphosis is called Cobb's angle. It helps evaluate kyphosis in the thoracic and vertebral regions and is applied to assess cervical spine alignment. The cervical Cobb's angle is measured on lateral radiographs between C2 and C7 and serves as an estimator for cervical lordosis. The Cobb angle of the cervical spine is generally between 20° and 40°. An angle less than the lower limit suggests straightening of the spine or kyphosis, which is frequently seen in FHP [36,37]. Such reduced cervical spine curvature alters the way loads are distributed in the spine, leading to increased strain on the intervertebral discs, facet joints, and surrounding muscles, while also enhancing the stress-bearing capacity of the structure [38, 39]. Importantly, an inverse relationship between Cobb's angle (both thoracic and cervical) and CVA tends to exist. An increase in thoracic kyphosis or a decrease in cervical lordosis reduces CVA, illustrating how different parts of the spine curvature depend on one another [39, 40]. Decreased CVA and changing posture to look downward can hinder cervical proprioception and balance control, impairing TMJ function [41].

The joint proprioception deficit in the TMJ of postmenopausal women with FHP may be partly due to impaired muscle spindle signaling and neuromuscular imbalances. Because of increased age, fatigue, or other debilitating disorders, postmenopausal women tend to become more susceptible to these factors, which muscle spindles greatly rely on to maintain a sense of posture and position [42]. Moreover, this failure reduces proprioceptive input from the cervical spine and the masticatory system. Due to the intricate neural pathways and biomechanical design that interact with each other, any disturbance in cervical proprioception becomes responsive enough to alter the mandible's logical spatial and controlling microsystems [43]. Having FHP amplifies this problem by further compromising the yielding relaxation and contraction of the upper thoracic and cranial regions, as well as the rest of the neck muscles. This posture is usually described by a short and overactive motion of the suboccipitals, sternocleidomastoid, levator scapulae, scalenes, upper trapezius, pectoralis major and minor, as well as weak and lengthened deep neck flexors, lower trapezius, and rhomboids. These head positions help explain why the imaging is below the body's midline. This leads to muscular imbalance, which affects the brain's ability to accurately interpret diagnostic sensors and integrate joint position information in a significantly less realistic capacity [43]. Consequently, FHP women exhibit significantly greater TMJ JPE than their contemporaneous mandibular movements compared to women with normal head posture, emphasizing the importance of cervical-muscular balance in maintaining precise TMJ proprioception in postmenopausal subjects.

These deficits may stem from biomechanical factors, such as the backwards movement of the mandibular condyle due to cervical flexion and muscle imbalance, which potentially disrupts the peripheral signaling of periodontal and masticatory proprioceptors [17, 44, 45]. This deficit is a result of the quality of sensory feedback.

Another possible factor for the elevated JPE for all mandibular motions in the FHP group may be the effect of the stomatognathic system JPE [46]. The stomatognathic system, a fundamental aspect of postural regulation, encompasses the temporomandibular joint (TMJ), dental and periodontal tissues, and the masticatory neuromuscular system [47]. The suprahyoid and infrahyoid muscles are stretched due to increased passive tension in FHP. The normalized electromyographic (EMG) activity of the muscles was significantly lower in individuals with FHP compared to those with normal head posture. This finding suggests that FHP negatively affects the EMG activity of the hyoid muscles when stretched [48]. FHP, a significant risk factor for TMD, can potentially influence the positioning of the center of gravity, thereby affirming the correlation between bodily posture and TMD [46]. It has been documented that FHP impedes optimal muscle activation patterns by attenuating cervical spine endurance, which may subsequently influence spinal movement patterns and induce alterations in proprioceptive awareness [49].

The diminished perception of joint positioning, reflected by increased JPE, may be attributed to the exacerbation of cervical pain and disability in postmenopausal women with FHP. Prior investigations have elucidated a correlation between nociception and the dysfunction of joint position awareness, leading to the hypothesis that the cervical and mandibular pain experienced by TMD patients could result in a deficit in cervical joint position perception [16, 41, 50].

One of the neuromuscular explanations, increased jaw proprioception (JPE) during jaw opening, protrusion, and lateral movements, further supports the theory that FHP alters cervical muscle spindle sensitivity, thereby affecting sensorimotor integration between the cervical spine and the temporomandibular joint (TMJ) [51]. Previous studies have demonstrated that neuromuscular pathways between the cervical spine and TMJ are interdependent, making both regions vulnerable to postural misalignment [41, 52]. The study by Armijo-Olivo et al. shows a weaker correlation [22]. However, it did consider mediated influences, such as emotional strain and parafunctional activities. This influence was controlled for in our study design, which increased the validity of the relationship between FHP and TMJ dysfunction.

FHP inhibits proprioception at the TMJ due to its effect on sensorimotor and vestibular integration, resulting in deficient proprioception caused by a lack of input and integration. The posture of FHP causes FHP to modify the incoming signals from cervical mechanoreceptors to the muscle and somatic sensation to the brainstem, with a hardwired increase in sympathetic tone, resulting in constriction of motor control posture and sensorimotor functionalities, as well as mechanoreception, regulation, and maintenance. According to Moustafa et al.'s study, misalignment of the head and neck in the cervical region is associated with FHP, which negatively impacts feedback from the periphery to the central nervous system, leading to inappropriate peripheral muscle actions. Consequently, changes to the autonomic nervous system signals elicit an unhealthy response. Their results showed that patients with FHP had significantly greater amplitude responses, particularly when sympathetic activation was higher, compared to the group aligned in a normal headrest, with the same latency values. This suggests that the central nervous system perceives distorted head position as a constant stimulus, triggering stress and leading to overactive autonomic outputs [53]. Hypothetically, in the case of TMJ function, increased tone in the sympathetic nervous system, and restricted sensorimotor mechanism input prevent the brain from suitably programming the proprioceptive feedback necessary for measuring joint position during mandible movement. So, during jaw movements, the JPE is higher than anticipated. That information leads to false output prediction, further accentuating this situation. Incorrect input due to posture imbalance will inevitably hinder efficient and adaptive muscular control. The stated factors might explain why postmenopausal women are at higher risk for spinal issues due to the decline in neuromuscular control with age or the decremental effects of hormones on connective tissue quality, along with existing scoliosis. Thus, appropriate stance and head position are crucial for preserving TMJ proprioception and sensorimotor control accuracy [53].

Clinical Implications

The study's findings emphasize the importance of incorporating postural assessment and correction into the clinical management of temporomandibular disorders (TMDs), particularly in postmenopausal women. The possible effects of preventive measures, sensorimotor exercises, and posture realignment as a non-invasive technique addressing the quality-of-life issues associated with TMJ dysfunction in this group. Based on the results, further research into rehabilitation programs that incorporate cervical stabilization, proprioceptive training, and TMJ neuromuscular reeducation may help mitigate the synergistic effects of FHP and hormonal decline. TMJ-specific neuromuscular training and postural correction programs may help reduce the synergistic effects of FHP and hormonal decline, thereby counteracting the combined impact of hormonal decline and biomechanical dysfunction. Also, understanding how estrogen deficiency interacts with the pathology of TMJ disorders is essential for planning treatment approaches.

Limitations and Future Directions

This cross-sectional study cannot establish causal inferences. Additionally, the limited demographic scope may affect the generalizability of the findings. Future research should investigate whether correcting FHP can enhance TMJ proprioception and reduce TMD risk by utilizing longitudinal and interventional designs. Lack of radiographic imaging may restrict anatomical detail. No hormonal or EMG measurements were conducted.

CONCLUSION

This study suggested that FHP would severely compromise TMJ proprioceptive function, as seen by increased JPE during all mandibular motions. These proprioceptive deficits were more pronounced in the postmenopausal population studied here than in previous work involving younger individuals. As discussed earlier, this may be attributed to the hormonal effects synergizing with postural misalignment to amplify joint instability. Consequently, postural correction, proprioceptive training, and hormone-informed rehabilitation protocols should be emphasized in clinical practice to optimize patient outcomes.

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Conflict of interest

The authors have no conflict of interest.

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