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The relationship between forward head posture, postural control and gait: A systematic review

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ABSTRACT

Background: Forward head posture (FHP) is a common postural deviation. An increasing number of studies have reported that people with FHP present with impaired postural control and gait; however, there is conflicting evidence. A systematic review focusing on these relationships has been unavailable to date.
Research question: Is there a relationship between FHP, postural control and gait?
Methods: This systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement (PROSPERO ID: CRD42021231908). Web of Science, PubMed, Scopus, and CINAHL Plus (via EBSCO) were systematically searched, and a manual search was performed using the reference lists of included studies. Eligible studies included observational studies addressing the relationship between FHP, postural control and/or gait. Quality assessment was conducted using the Joanna Briggs Institute Critical Appraisal Checklist for Cross-Sectional Studies.
Results: Nineteen studies were selected for this review. Consistent evidence supported that people with FHP had significant alterations in limits of stability (n = 3), performance-based balance (n = 3), and cervical proprioception (n = 4). Controversial evidence existed for a relationship of FHP with static balance (n = 4) and postural stability control (n = 4). Limited evidence existed to support an alteration in gait and vestibular function. Three studies on induced FHP consistently identified no reduced postural control.
Significance: Current evidence supports an association between FHP and a detrimental alteration in limits of stability, performance-based balance, and cervical proprioception. Instead of simply indicating impaired overall balance, the findings of this review indicate that a reduction in specific aspects of the postural control requires to be clarified in clinical evaluation for individuals with FHP, which would facilitate the planning and application of appropriate interventions to prevent dysfunctions and disability.

1. Introduction

Forward head posture (FHP) is one of the most common postural deviations in the sagittal plane [1]. FHP is generally manifested by an excessively anterior head position relative to the shoulder [2]. A significant association exists between sagittal spinal alignment, postural control and fall risks [3], and a radiographic study further demonstrates that alterations in sagittal cervical alignment are associated with decreased postural control [4]. Therefore, recent studies have focused their investigations on the relationship between FHP and postural control [5,6]. Current research indicates that participants with FHP have reduced vestibular and proprioceptive functions, which are crucial sensory inputs for postural control [7,8].

Postural control requires accurate sensory integrations of vestibular, visual and proprioceptive inputs and appropriate motor responses to the displacement of the centre of gravity (COG) [9,10]. Proper postural control is one of the prerequisites for a normal gait [11], while gait disturbance also causes immobility, falls, and increased mortality [12]. One cohort study indicates that increased risk of all-cause, cardiovascular disease and cancer mortality are associated with balance disorders, including vestibular, visual and proprioceptive-specific balance disorders [13].

A systematic review focusing on the relationship between FHP, postural control and gait has been unavailable to date, which impedes

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researchers' understanding and further investigation. Considering the significant hazards of postural control and gait disorders, it is imperative to clarify these relationships. Further understanding and early warning of the impacts of FHP can facilitate the planning and application of appropriate interventions to prevent dysfunction and disability. Therefore, this systematic review aimed to determine whether there is a relationship between FHP, postural control and gait.

2. Methods

This systematic review was conducted according to the PRISMA statement [14] and registered in the PROSPERO International Prospective Register of Systematic Reviews (CRD42021231908).

2.1. Eligibility criteria

The eligibility criteria were presented based on population, exposure, comparator, outcome, and study design (PECOS framework) [15], as listed in Table 1.

2.2. Information sources and search strategy

The systematic search was conducted in the following databases: Web of Science, PubMed, Scopus and CINAHL Plus (via EBSCO) from inception to 28 January 2021. Restrictions applied were human studies, observational design (e.g., cohort study, case-control study, and cross-sectional study), and English language. No restrictions were imposed on the publication date, sex, and age of participants. Also, the reference lists of included studies were searched for additional studies. The complete search strategy is presented in Supplementary Appendix 1.

2.3. Study selection

All titles and abstracts were imported into Mendeley Desktop© (version 1.19.4) for removing duplicates and screening irrelevant studies. Two independent reviewers (GHL and XZ) initially screened a random sample of 100 studies as a training exercise to optimise inter-reviewer reliability before the formal screening. Following the initial training period, the same two reviewers independently screened all studies according to the eligibility criteria (Table 1). Two reviewers were blinded to each other's decisions before final comparisons. After titles and abstracts screening, full texts of potentially relevant studies were retrieved for further identification. The reasons for excluding studies were recorded. Discrepancies in decisions from the reviewers were resolved by discussion with a third reviewer (TW) until consensus was reached.

Table 1
Eligibility criteria based on PECOS.

Inclusion Criteria		Exclusion Criteria
Population	• Healthy participants • Any sex • Any age	• Any condition impairing postural control and gait
Exposure	• FHP measured by using reliable and objective methods (distance or angles between anatomical landmarks, e.g., craniovertebral angle, occiput-to-wall distance, cervical range of motion, and head shift distance)	• No FHP measured • No reliable and objective methods used
Comparators	• No FHP or lower severity of FHP	• Any condition impairing postural control and gait
Outcomes	• Studies investigating a relationship between FHP, postural control and/or gait (must include one of the following aspects: proprioception, vestibular function, postural control and gait)	• Studies not investigating a direct relationship between FHP, postural control and/or gait
Study design	• Observational studies (e.g., cohort study, case-control study, or cross-sectional study) • Human studies • Published as research articles • English only • Studies published up to 28 January 2021	• All studies not including observational design (e.g., clinical trials) • All studies using animals • Full text not available

PECOS: population, exposure, comparator, outcome, and study design; FHP: forward head posture.

2.4. Data extraction and data items

The two reviewers independently extracted data from each eligible study using a standardised form. To ensure inter-reviewer consistency, they initially extracted data from three excluded studies as a calibration exercise. All data extracted were compared, and disagreements were resolved by discussion. The data extracted from eligible studies were presented in tabular format (Tables 2 and 3), according to (1) general study information (authors and year), (2) demographic characteristics of participants, (3) recruitment criteria, (4) measuring methods and results of FHP, (5) outcome measures, (6) statistical analysis, (7) main outcomes, and (8) conclusions.

2.5. Quality assessment

For methodological quality assessment, the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Cross-Sectional Studies was used. As all included studies adopted a cross-sectional design, the JBI appraisal tool was implemented (Table 4) [16]. It includes eight aspects: (1) criteria for sample selection, (2) descriptions of subjects and setting, (3) exposure measurement methods, (4) measurement of the condition, (5) confounder identification, (6) strategies for confounder control, (7) outcome measurement methods, and (8) statistical analysis.

The reviewers independently assessed the methodological quality of each study. Corresponding authors were contacted for more details when available information was insufficient for quality assessment. Disagreements between reviewers were resolved by discussion with a third reviewer when necessary. Findings of eligible studies with low quality were interpreted with caution, although all studies matching eligibility criteria were included. Furthermore, studies were excluded from data synthesis if they did not meet the eighth criterion about statistical analysis in quality assessment.

2.6. Data synthesis

Results from high-quality studies with a low risk of bias were prioritised in data synthesis. The included studies were grouped according to their topics, i.e., postural control, gait, and induced FHP. Postural control was further divided into static balance, dynamic balance, performance-based balance, proprioception and vestibular function (Table 5). Performance-based balance was defined as postural control assessed by physical performance tests and scales. The extracted data were synthesised and analysed using a narrative method due to high heterogeneity in populations, diagnostic criteria of FHP, outcome measures, and data types across studies.

2.7. Reporting

For complete and transparent reporting, this systematic review complies with the PRISMA statement [14] and the Synthesis Without Meta-analysis (SWiM) reporting guideline [17].

3. Results

3.1. Study selection

The study selection process is presented as a flow diagram (Fig. 1) according to the PRISMA guideline [14]. A total of 7142 studies were identified across four selected databases through manual search. After the removal of duplicates, 4407 studies remained for further screening according to the eligibility criteria (Table 1). Full texts of 37 studies were assessed for eligibility. At the conclusion of the selection process, a total of 19 including two manually searched studies [18,19], were selected for this review, while 18 were excluded for specific reasons (Fig. 1).

3.2. Study characteristics

All studies included in this review were cross-sectional studies published between 2006 and 2020. Sixteen studies recruited participants with habitual FHP and neutral head posture [5,6,18–31], while the remaining three studies instructed healthy participants to simulate FHP [32–34]. Based on their subtopics, the studies included were categorised into seven groups (Table 5). Six studies without a comparison group only reported correlation data between FHP and relevant topics [6,18,20,24,26,29]. The overview of the studies and the retrieved data are presented in Tables 2 and 3.

3.3. Quality assessment

Results of the quality assessment using the JBI Critical Appraisal Checklist for Cross-Sectional Studies are presented in Table 4. The inter-reviewer agreement for quality assessment was 92.8 %. Of the 19 studies included, 13 received affirmative scores over 80 % [5,6,18,20,24–27,29–33], two of which fulfilled all eight criteria of the JBI checklist [6,27]. The second criterion of the JBI checklist was the frequently missed component, particularly in locations and time periods of the study setting. The fifth and sixth criteria, involving confounders identification and strategies, were not met in six studies [19,21–23,28,34] and were not applicable in five studies [18,20,24,26,29]. One study did not report the demographic characteristics of participants [19]. Two studies had an unclear mark in the fourth criterion due to limited information and no authors' email [19,22]. Additionally, the results of one study were not synthesised in corresponding subgroups because this study used a paired t-test for two unpaired groups of subjects [21].

3.4. FHP assessment

All studies employed reliable and objective methods to measure FHP (Tables 2 and 3). A total of 13 studies adopted the craniovertebral angle (CVA) as the measurement of FHP but with different diagnostic criteria: (1) <53 degrees as FHP group by four studies [19,21,27,28]; (2) <50 degrees by two studies [5,22]; (3) <49 degrees by one study [34]; (4) <48 degrees by one study [31]; (5) no clear criteria given by five studies [20,25,26,29,32].

Of the remaining six studies, two studies used the head postural

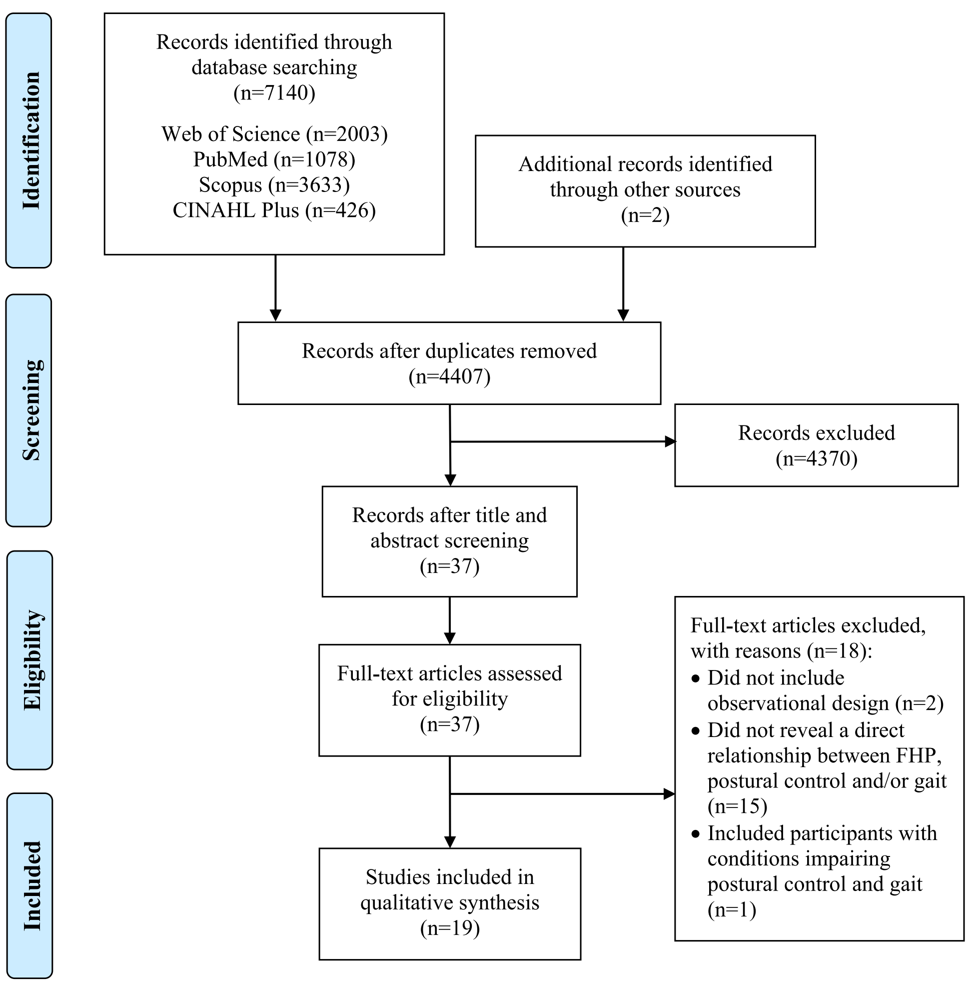

Fig. 1. PRISMA flow diagram of study selection.

Table 2
Characteristics of the included studies.

Studies	Participants	Recruitment criteria	FHP measurement			Outcome measures	Statistical tests	Main outcomes	Conclusions
			Measures	**Position**	**Results**				
Hyong and Kim [20]	N=51 (M 22/F 29) Age=21.8±2.1 years Height=166.8 ±9.7 cm Weight= 62.0 ±12.0 kg	I: healthy undergraduates without cervical or shoulder pain, or hospital diagnosis of musculoskeletal dysfunction in the previous four weeks	CVA by photo	Sitting	52.0±5.1 degrees	•Static balance: COG, COP (Tetrax Portable Multiple System) •ROM of ankle joints in supine position: Distal dualer-IQ	Multiple regression	•STI (P>0.05) •ROM of ankle joints (P<0.05)	FHP had no influence on static balance but reduced ROM in plantarflexion of ankle joints.
Lee [21]	N=30 •Experimental group: N=14 (M 7/F 8)[i] Age= 22.1±1.6 years Height=166.1 ±8.8 cm Weight=59.4 ±10.7 kg BMI=21.3±2.4 •Control group: N=16 (M 8/F 8) Age= 21.6±1.1 years Height=168.4 ±8.2 cm Weight=60.4 ±11.6 kg BMI=21.25±2.4 kg/m^2	I: no history of neuromuscular or spinal disease or surgery in the neck or spinal vertebrae	CVA by photo (<53 degrees)	N/A	N/A	•Static balance: COG (I Balance S) •Dynamic balance: Spine Balance 3D	Paired t-test	•Hard surface: COG sway velocity with eyes open or closed was higher in FHP (P<0.05) •Unstable surface: COG sway velocity with eyes closed was higher in FHP (P<0.05) •On both surfaces: COG total sway distances with eyes open and closed were higher in FHP (P<0.05) •Dynamic balance scores in eight directions (P>0.05)	FHP had a greater effect on static balance control than on dynamic balance control.
Karajgi et al. [22]	N=50 Age: 18-25 years •Experimental group: N=25 •Control group: N=25	I: <50° (CVA), asymptomatic E: neck pain or muscle spasm and any known musculoskeletal or neurological disease with balance impairment	CVA by photo (<50 degrees)	N/A	N/A	•Static balance: COG (MCTSIB using Neurocom® Balance Master) •Dynamic balance: LOS (Neurocom® Balance Master)	Unpaired t-test (Modified clinical test for sensory interaction in balance) ANOVA (Limits of stability)	•COG sway velocity (P>0.05) •Reaction time in the forward direction (highest), right forward and left forward (P<0.05) •Endpoint excursion (not shown)	FHP resulted in increase in reaction time, movement velocity and endpoint excursion in forward head direction but had no effect on balance in MCTSIB.
Kang et al. [23]	N=60 •Experimental group: N=30 (M 22/F 8) Age=34.9±2.1 years Height=173.6 ±6.2 cm Weight=72.5 ±5.1 kg Computer=6.5 ±0.4 hrs/day •Control group: N=30	I: adults aged between 30 and 40 with no abnormal finding confirmed through physical examination and cervical radiology examination E: Individuals with a history of treatment for cervical, thoracic, or lumbar disorders, and current conditions of joint pains in ankles, knees, or hips, as well as	Difference Subtracting monitor-facing angle from CVA by photo	Sitting (2 hours after using a computer)	•Experimental group=28.2 ±8.3 degrees •Control group=32.9 ±6.0 degrees	•Static and dynamic balance: COG (Gait view®); SOT, LOS (Neurocom® Balance Master)	Independent t-test; Pearson's correlation	•COG (static and dynamic) (P<0.05) •SOT (Equilibrium score in conditions 5 and 6) (P<0.05) •LOS (MVL, EPE and MXE, P<0.05) (RT and DCL, P>0.05) •Pearson correlation coefficient between condition 6 and the severity of FHP, between COG in static and balance ability in condition 6,	COG moving forward and reduced balancing ability were confirmed in heavy computer users with FHP.

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Table 2 (*continued*)

Studies	Participants	Recruitment criteria	FHP measurement			Outcome measures	Statistical tests	Main outcomes	Conclusions
			Measures	**Position**	**Results**				
	(M 21/F 9) Age=35.2±2.1 years Height=173.4 ±6.7 cm Weight=70.5 ±4.9 kg Computer=0.8 ±0.7 hrs/day	limited mobility that could affect body balancing ability						between COG in dynamic balance and condition 5&6 ($P<0.05$)	
Jain [19]	N=60 •Experimental group: no data •Control group: no data	I: experimental group (CVA<53 degrees), control group (CVA>53 degrees)	CVA by photo (<53 degrees)	N/A	N/A	•Dynamic balance: LOS (Neurocom® Balance Master)	Paired t-test	•LOS (RT, MVL, EPE, MXE and DCL, $P<0.05$)	Individuals with FHP showed decreased balancing ability compared to normal head posture group.
Abdelghany et al. [24]	N=40 Age=19±1.15 years (18-21 years) Height=172.45 ±5.22 cm (159-179 cm) Weight=68.55 ± 11.03 kg (50-86 kg) BMI=23.03 ±3.39 kg/m^2	I: FHP, asymptomatic E: No visual, auditory or perceptual deficits, no structural deformities at any joint of the lower limbs and spine, no surgical operations in the lower limbs, no deep sensory loss, no history of epilepsy, no diabetes, and no diseases affecting balance and neuromuscular control.	Head postural index by Biotonix posture print	Standing	N/A	•Dynamic balance: Biodex balance system SD (level 8)	Pearson product-moment correlation coefficient	•Pearson correlation coefficient (between head postural index and stability indices at level 8, $P>0.05$)	There was no relationship between postural changes of the head and dynamic balance in FHP students.
Gabr et al. [18]	N=35 (M 25/F 10) Age=19.62±0.73 years Height=169.77 ±7.17 cm Weight=67.71 ±10.25 kg BMI=23.5±3.22 kg/m^2	I: FHP, asymptomatic E: Visual, auditory, or perceptual deficits, structural deformities at any joint of lower limbs and spine, surgical operations in lower limb, deep sensory loss, history of epilepsy, previous cervical trauma and history of ankle sprain.	Head postural index by Biotonix posture print	Standing	N/A	•Dynamic balance: Biodex balance system (level 4 and 8) •Ankle ROM	Pearson product-moment correlation coefficient	Balance •Correlation between head posture changes and stability indices at level 4 (between MLSI and head Tx, $P=0.05$) •Correlation between head posture changes and stability indices at level 8 ($P>0.05$) •Correlation between the head postural index and stability indices at level 4 and 8 ($P>0.05$) Ankle ROM •Correlation between head postural changes and ankle active ROM (between head Ry and left ankle dorsiflexion, also between head Rx and left ankle plantar flexion, $P\leq0.05$) •Correlation between head postural index and ankle active ROM (right ankle dorsi and plantar flexion,	Dynamic balance was affected as changes of head posture altered centre of gravity position; three-dimensional head posture changes affected ankle joint range of motion.

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Table 2 (*continued*)

Studies	Participants	Recruitment criteria	FHP measurement			Outcome measures	Statistical tests	Main outcomes	Conclusions
			Measures	**Position**	**Results**				
								left ankle plantar flexion, p≤0.05) •Correlation between total postural index and ankle active ROM (right and left ankle plantar flexion, P≤0.05)	
Moustafa et al. (2020) [5]	N=160 (sex-, age- and BMI-matched) •Experimental group: N=80 •Control group: N=80 (M 50/F 30) Age: 20-25 years (n=30), 25-30 years (n=40), 30-35 years (n=10) BMI: <25 kg/m^2 (n=20), 25-30 kg/m^2 (n=51), >30 kg/m^2 (n=9) Smoking	I: Significant anterior head translation as measured by the CVA E: (1) Systemic pathology, including any inflammatory joint disease; (2) prior history of apparent injury or surgery relating to musculoskeletal system or disorder connected to spine and extremities; (3) musculoskeletal pain in previous three months.	CVA (<50 degrees)	N/A	N/A	•Dynamic balance: Biodex balance system SD (level 4) •Proprioception: HRA test (cervical joint position sense testing by CROM device; sitting; 30° rotation) •Head and eye movement control: SPNT by electrooculography •Sympathetic skin response: surface EMG	Student's t-test, Pearson's correlation	Sensorimotor variables (P<0.05) •SPNT •OSI •Repositioning error in right and left rotation Neurophysiological variables •SSR amplitude (P<0.05) •SSR latency (P>0.05) Correlations in both FHP and control groups (P<0.05) •SSR amplitude •SSR Latency •SPNT •OSI •Repositioning error right and left	Participants with FHP exhibited abnormal sensorimotor control and autonomic nervous system dysfunction.
Ziebart et al. [6]	N=158 (F) Age=75.9±6.5 years Height=156.4 ±7.1 cm Weight=65.4 ±14.1 kg BMI=26.7±5.3 kg/m^2 Fracture number=2.2 ±1.8	N/A	OWD (>5 cm)	Standing	5.7±4.6 cm	•Performance-based measures of balance and mobility: TUG, five times sit-to-stand, four-metre walk, step test	Multivariable linear regression	OWD in both unadjusted and adjusted models (P<0.05) •TUG •five times sit-to-stand •four-metre walk •step test	OWD was significantly associated with physical performance, but fracture characteristics were not.
Nemmers [25]	N=112 (F) •Fall group: N=40 Age=74.88±8.99 years Height=63.16 ±1.92 inches Weight=151.35 ±28.37 pounds •No-fall group: N=72 Age=76.99±8.46 years Height=63.17 ±2.98 inches	I: >60 years, living independently in the community E: not living independently in the community, or dependent on others for self-care, shopping, meal preparation, or light housework; currently experiencing problems with balance, or experiencing a major medical problem under medical care	CVA by photo	Standing (with feet together for one minute)	48.45±11.50 degrees	•Balance: ABC, BBS, PASE, fall history	Multiple ANOVA, Pearson correlation coefficient, hierarchal regression	•Negative correlation between FHP and risk factors (ABC, BBS and PASE) (P<0.05); between FHP and number of falls (P>0.05)	The basic premise of the influence of FHP on balance stability, fall self-efficacy, and activity level was statistically validated.

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Table 2 (*continued*)

Studies	Participants	Recruitment criteria	FHP measurement			Outcome measures	Statistical tests	Main outcomes	Conclusions
			Measures	**Position**	**Results**				
	Weight=148.88 ±27.67 pounds								
Nemmers and Miller [26]	N=203 (F) Age=77.33±7.59 (60-96 years)	I: age 60 years or older, living independently in the community, in good health, not requiring assistive device for ambulation E: living in the community but dependent upon others for self-care, shopping, meal preparation, or housework, under medical care for problems with balance or a major medical problem.	CVA by photo	Standing (with feet together for one minute)	48.12±10.29 degrees	•Balance: ABC, BBS, PASE	Pearson correlations, hierarchical regression	•Negative correlation between FHP and known risk factors (ABC, BBS and PASE) (P<0.05), positive correlation between FHP and age (P<0.05) •Regression analyses: FHP added 6.1% (P<0.05) to the total variance in balance stability; balance confidence, physical activity, and age accounting for 43% (P<0.05) of the total variance in balance stability	The basic premise of the influence of FHP on balance stability was demonstrated. Additionally, the influence of balance stability was also demonstrated.
Khan et al. [27]	N=44 •Experimental group: N=22 Age=25.7±2.59 years Height=164 ±6.04 cm Weight=64.9 ±14.8 kg BMI=23.9±4.99 kg/m^2 •Control group: N=22 Age=24.3±2.19 years Height=160.2 ±6.80 cm Weight=62.1 ±1.32 kg BMI=24.1±3.99 kg/m^2	I: no symptoms of neck pain E: history of traumatic neck injuries, inflammatory joint disease, cervical spine infection, severe osteoporosis, cervical spine disc protrusion, foramen nerve blockage, cervical spine fracture or dislocation, cervical surgery, severe migraine, vestibular disorders, or vertebrobasilar insufficiency	CVA by photo (≤53 degrees)	Standing	•Experimental group: 50.0 ±1.77 degrees • Control group: 67.4±7.89 degrees	•EMG: UT and SCM muscles •Proprioception: HRA test (cervical position sense error value; sitting; full ROM)	Independent t-test, Pearson's correlation coefficient	•Position sense error values for all six directions were greater in FHP (P<0.05), including flexion, extension, right rotation, left rotation, right side flexion and left side flexion •EMG activity of UT and SCM muscles were raised (P<0.05) at rest and during activity	Cervicocephalic kinaesthesia and activation patterns of the neck muscles may be significantly altered in individuals with FHP. Also, cervicocephalic kinaesthesia is significantly associated with the severity of FHP.
Lee et al. [28]	N=39 •Experimental group: N=19 (M 7/F 12) Age=22.2±1.9 years Height=166.0 ±7.4 cm Weight=63.8 ±12.3 kg •Control group: N=20 (M 12/F 8) Age=22.7±2.1 years	I: no history of neuromuscular disorder, fracture, or moderate or severe scoliosis	CVA by photo (<53 degrees)	N/A	N/A	•Proprioception: HRA test (cervical position sense error value; full ROM)	independent t-test, Pearson correlation coefficients	•Position sense error values for all four directions were greater in FHP (P<0.05), including flexion, extension, right rotation, and left rotation •Inverse correlation between FHP and error values of position sense in all four directions (P<0.05)	FHP was associated with reduced proprioception. Also, proprioception worsened as FHP became more severe.

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Table 2 (*continued*)

Studies	Participants	Recruitment criteria	FHP measurement			Outcome measures	Statistical tests	Main outcomes	Conclusions
			Measures	**Position**	**Results**				
	Height=169.7 ±7.3 cm Weight=64.0 ±12.6 kg								
Yong et al. [29]	N=72 (M 35/F 37) Age=22.26±2.10 years Height=167.98 ±11.89 cm Weight=62.56 ±11.89 kg	I: no history of fracture, neuromuscular disorder, or pain in the cervical region	CVA by photo	Standing	53.70±5.05 degrees	•Proprioception: joint position sense of cervical spine by a dual digital inclinometer (standing; full ROM)	Spearman's correlation coefficient	•Negative correlation between CVA and position sense error for flexion (P<0.05) and extension (P<0.05)	FHP correlated with greater repositioning error than a more upright posture.
Coelho Júnior et al. [30]	N=60 (sex, age and height matched) Clinical data •Experimental group: N=30 (M 7/F 23) Age=52.63±6.97 years •Control group: N=30 (M 7/F 23) Age=52.13±7.25 years	I: suffering from chronic dizziness characterised by presence of this symptom on at least three days a week over preceding three months (experimental group); no dizziness or other vestibular complaint and normal results from otoneurologic assessment (control group) E: Individuals in UVH or control group who had orthopaedic diseases in cervical, dorsal and/or lumbar spine that might cause postural changes, abnormalities in the girdle or lesions in the brachial plexus; central or mixed vestibular diseases, neurological diseases, physical deformities (both congenital and acquired) and obesity; abnormalities in knee axis (varus or valgus) or in foot axis (planus or cavus).	C7 angle (C7 spinous process, temporomandibular joint and vertical line through C7)	Standing	•Experimental group: 55.445 ±16.339 degrees • Control group: 34.345±4.604 degrees	•Vestibular: caloric test, i. e., main phase of electronystagmography •Intensity of dizziness: VAS •Head alignment: temporomandibular interjoint angle •Shoulder alignment: interacromial angle	Mann-Whitney nonparametric test, Spearman correlation coefficients	•Greater forward and lateral head deviation in patients with UVH (P<0.05) •Greater temporomandibular joint angle in UVH group (P<0.05) •Correlation between FHP and duration of clinical symptoms of vestibular disease, intensity of dizziness and occurrence of falls (P<0.05)	Forward head deviation increased with age, duration of clinical symptoms and greater self-perception of intensity of dizziness. Forward head deviation was also greater among patients who reported having falls.
Jafarnezhadgero and Sheikhalizade [31]	•Experimental group: N=12 Age=11.8±1.3 years Height=148.2 ±6.6 cm Weight=39.6 ±5.4 kg •Control group: N=16	E: history of neck pain, fracture of cervical column, scoliosis, severe thoracic kyphosis, rheumatic disease, torticollis, vestibular or neurological disorder, use of hearing aid and	CVA by goniometer (<48 degrees)	N/A	•Experimental group: 42.17 ±1.5 degrees • Control group: 52.6±1.9 degrees	•GRF: Kistler force Platforms (1000 Hz)	MANOVA test	In non-dominant limb: •mediolateral GRF during push-off phase in FHP was greater (P<0.05) In dominant limb: • time to peak for vertical GRF during heel contact and push off were lower (P<0.05) •mediolateral GRF during	GRF components (especially time to peak for ground reaction forces) in forward head children may have clinical importance for improving walking mechanics of these individuals.

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Table 2 (*continued*)

Studies	Participants	Recruitment criteria	FHP measurement			Outcome measures	Statistical tests	Main outcomes	Conclusions
			Measures	**Position**	**Results**				
	Age=11.7±1.4 years Height=149.7 ±6.2 cm Weight=38.0 ±4.7 kg	persistent respiratory problems.						heel contact and push off were lower ($P<0.05$) Others •Vertical loading, peak positive and negative free moment, and impulses in all axes ($P>0.05$)	

ABC: activity-specific balance confidence scale; BBS: Berg balance scale; BMI: body mass index; COG: centre of gravity; CROM: cervical range of motion; CVA: craniovertebral angle; COP: centre of pressure; DCL: directional control; E: excluded; EMG: electromyography; EPE: end point excursion; FHP: forward head posture; GRF ground reaction force; HRA: head repostioning accuracy; I: included; LOS: limits of stability; MCTSIB: modified clinical test for sensory interaction in balance; MLSI: mediolateral stability index; MVL: movement velocity; MXE: maximum excursion; OSI: overall stability index; OWD: occiput-to-wall distance; PASE: physical activity scale for the elderly; ROM: range of motion; RT: reaction time; Rx: flexion-extension; SCM: sternocleidomastoid; SOT: sensory organisation test; SPNT: smooth pursuit neck torsion test; SSR: sympathetic skin response; STI: stability test index; TUG: timed up and go; Tx: lateral translation; UT: upper trapezius; UVH: unilateral vestibular hypofunction; VAS: visual analogue scale.

index by Biotonix Posture Print [18,24]; one study used the difference between a monitor-facing angle and CVA [23]; one study measured the occiput-to-wall distance [6]; one study used the C7 angle (a complementary angle of CVA) [30]; and one study used a cervical range of motion device [33]. Overall, there appeared to be no consensus or established criteria regarding FHP assessment, but CVA was the most common measure used in the literature.

3.5. Postural control

3.5.1. Static balance

Excluding the study using inappropriate statistics [21], two studies supported no relationship between FHP and static balance [20,22], while one study concluded the opposite [23].

The outcome measures of the three studies were not all quantified using the same metrics. Hyong and Kim [20] reported no statistically significant correlation between CVA and 'stability test index' by multiple regression analysis. But only one 'stability test index' was reported, while the Tetrax Portable Multiple System produced a corresponding 'stability test index' for each of four test conditions. Karajgi et al. [22] compared 'COG sway velocity' between FHP and control groups using the modified clinical test for sensory interaction in balance, and found no statistically significant difference for all test conditions. Kang et al. [23] found a statistically significant difference in the 'equilibrium scores' between heavy computer users (FHP) and control groups in conditions 5 and 6 of the sensory organisation test (SOT).

3.5.2. Dynamic balance

A total of seven studies investigated the relationship between FHP and dynamic balance [5,18,19,21–24]. Of these, three studies examined limits of stability (LOS) [19,22,23], while four studies assessed postural stability control [5,18,21,24].

3.5.2.1. Limits of stability. Three studies identified significantly reduced LOS in participants with FHP [19,22,23]. These studies reported statistically significant differences in movement velocity, endpoint excursion and maximum excursion in the anteroposterior direction between FHP and control groups. Kang et al. [23] additionally determined that the COG of computer workers with FHP was relatively anterior to that of the control group under both static and dynamic balance using a foot pressure measurement system.

These studies, however, also reported conflicting evidence regarding reaction time and directional control. Karajgi et al. [22] found that participants in the FHP group had a significantly longer reaction time in the forward, left and right forward directions compared to the control group, but this study did not present data on directional control. Kang et al. [23] only compared reaction time and directional control in anteroposterior directions between FHP and control groups, but the difference was not statistically significant in either parameter. The study by Jain [19] showed significantly increased reaction time in right and posterior directions and reduced directional control in the right and left forward directions in the FHP group. Although all three studies employed the Neurocom® Balance Master for balance assessment, there were differences in sample selection and FHP assessment methods, which prevented a meta-analysis. Thus, the significant findings in reaction time and directional control were less comparable.

3.5.2.2. Postural stability control. Four studies reported contradictory findings related to postural stability [5,18,21,24]. Three studies employed the Biodex balance system with eight stability levels, ranging from level one (most unstable condition) to level eight (most stable condition), while the remaining study was excluded due to inappropriate statistical analysis [21]. Abdelghany et al. [24] measured the relationship between head postural index and stability index in participants with asymptomatic FHP at level eight and found no statistically

Table 3
Characteristics of the included studies on induced FHP.

Studies	Participants	Recruitment criteria	Exposure	Outcome measures	Statistical tests	Main outcome	Conclusion
Silva and Johnson [32]	N=25 (M 9/F 16) Age=20.76 ±2.19 years Height=166.63 ±9.81 cm Weight=61.87 ±10.33 kg Natural CVA=51.59 ±5.53 degree	E: dizziness, pain or any orthopaedic, vestibular, or neurological disorder; drinking alcohol during the 24 h preceding data collection	Exaggerated FHP as 6 degrees decrease in CVA to participants' natural FHP; standing	• COP by static standing using a stable force platform (1000 Hz) in 8 different conditions	Wilcoxon Signed Ranks test	•Sway area for condition 1 was higher than condition 2 (P<0.05) •Total distance covered by COP was higher for condition 1 than condition 2 (P<0.05) •Centre of pressure sway area, distance covered, mean velocity in other conditions (P>0.05)	Induced FHP in young healthy adults does not challenge them enough to impair postural control.
Sivayogam et al. [33]	N=25 (M) Age=25.1±3.4 years Height=175.6 ±5.1 cm Weight=76.0 ±8.2 kg	I: male, free from any history of neck pain or neck injury in 12 months preceding data collection E: a history of vertigo, neuro-musculoskeletal problems or spinal pathologies either acquired or congenital, cervicogenic headache, dizziness during head and neck movements, diabetes, vertebrobasilar insufficiency, visual problems and/or balance disturbances	Head protrusion (maximal forward glide or maximal anterior translation of the head while maintaining the jaw parallel to the ground to maintain zero sagittal rotation); Head retraction (maximal backward glide or maximal posterior translation of the head whilst maintaining the jaw parallel to the ground to main zero sagittal rotation); standing	• SOT (NeuroCom® balance manager)	Repeated ANOVA	•Equilibrium score for any balance task (in all six conditions with three head postures) (P>0.05)	Postural stability is unaltered in extreme simulated head postures in healthy adult males even when the balance is challenged across a range of different sensory testing conditions.
Ha and Sung [34]	•Experimental group: N=11 (M 7/F 4) Age=21.82 ±1.78 years Height=171.91 ±7.98 cm Weight=66.91 ±12.96 kg •Control group: N=11 (M 5/F 6) Age=21.36 ±1.43 years Height=167.18 ±4.92 cm Weight=61.09 ±8.73 kg	I: no visual impairment, no musculoskeletal disease, no arthritis or other inflammatory disease, no neck pain. E: trauma or surgery inprevious six months, vestibular or neurological disorders	Experimental group: CVA<49 degrees watching smartphone for 40 min Control group: CVA>50 degrees watching smartphone for 40 min; sitting	• Ultrasonography (SonoAce X8) • Proprioception (cervical joint position sense in left and right rotation) • Vestibular function (subjective visual vertical and horizontal tests) • Static balance (Romberg test with Wii balance board)	Independent t-test	•Changes in area of deep neck flexor muscles (longus colli and longus capitis) (P>0.05) •Changes in proprioception (right rotation, P<0.05) (left rotation, P>0.05) •Changes in vestibular function (P>0.05) •Changes in static balance (P>0.05)	Proprioception was significantly different when watching smartphone for 40 min with induced FHP, but deep neck flexor muscles, static balance, and vestibular function were not significantly different.

COP: centre of pressure; CVA: craniovertebral angle; E: excluded; FHP: forward head posture; I: included; SOT: sensory organisation test.

significant correlation. Gabr et al. [18] demonstrated that the anterior-posterior translation of the head was associated with neither the anteroposterior stability index nor the overall stability index at levels four (moderately unstable condition) and eight. Moustafa et al. [5] compared the overall stability index between the FHP group and age-, sex-, and BMI-matched control groups at level four. The results showed a statistically significant difference in overall stability index between the two groups, and the decrease in CVA was associated with an increase in overall stability index. A higher overall stability index indicated limited balance.

3.5.3. *Performance-based balance*

Three studies revealed impaired performance-based balance in the elderly with FHP, using physical performance tests and scales [6,25,26]. Ziebart et al. [6] demonstrated that the occiput-to-wall distance was significantly associated with physical performance in both the age- and pain-adjusted model and the unadjusted model, using the timed up and go test, five times sit-to-stand test, four-metre walk test and step test. The other two studies used the same scales, including the activity-specific balance confidence scale, physical activity scale and Berg balance scale, and found that performance was significantly reduced as FHP severity increased [25,26]. Furthermore, Nemmers [25] reported no statistically significant correlation between FHP and the number of falls.

3.5.4. *Proprioception*

The finding of four studies demonstrated a consensus that FHP was significantly associated with head position sense error [5,27–29]. Moustafa et al. [5] compared repositioning errors in right and left rotation between the FHP and control groups, and also revealed a significant negative correlation between CVA and horizontal head rotation.

Table 4
Quality assessment of the included studies.

Studies	1	2	3	4	5	6	7	8	Total	Percentage
Hyong and Kim [20]	Y	N	Y	Y	NA	NA	Y	Y	5/6	83.3 %
Lee [21]	Y	N	Y	Y	N	NA	Y	N	4/7	57.1 %
Karajgi et al. [22]	Y	N	Y	?	N	NA	Y	Y	4/7	57.1 %
Kang et al. [23]	Y	N	Y	Y	N	NA	Y	Y	5/7	71.4 %
Jain [19]	N	N	Y	?	N	NA	Y	Y	3/7	42.9 %
Abdelghany et al. [24]	Y	N	Y	Y	NA	NA	Y	Y	5/6	83.3 %
Gabr et al. [18]	Y	Y	Y	Y	NA	NA	Y	Y	6/6	100 %
Moustafa et al. [5]	Y	N	Y	Y	Y	Y	Y	Y	7/8	87.5 %
Ziebart et al. [6]	Y	Y	Y	Y	Y	Y	Y	Y	8/8	100 %
Nemmers [25]	Y	N	Y	Y	Y	Y	Y	Y	7/8	87.5 %
Nemmers and Miller [26]	Y	N	Y	Y	NA	NA	Y	Y	5/6	83.3 %
Khan et al. [27]	Y	Y	Y	Y	Y	Y	Y	Y	8/8	100 %
Lee et al. [28]	Y	N	Y	Y	N	NA	Y	Y	5/7	71.4 %
Yong et al. [29]	Y	N	Y	Y	NA	NA	Y	Y	5/6	83.3 %
Coelho Júnior et al. [30]	Y	N	Y	Y	Y	Y	Y	Y	7/8	87.5 %
Jafarnezhadgero and Sheikhalizade [31]	Y	N	Y	Y	Y	Y	Y	Y	7/8	87.5 %
Silva and Johnson [32]	Y	N	Y	Y	Y	Y	Y	Y	7/8	87.5 %
Sivayogam et al. [33]	Y	N	Y	Y	Y	Y	Y	Y	7/8	87.5 %
Ha and Sung [34]	Y	N	Y	Y	N	NA	Y	Y	5/7	71.4 %
Sums (Y/N/?)	18/1/0	3/16/0	19/0/0	17/0/2	8/6/0	8/0/0	19/0/0	18/1/0	——	——

Y: yes; N: no; ?: unclear; NA: not applicable.
(1) Criteria for sample selection, (2) descriptions of subjects and setting, (3) exposure measurement methods, (4) measurement of the condition, (5) confounder identification, (6) strategies for confounder control, (7) outcome measurement methods, and (8) statistical analysis.

Table 5
Classification of the eligible studies.

Topics	Subtopics	References
Postural control	Static balance	[20–23]
	Dynamic balance	[5,18,19,21–24]
	Performance-based balance	[6,25,26]
	Proprioception	[5,27–29]
	Vestibular function	[30]
Gait	Ground reaction force	[31]
Induced FHP	–	[32–34]

Khan et al. [27] reported statistically significant differences in head position sense error in six motion directions between FHP and control groups. Lee et al. [28] assessed four motion directions of the cervical spine, including flexion, extension, right and left rotation. Yong et al. [29] reported a significant negative correlation between CVA and head position sense error in flexion and extension motions of the cervical spine. The measurement processes and metrics of the repositioning error varied across these studies, although all four studies employed the head repositioning accuracy test.

3.5.5. *Vestibular function*

A single study measured the relationship between head alignment and vestibular function [30]. This study diagnosed vestibular hypofunction using the caloric test and demonstrated that patients with unilateral vestibular hypofunction presented greater forward and lateral head deviations than the control group. Sixty per cent of the lateral head deviations were ipsilateral to the vestibular hypofunction side, while forty per cent were contralateral. They also reported that the severity of FHP was significantly and positively correlated with age, duration of clinical symptoms of the vestibular disease, self-perception of the intensity of dizziness, and occurrences of falls.

3.6. *Gait ground reaction force*

Only one study compared gait parameters between FHP and control groups [31]. Ground reaction force in children was the only gait parameter measured. The results showed that children with FHP had greater mediolateral ground reaction force (GRF) during the push-off phase in the non-dominant limb, less time to peak for vertical GRF, and lower mediolateral GRF during heel contact and push-off phases in the dominant limb.

3.7. *Induced FHP*

Three studies examined the impacts of FHP by instructing healthy participants to simulate FHP [32–34]. Silva and Johnson [32] reported that exaggerated FHP with 6 degrees anterior head translation did not disrupt the static postural control in young healthy participants. Sivayogam et al. [33] compared postural stability between the neutral head posture and extreme simulated head postures of protrusion and retraction, and reported that postural stability was unaltered in all six conditions of SOT. Ha and Sung [34] found no statistically significant differences in comparisons of deep neck flexor muscles, vestibular function, and static balance between simulated FHP and the control groups, except for cervical joint position sense. However, the repositioning accuracy test used in this study was different, with the head position passively rotated by investigators instead of actively moving, in contrast to the comparative studies.

4. Discussion

This systematic review aimed to determine whether there is a relationship between FHP, postural control and gait. Consistent evidence supported that people with FHP had significant alterations in LOS [19,22,23], performance-based balance [6,25,26], and cervical proprioception [5,27–29]. Controversial evidence existed for a relationship of FHP with static balance [20–23] and postural stability control [5,18,21,24]. Limited evidence existed to support an alteration in vestibular function [30], while information on gait [31] was rather limited. Three studies on induced FHP consistently identified no reduced postural control [32–34].

4.1. *Relationship between FHP and postural control*

The results suggest that individuals with FHP present with decreased LOS, reduced performance-based balance, and impaired cervical proprioception. These findings support a recent systematic review by Szczygiel et al. [8]. However, they did not review the evidence on different aspects of postural control and only included four relevant studies. Postural control depends on the integration and coordination of multiple factors [35]. Thus, it is essential to evaluate and review postural control based on its different aspects.

Three studies proposed the same possible explanation for the decreased LOS; a forward shifted COG by FHP caused plantarflexion of the ankle joint and restricted movement of the knee and hip joints, which diminished LOS [19,22,23]. The explanation is plausible, given that two studies found that the severity of FHP had a negative correlation with the ROM of ankle joints, particularly in plantarflexion [18,20]. However, a significant amount of ankle strength is also a prerequisite for successfully executing an ankle strategy [35], which was not measured and controlled in these studies.

Similar deficits in performance-based balance were identified in three studies using different assessment tools. In fact, the Berg Balance Scale evaluates similar functions to the timed up and go, sit-to-stand, and step tests, but this scale lacks mobility tasks as evaluated by the four-metre walk test [6,36]. However, the occiput-to-wall distance used by Ziebart et al. [6] is not a common measure of FHP, and the distance is influenced by both thoracic kyphosis and FHP. The significant association between FHP and performance-based balance proposed by Ziebart et al. [6] should be interpreted with caution, because increased thoracic kyphosis and FHP can coexist or exist alone [37]. Both age and sex are possible confounders for FHP and postural control [7,38,39], while all participants in the three studies were elderly females, suggesting a sample bias might affect the results.

Consistent evidence supported impaired proprioception associated with cervical spine motion. The impaired proprioception is associated with muscle spindle function as a length sensor [40]. Neck muscles have abundant muscle spindles as proprioceptors and are essential for postural control [7,41], in particular rectus capitis posterior major and minor, obliquus capitis superior and inferior, as well as longissimus capitis [42]. The major changes in neck muscle length are shortening of occipital extensors and lengthening of cervical extensors during FHP, thus affecting normal proprioceptive inputs of muscle spindles [43,44]. Alterations in muscular tension following changes in muscle length would affect Golgi tendon organs, which are other important proprioceptors [40]. Lower limb joint proprioception in people with FHP should be assessed to provide more information [45]. Additionally, proprioceptive and vestibular inputs interact with each other and with postural control [46,47].

For static balance and postural stability control, differences in research methodology may contribute to the contradictory findings. These studies used different outcome variables and sample selection criteria, leading to a lack of comparability. Two studies recruited participants of similar age (18–25 years) and assessed FHP using CVA, concluding there was no relationship between static balance and FHP [20,22]; however, the study with supporting evidence recruited participants between 30 and 40 years of age (the experimental group using a computer 6 hrs/d, >10 years), and assessed FHP using the difference between monitor-facing angle and CVA after a two-hour computer task [23]. This difference suggests that age and computer use time may be associated with static balance in individuals with FHP. Also, although the three studies on postural stability used the same equipment to assess stability, only the study by Moustafa et al. [5] found differences in overall stability among age-, sex-, and body mass index-matched participants. It seems that studies without confounder control may draw biased conclusions.

Although there is only one study revealing the relationship between FHP and vestibular function [30], the findings of the study by Kang et al. [23] also implied vestibular loss, because the participants with FHP had significantly lower equilibrium scores in conditions 5 and 6 of SOT [35,48]. To maintain balance, the normal vestibular system as a primary sensory system is essential [49]. Vestibular impairment may affect postural control via the vestibulospinal reflex, thus leading to imbalance and falls after changes in head position and orientation [50,51]. Also, vestibular impairment can cause dizziness and spatial disorientation via vestibulo-ocular and vestibulo-thalamo-cortical reflexes, respectively [52–54].

The absence of significant differences in studies on induced FHP indicates that temporary deviations of the sagittal spinal alignment are not challenging enough for postural control. Compared to evidence from the studies on chronic FHP, this finding suggests that a single change in COG by FHP is not a direct cause of balance disorder. However, all three studies recruited healthy young adults who could adapt to temporary spinal deviations due to their good physical condition; the duration of maintaining induced FHP could be another confounder.

4.2. Relationship between FHP and gait

The only evidence for gait disorders of individuals with FHP derived from children, and the single measure was the ground reaction force. Although altered muscle contributions could cause the difference in mediolateral ground reaction force in healthy people [55], it remains unclear whether the mechanism is similar in FHP, as little research has explored lower limb muscular activity in individuals with FHP.

Nevertheless, it is plausible to hypothesise that gait disorders are associated with FHP. A normal gait requires proper postural control, constant adaptation to the environment, and enough body forward propulsion [11]. These functions appear to exhibit a significant reduction in populations with FHP, according to the evidence above, e.g., impaired multisensory information, obstacle avoidance, perturbation resistance, and lower functional muscle strength. Therefore, an individual with FHP may not walk economically, or may have to adopt a series of compensations to adapt to the reduced functions, although very limited direct evidence exists for this at present.

4.3. Diagnostic criteria for FHP

There appears to be no standard method of FHP assessment and consensus on diagnostic criteria for FHP. The most common method adopted in the included studies is CVA by photogrammetry with good discrimination and excellent intra- and inter-rater reliability [56], where a lateral photo combined with software analysis can obtain accurate degrees of FHP. Most of the cut-off points were based on whether participants with FHP had self-reported neck pain or not. It seems arbitrary to diagnose FHP only on subjective pain, rather than considering other deficits related to FHP. Undoubtedly, the lack of a unified criterion is not favourable for either diagnosis or treatment of FHP. Also, a diagnostic criterion for FHP considering specific functions (e.g., postural control and gait) would be beneficial to clinical screening and precaution.

4.4. Strengths and limitations

To our knowledge, this is the first systematic review evaluating the relationship between FHP, postural control and gait. Also, evidence of postural control was synthesised in terms of different balance types and primary sensory inputs, thus determining changes in specific aspects of postural control rather than a global measure. This might assist in mapping the research scope and specific directions for future research. Moreover, two independent reviewers performed training exercises before the study selection, data extraction, and quality assessment for improving reliability.

There are some limitations in this review. First, all the included articles meeting the eligibility criteria were cross-sectional studies only, addressing correlation issues instead of a causal relationship. Second, most eligible studies were of low methodological quality, and only two studies fulfilled all eight items of methodological quality assessment, thus increasing the risk of bias. Third, this review may have missed some relevant studies in languages other than English or the grey literature.

4.5. Future research

Based on the findings of this review, the recommendations for future research on the relevant topics include: (a) standardise the FHP measurement method; (b) unify the diagnostic criterion for FHP; (c) control the important potential confounding factors, e.g., age, sex, FHP duration, neck pain severity, muscle strength, and physical activity levels; (d) pay more attention to other relevant alterations in individuals with FHP, e.g., muscle activation, muscle strength and power, vestibular function, and gait; and (e) perform high-quality longitudinal cohort studies.

5. Conclusion

This systematic review found consistent evidence supporting reductions in LOS, performance-based balance, and cervical proprioception in the population with FHP. However, heterogeneity and lack of high-quality studies weaken the evidence base. The current evidence for the relationship of FHP with static balance and postural stability control remains conflicting, and the evidence for the relationship between FHP with the vestibular deficit and gait disorder is very limited. Accordingly, further research is required to investigate the specific postural control with controversial evidence and explore changes in gait parameters of the population with FHP.

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Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gaitpost.2022.10.008.

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