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Systematic review

Differences in the kinematics of the cervical and thoracic spine during functional movement in individuals with or without chronic neck pain: a systematic review

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Abstract

Background Chronic neck pain is common, impacting a person's ability to complete functional tasks. One method of quantifying functional movement is three dimensional (3D) motion analysis, however, it is unknown whether it may detect alterations in movement kinematics in individuals with neck pain.
Objective To systematically review studies to determine possible differences in cervical and thoracic kinematics during functional movement as measured by 3D motion analysis in individuals with neck pain compared to controls.
Data sources Medline, Amed, Scopus, Cochrane, Embase, CINAHL searched on 11/11/2017.
Study selection Studies reported 3D kinematics of functional movement (based on real-world situational biomechanics, i.e., multi-planar movements) of the cervical and thoracic spine in individuals with and without neck pain.
Study appraisal and synthesis Two reviewers assessed study quality; studies were summarised using discussion.
Results Four thousand four hundred and sixteen title/abstracts were screened, 11 full texts retrieved. Common reasons for exclusion were participants ≤8 years of age and studies that did not investigate functional movement. Included studies ($n = 5$) used 3D motion analysis to assess kinematics during functional tasks including typing, gaming and resting posture. Participants with neck pain displayed greater neck flexion postures, reduced head velocity and smoothness of movement.
Limitations Variations in measurement methods and participant samples prevented meta-analysis.
Conclusion Though few studies were identified, altered kinematics were observed in individuals with neck pain, suggesting further research examining cervical spine kinematics is warranted. Recognising kinematic differences is important for clinicians to identify possible movement risk factors in individuals with neck pain that may be targeted with treatment.
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Keywords: Neck; Cervical vertebrae; Kinematics; Biomechanical phenomena

Introduction

Chronic neck pain is a common and costly problem [1], with one-year prevalence estimated to be between 30% to 50% [2,3]. Approximately 2–12% of those with neck pain have activity-limiting pain [1–4], impacting on quality of life by reducing ability to perform daily functional activities and work [3]. It is a costly burden for society and for patients, for example, health related expenditure is estimated to be approximately $1.2 billion per year in 2015 in Australia [5].

Physiotherapy is currently the mainstay of conservative treatment for individuals with neck pain. Patients usually seek treatment because their pain is aggravated by functional movements and/or they are unable to complete them [3,4].

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The effectiveness of physiotherapy treatment on a patient's neck function is usually assessed using self-reported disability questionnaires [6]. These are limited by patient recall and possible bias based on how a patient may be feeling when they complete the questionnaire [3]. Thus, physiotherapists also use more objective means of assessing functional ability. For example, they routinely perform neck range of motion (ROM) assessments [7] typically involving measurement of movement in the frontal, sagittal and transverse plane with instruments such as the Cervical Range of Motion (CROM) instrument [8]. However, these instruments are limited to movement in a single plane, and are not accurate for assessing multi-planar movements as they are affected by movement in other planes [8]. Also, they do not provide a reliable quantitative measurement of functional movement. Nevertheless, if a clinician could analyse functional movement quantitatively, it would provide an assessment of a patient's ability to complete activities of daily living affecting their quality of life, and thus provide a method to quantify the effectiveness of a physiotherapy intervention.

One way to objectively analyse functional movement is three-dimensional (3D) motion analysis, which combines an examination of the individual's physical structure with measurements of their movement during activity [9]. Currently, 3D motion analysis has been used in laboratory studies, mostly for biomechanical assessments of lower limb musculoskeletal injuries during complex 3D motions [9,10]. It affords a potentially powerful tool for assessing functional movement in individuals with neck pain. However, it is unknown whether 3D motion analysis could detect alterations in functional movement in individuals with neck pain. Therefore, the aim of this systematic review is to report differences in cervical and thoracic kinematics during functional tasks as measured by 3D motion analysis between individuals with and without neck pain.

Methods

Study design

Included study designs were cross-sectional, observational, case-control and randomised control trials. Studies had to be peer-reviewed and in English, and were included with or without blinding of participants and assessors. This review was registered under Prospero (CRD42017076053) on 24/10/2017.

Participants and comparisons

The authors included studies of human participants ≥age 18 that reported data from individuals with neck pain, as compared to an asymptomatic (no neck pain) comparison group. All types of neck pain (i.e., acute, subacute and chronic) and neck pain of any origin (e.g., idiopathic and whiplash associated disorder) were included. Non-human and cadaver studies were excluded, as were studies that reported mathematical modelling without data collected from human participants.

Outcome measures

Included studies reported 3D kinematics (e.g., range of motion, velocity (m/second), joint angles and their timing) of functional movement of the cervical and thoracic spine. Functional movement was defined as movement based on real-world situational biomechanics, i.e., multi-planar movements. Studies measuring standardised physiological range of motion in a single plane were excluded; for example, studies using only the CROM instrument.

Search method of identification of papers

Electronic searches of the following databases were undertaken from inception to 11/11/2017: Medline, AMED, Scopus, Cochrane, Embase and CINAHL. The search strategy was developed in Medline (supplementary file) and subsequently tailored for the other databases in consultation with a biomedical librarian. Hand searching of the reference lists of retrieved full text studies was performed.

Selection of studies

Titles and abstracts were independently screened by two reviewers (DM and RdZ) to determine their eligibility. The full text of studies deemed to be possibly relevant were retrieved and then independently screened by two reviewers (DM and RdZ). The level of agreement for independent screening at each stage is reported as percent agreement. Disagreements that could not be resolved by consensus between the two reviewers were resolved by consulting a third reviewer (SS).

Methodological quality assessment

Two reviewers (DM and RdZ) assessed the methodological quality of studies using the "US National Institute of Health Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies" [11] (Table 1). Disagreements concerning quality assessment were resolved through discussion, including a third reviewer (SS) as necessary.

Data extraction and synthesis

One review author (DM) extracted data for the included studies using a data extraction tool agreed upon by all authors. Data recorded included participant demographics (age, gender, neck pain condition, inclusion/exclusion criteria), sample size, comparison group (age, gender, inclusion/exclusion criteria), outcome measures including methods of measurement, and results including measures of central tendency

Table 1
Participant demographics in the included studies investigating 3D kinematics of functional movement in individuals with neck pain (A) and healthy matched control participants (B).

Study	Sample size		Age [years ± SD]		Female:male		Type of dysfunction	Inclusion criteria[a]	Exclusion criteria
	A	B	A	B	A	B			
Falla *et al*. 2017 [16]	14	14	28 (7)	24 (4)	11:3	11:3	Non-specific neck pain ≥3 months	• Non-specific neck pain • Symptom aggravation and remission in the last 6 months, each episode lasting at least one week • ≥18 years of age	• Acute neck pain <3 months • Neurological pain
Tsang *et al*. 2014 [14]	30	30	38 (11)	35 (9)	22:8	21:9	Non-specific neck pain ≥3 months	• Non-specific neck pain • ≥18 years of age	• Neurological pain • Neck trauma • Neck surgery • Sensory/vestibular defects • Rheumatic disease • TMJ dysfunction
Sarig-Bahat *et al*. 2010 [12]	25	42	39 (13)	35 (12)	16:9	31:11	Chronic neck pain ≥6 weeks	• Insidious onset neck pain ≥6 weeks (insidious onset and whiplash) • ≥18 years of age	• Positive neurologic signs • Imaging evidence indicating nerve root/spinal cord compression • Pathologic entities e.g., diffuse connective tissue disease, rheumatic syndromes • Fractures of the neck/thoracic spine/shoulder • Neoplasm • Dislocations • Medications that may affect pain • People with suspected cervical dystonia
Boccagni *et al*. 2008 [13]	15	10	30 (14)	30 (2)	8:7	6:4	Cervical dystonia	• Cervical dystonia diagnosed by the presence of abnormal clinical posture/movements of the head and neck and EMG evidence of prolonged muscular activity/co-contraction of agonist and antagonist muscles. • >18 years of age	
Szeto *et al*. 2005 [15]	21	17	36 (5)	36 (5)	21:17	0:0	Chronic neck pain ≥3-month history ≥18 years of age	• Female office workers • People with past complaints of neck pain lasting ≥3 months who still have pain. Neck pain could include whiplash or any long-term neck condition • Must have had neck pain in the past 7 days	• Male • Non-office workers • Acute neck pain <3 months

[a] Control groups in for Sairg-Bahat *et al*. [12], Szeto *et al*. [15], Falla *et al*. [16], and Tsang *et al*. [14], were people with no history of neck pain in the past 12 months. Control group for Boccagni *et al*. [13] were people with no history cervical of dystonia.

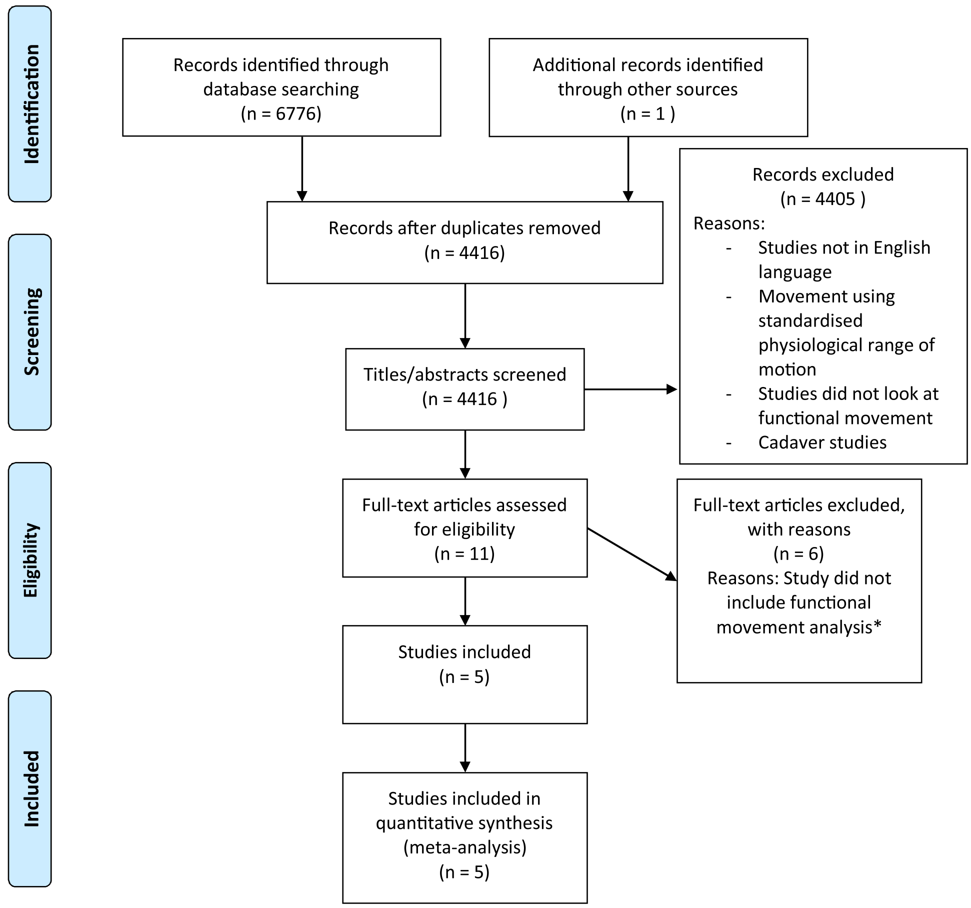

Fig. 1. Flow of studies through the review.
*Functional movement was defined as movement based on real-world situational biomechanics, i.e., multi-planar movements.

(mean, median) and dispersion (standard deviations, confidence intervals) where available.

Results

Flow of studies through the review

Fig. 1 illustrates the flow of studies in the selection process. Searches of the databases identified 6496 records. Duplicates were removed by the first author and 4416 studies remained for title and abstract analysis. Studies not in English (2478) were excluded. Both reviewers agreed on 11 relevant full text articles for retrieval. From the 11 articles, five were selected for inclusion in the review. Common reasons for excluding studies were they measured standard physiological range of movement (i.e., goniometry) and or did not examine a functional task.

Study characteristics

Study design

All five included studies were case-control and examined functional movement in participants with neck pain compared to individuals with no history of neck pain. Sample sizes ranged from 35 to 67. The agreement between reviewers for the title and abstract screening was 90%, and for the full text screening was 100%.

Participants

Participants were adults aged ≥18 years with neck pain ≥6 weeks duration compared with a control group of adults who were also aged ≥18 years with no history of neck pain and/or neck dysfunction (Table 1). Neck pain participants were either female office workers with chronic neck pain of any origin [15], individuals with chronic insidious onset neck pain or whiplash ≥6 weeks [12], individuals with non-specific neck pain only ≥3 months [14,16] or individuals with cervical dystonia [13]. Each were compared to groups of asymptomatic participants (Table 1).

Comparisons

Details of the functional movements performed and measurement methods (equipment, body segment definitions) are described in Table 2. Movements included walking, overhead lift in a sitting posture, sitting posture and typing, sanding posture, and a game-based task [12–16]. Three studies [12–14] used the same electromagnetic tracking system, and

Table 2
Measurement methods, outcome measures and results of included studies.

Study	3D measurement methods	Outcome measures	Result	Authors' conclusion
Falla *et al*. 2017 [16]	*Equipment:* eight retroreflective cameras (128 Hz, Oqus 300, Qualisys)	1. Speed of gait during self-selected speed	1. Average self-selected speed for neck pain was 3.6 (SD 0.5) km/hour. There was no significant difference between groups.	People with neck pain walk with reduced trunk rotation, especially when challenged by walking with their head rotated.
	Movement: participants walked on a treadmill at three different speeds (self-selected, 3 km/hour and 5 km/hour) with head in neutral, rotated 30° to left and 30° to right). For each trial participants walked for 120 seconds, with 30 seconds given to adjust to the new condition	2. Neck and truck rotation	2. People with neck pain demonstrated smaller stride lengths ($P < 0.001$).	
	Tracking markers: participants wore a custom made helmet for forehead markers which included center forehead, middle forehead, back head (center). Markers were also placed on the following: - C7 - L + R acromion - L + R ASIS and PSIS - L + R greater trochanter - L + R lateral epicondyle - L + R lateral malleolus - L + R 5th metatarsals	3. Variability of neck and trunk rotation, which were derived from the difference between transverse plane component of head and thorax and thorax pelvis angles	3. People with neck pain demonstrated less trunk rotation compared to controls (*post hoc* $P < 0.001$), and this reduced further when walking with the head rotated. 4. Variability of trunk rotation increased with speed ($F = 6.2$ $P = 0.002$) in both groups, with higher variability detected when walking at 5 km/hour compared to self-selected speed and to 3 km/hour ($P = 0.013$ and $P = 0.004$ respectively, for *post-hoc* tests)	
	Segments: defined the head as a rigid body comprised of the three markers on the helmet, the thorax as a rigid body defined by C7 and bilateral acromion; transverse plane rotation calculated as the difference between the transverse plane angles of each of these rigid bodies in relation to the lab coordinates.			

Table 2 (*Continued*)

Study	3D measurement methods	Outcome measures	Result	Authors' conclusion
Tsang *et al*. 2014 [14]	*Equipment:* three electromagnetic sensors (40 Hz; FasTrack, Polhemus) *Movement:* participants sat on a chair and transferred a 2 kg weight which was placed 20 cm in front of them with their right hand and then relocated it to a shelf 70 cm above the desk. They then released the weight and returned it to its starting position on the desk. Trial was repeat three times, *Tracking sensors:* sensors were placed on: – Plastic plate which was secured with strap around the skull around the external occipital protuberance – Second sensor was attached to T1 – Third sensor attached to T12 *Segments:* defined the head using a single sensor over the occipital protuberance, and trunk using two sensors (T1 and T12).	1. Angular displacement 2. Velocity and acceleration of cervical and thoracic spine in flexion/extension while participants were "raising" the object and when participants "lowered" the object	1. No significant difference between neck pain and control group for peak joint angles: Cervical flexion peak: – Neck pain: 10.86° (SD = 3.31°) – Control group: 12.61° (SD = 4.3°) Cervical extension peak: – Neck pain: 9.26° (SD = 3.84°) control group: 7.73° (SD = 2.59°) 2. Neck pain participants had significantly lower velocity and acceleration of the cervical spine in flexion/extension compared to people with no neck pain. Average raising velocity: - Neck pain: 14.89°/second, - Control group: 20°/second Average lowering velocity: - Neck pain: 28.01°/second - Control group: 32.67°/second Acceleration - Neck pain: 68.29°/second^2 - Control group: 86.69°/second^2	People with neck pain have decreased neck velocity and acceleration during overhead reach tasks.
Sarig-Bahat *et al*. 2010 [12]	*Equipment:* two electromagnetic sensors (60 Hz FasTrack, Polhemus) *Movement:* 16 trials were measured throughout a virtual reality game that involved participants hitting certain targets by moving their head. Each trial period was defined by the time the target appeared and when the target was hit. *Tracking sensors:* two sensors were placed on:	During four movement directions (flexion, extension, right rotation and left rotation), head/thorax mean values for: 1. Response time from target appearance to motion initiation. 2. Peak velocity: peak velocity value throughout the trial 3.	1. No difference between groups in response time 2. Lower peak velocity in individuals with pain compared to controls (mixed model ANOVA $P < 0.0001$, mean differences across movement directions ranged from 35 to 62°/second 3. Lower mean velocity in individuals with pain compared to controls (mixed model ANOVA $P < 0.0001$, mean differences across movement directions ranged from 9 to 20°/second	Velocity and smoothness of cervical motion are reduced in people with neck pain.

Table 2 (*Continued*)

Study	3D measurement methods	Outcome measures	Result	Authors' conclusion
	The back on of the "head mounted display" adjacent to the occipital protuberance and the sternal notch *Segments:* defined the head using a single sensor over the occipital protuberance, while subtracting trunk movement defined by a single sensor on the sternal notch.	3. Mean velocity: average velocity from motion initiation to target hit in game 4. Time to peak percentage: time from motion initiation to the velocity peak moment as percentage of total movement time. 5. Smoothness: number of velocity peaks from motion initiation to target hit.	4. No difference between groups in time to peak percentage 5. Greater number of velocity peaks in individuals with pain (mixed model ANOVA $P < 0.0036$, mean differences across movement directions ranged from 1.1 to 1.9 velocity peaks, indicating impaired motion smoothness	
Boccagni *et al*. 2008 [13]	*Equipment:* four electromagnetic sensors (30 Hz; FasTrack, Polhemus) *Movement:* static head position. *Tracking sensors:* sensors were placed on: – Head vertex (the conjunction point of the bi-auricular and medial sagittal line) – Bi-auricular line near the left mastoid – Bi-auricular line near the right mastoid – Chin *Segments:* the head segment was defined separately for each of the three planes using a line connecting two markers, measuring its rotation within the specific plane, as described by Galardi *et al*. [17].	Head position at rest in the sagittal plane, axial plane and coronal plane	Cervical dystonia mean head position: Sagittal plane: 5 (range: −25° to 36°) Axial plane: 1.21° (range: −44.6° to 24.0°) Coronal plane: 4.13 (range: −14.1° to 21.8°) Healthy subjects mean head position: Sagittal plane: −0.21° (range: −8.3° to 6.0°) Axial plane: −1.07° (range: −5.9° to 2.5°) Coronal plane: −1.10° (range: −3.5° to 1.0°)	3D motion analysis demonstrates differences in head–neck posture and movement that are not detected with clinical examination

Table 2 (*Continued*)

Study	3D measurement methods	Outcome measures	Result	Authors' conclusion
Szeto *et al*. 2005 [15]	*Equipment:* six retroreflective cameras (60 Hz; Vicon 370, Version 3.1, Oxford Metrics, UK)	Mean joint angles:	1. Head–neck: pain participants flexion/extension range (difference between the 10th and 90th percentile of the amplitude probability distribution function [APDF]) of 7 (SD 4) was less than control participants (5, 2, $P=0$), and their median (50th percentile of the APDF) lateral flexion angle was less to the left (−1, SD 2) and rotation less to the left (2, SD 2) compared to controls (lateral flexion −3, 2, $P=0$; rotation 4, 3, $P=0$)	Small differences in lateral flexion and rotation between groups
	Movement: 1 hour typing task with kinematics captured during the 5th, 20th, 35th, 50th and 60th minute of the typing task. Standardized typing package was used to display tasks for participants.	1. Head–neck (flexion/extension, lateral flexion, rotation) 2. Thorax (flexion/extension and lateral flexion)	2. Static sitting posture mean flexion: 61 (6) neck pain and 57 (6) control	Trends for increased head/neck flexion angles in individuals with neck pain
	Tracking markers: retroreflective markers were placed on the following: – Head–neck segment (two markers at two sides of the forehead) – Thorax (sternum, C7 and T8)	– Shoulder (flexion/extension and abduction/adduction)	3. Thorax: no difference between groups	
	Shoulder (AC joint and midpoint of humerus between lesser tuberosity and olecranon) *Segments:* used the Vicon standard biomechanical model that defined the head–neck as one segment. Specific details defining the head–neck segment were not described.		4. Shoulder: no difference between groups	

L = left, R = right.

two studies used different optical motion capture systems [15,16]. Body segments were uniquely defined for each study (Table 2), but no studies differentiated head movement from neck movement, only reporting head or head–neck related to trunk motion.

Outcome measures

The primary outcome measures were the kinematics of the cervical spine while performing a functional task (Table 2). Tsang *et al*. [14] and Sarig-Bahat *et al*. [12] quantified the velocity of neck of movement in two planes; sagittal (flexion/extension) and transverse (right/left rotation). Falla *et al*. [16] and Sarig-Bahat *et al*. [12] assessed smoothness of movement. Falla *et al*. [16] examined smoothness of movement by looking at the variability of neck and trunk rotation that was derived from the difference between the transverse plane component of head and thorax and thorax and pelvis angles. In addition to mean velocity, Sarig-Bahat *et al*. [12] also examined the number of velocity peaks indicating smoothness of movement in all four neck directions, as well as peak head velocity, time to peak velocity as a percentage of total movement and response time. Szeto *et al*. [15] and Boccagni *et al*. [13] measured static joint angles. Szeto *et al*. [15] examined the head–neck (flexion/extension, rotation and lateral flexion), thorax (flexion/extension and lateral flexion) and shoulder (flexion/extension and abduction/adduction) segment angles while sitting and during a typing task. Similarly, Boccagni *et al*. [13] reported head–neck joint angles in all planes of movement in individuals with cervical dystonia, but only during static standing.

Summary of findings

Altered kinematics in individuals with neck pain included decreased neck velocity, decreased smoothness of neck movement and varied neck angles during functional movement tasks (Table 2). Velocity of neck movement was analysed during reaching [14] and a gaming task [12] with individuals with neck pain having decreased head velocity compared to asymptomatic controls. Falla *et al*. [16] found individuals with neck pain had less trunk rotation compared to healthy controls during walking. Both Falla *et al*. [16] and Sarig-Bahat *et al*. [12] analysed smoothness of movement, but only Sarig-Bahat *et al*. [12] found a difference in movement smoothness in individuals with neck pain compared to controls, which they defined as a greater number of velocity peaks in all three planes of neck movement during their gaming task. Szeto *et al*. [15] reported increased neck flexion angles in individuals with neck pain compared to asymptomatic controls during sitting and typing. Boccagni *et al*. [13] found increased head/neck movement during attempted static standing in individuals with cervical dystonia compared to an asymptomatic control group. As studies used varying methods of measurement and reported on different kinematic variables and functional tasks, data could not be pooled for meta-analysis.

Study quality

There was 100% agreement between reviewers for the quality assessment (Table 3). All studies scored positively on clearly defining the population and outcome measures, and negatively scored for not accounting for confounding variables and blinding assessors. Three studies [13,15,16] scored negatively for small sample sizes.

Discussion

The results of this systematic review suggest that cervical kinematics are different in individuals with neck pain as compared to asymptomatic individuals. All included studies reported kinematic movement variables recorded during observation of movement in people with neck pain compared to pain-free control participants. All studies were cross-sectional, therefore, evidence for differences in 3D kinematics between individuals with and without neck pain reported in the current review represents only Level 3 evidence, according to GRADE [18]. Some of the findings in individuals with neck pain were reduced velocity and smoothness of head movement, reduced trunk rotation when walking at a normal pace, reduced head velocity and acceleration when performing a reach task, and differing head positions in static postures as compared to pain-free individuals. Importantly, these kinematic variables were observed in individuals with varying types of neck pain (idiopathic, whiplash and cervical dystonia), suggesting that there are some kinematic differences present across varying neck pain types. However, each study measured different kinematic variables, so it is unknown whether these kinematic differences are unique to neck pain type, experimental movement task or simply observed because the authors chose to measure those particular variables. There were only five studies included in this review, three with small sample sizes [13,15,16]. Nevertheless, these findings suggest 3D motion analysis may be a useful tool for measuring cervical kinematics in individuals with neck pain, as there were altered kinematics in individuals with a range of neck pain types. Future research may identify whether these kinematic changes increase the risk of a subsequent neck pain episode, and whether they can provide a quantitative method for assessing the effectiveness of rehabilitation.

3D motion analysis of spinal posture

Review findings suggest 3D motion analysis may be a useful tool for evaluating spinal postural changes during static sitting or standing in individuals with neck pain. Boccagni *et al*. [13] demonstrated increased head/neck movement in all planes in individuals with cervical dystonia while attempting static posture, suggesting larger dystonic patterns as compared to asymptomatic individuals. Szeto *et al*. [15] examined head/neck angles recorded static sitting posture for two minutes in office workers prior to their typing task, showing.

Table 3
Quality assessment for the three included studies using the NIH Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies (First author).

Question	Falla 2017 [16]	Tsang 2014 [14]	Sarig-Bahat 2010 [12]	Boccagni 2008 [13]	Szeto 2005 [15]
Research question clearly stated	Y	Y	Y	Y	Y
Was population clearly specified and defined?	Y	Y	Y	Y	Y
Was the participation rate of eligible persons at least 50%	N	Y	Y	N	N
Were all subjects selected or recruited from the same or similar populations?	Y	Y	Y	X	Y
Was a sample size justification, power descripted, or variance and effect estimates provided?	N	Y	Y	N	N
Was the exposure of interest measured prior to the outcome being assessed?	Y	Y	Y	Y	Y
Was the time frame sufficient so that one could reasonable expected to see an association between exposure and outcome?	Y	Y	Y	Y	Y
Did the study examine different levels of the exposure as related to the outcome?	NA	NA	NA	NA	NA
Were the exposure measures clearly defined, valid, reliable and implemented consistently across all study participants?	NA	NA	NA	NA	NA
Was the exposure assessed more than once over time?	N	N	N	N	N
Were the outcome measures clearly defined, valid, reliable and implemented consistently across all study participants?	Y	Y	Y	Y	Y
Were the outcome assessors blinded to the exposure status of participants?	N	N	N	N	N
Was loss to follow-up after the baseline 20% or less?	NA	NA	NA	NA	NA
Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure and outcome?	N	N	N	N	N

Y = yes, N = no, NA = not applicable.

increased mean neck flexion angles during sitting in individuals with neck pain compared to asymptomatic individuals (Table 2). While these results suggest 3D motion analysis provides quantitative postural information that may by clinically important, notion should be interpreted with caution as both studies had small sample sizes and the study by Boccagni *et al*. [13] was restricted to individuals with cervical dystonia.

Functional tasks assessed with 3D motion analysis

Most patients usually seek treatment because their neck pain is aggravated by certain functional movements and/or they are unable to complete these tasks [19]. Researchers have demonstrated 3D motion analysis can identify specific biomechanical risk factors in athletic populations [9,19,20]. For example, it has been used to identify musculoskeletal injury risk factors in acute [9] and chronic knee and groin injuries [19] during jump-landing tasks and low back pain during running [20]. It has also been used to demonstrate variability in motor control coordination in runners with low back pain [22] and in patients with stroke [23]. The use of 3D motion analysis has also been suggested as useful in prescribing rehabilitation for patients with lower back pain [21] and stroke [23]. Hence, the use of 3D motion analysis by clinicians may assist them to identify and quantify movement impairments in their patients. However, there is little research analysing functional tasks in individuals with neck pain. Therefore, the clinical benefits that might arise from greater knowledge of spinal kinematics are largely unknown, and this area warrants further study.

Four of the included studies in the current review analysed differences in cervical and thoracic spine 3D kinematics during functional tasks [12,14–16]. All four studies examined functional movements that would be relevant to the general population: a typing task, overhead reach, gaming task and walking. In the study by Szeto *et al*. [15], participants performed a typing task involving copy-typing for one hour from a document presented on screen. Individuals with higher levels of neck pain had increased neck flexion angles compared to healthy individuals, however, the differences between groups were small (4–8° greater for those with neck pain as compared to health controls, Table 2) and not statistically different between groups. They did find a statistically significant difference in lateral flexion and rotation between their groups, with the healthy control participants demonstrating greater right lateral flexion and right rotation compared to participants with neck pain. These differences were also small (1.5° for lateral flexion and 2.4° for right rotation) and potentially within the margin of measurement error, suggesting these conclusions about head/neck angles in individuals with neck pain should be interpreted with caution. Furthermore, their results are based on a small sample of female office workers positioned at their own workstations that can involve many variable settings. Though this improves generalisability to the workplace, it may have introduced movement variability that may have masked a possible difference between groups. In the study by Tsang *et al*. [14], participants performed an overhead reach task requiring them to move a 2 kg object to above head height. Individuals with neck pain had significantly lower peak extension cervical spine angular acceleration into extension when raising an object and into flexion when lowering an object as compared to asymptomatic individuals (Table 2). Sarig-Bahat *et al*. [12] used a customised virtual game requiring rapid head movement in order to hit on-screen targets, effective experimental task for observing natural movement of the head and neck without excessive instruction or prescription of movement. Similar to Tsang *et al*. [14], they [12] found individuals with neck pain demonstrated decreased head velocity, suggesting individuals with neck pain move their head slower compared to people without neck pain. Falla *et al*. [16] examined neck kinematics while participants walked on a treadmill at three difference speeds (self-selected, 3 km/hour and 5 km/hour). The authors demonstrated that individuals with chronic idiopathic neck pain had significantly decreased neck and trunk rotation regardless of walking speed and increased variability of neck and trunk rotation at increased walking speeds compared to individuals without neck pain. Sarig-Bahat *et al*. [12] also investigated movement variability using a different outcome variable: the number of velocity peaks during head movement during their gaming task. They found people with neck pain have reduced peak velocity during neck rotation making their movement less "smooth" compared to people with no neck pain. Future research is needed to determine if slower head velocity places these individuals at greater risk of re-injury or neck pain chronicity due to continued aggravation of pain with tasks requiring rapid head movement, e.g., checking a blind spot while driving.

In summary, 3D motion analysis appears to be an effective tool for quantifying cervical kinematic variables during functional tasks in a laboratory setting [22]. Future research may develop and validate inertial measurement unit technology in order to provide clinicians with a simple, reliable and valid field-based method of 3D motion analysis tool to quantify 3D functional movement during clinical assessments in day-to-day practice. This would then provide a tool to assist clinicians to reliably quantify functional movement and use this tool to develop rehabilitation programs and monitor a patient's rehabilitation progress. Researchers may also benefit from field-based methods of quantifying 3D motion in order to design larger studies and utilize the workplace environment to determine if altered kinematics may increase injury risk. This systematic review identified only five studies measuring 3D neck motion during functional tasks, suggesting further research is needed. This review provides the basis to assist future researchers to design studies to effectively analyse neck kinematics.

Strengths and limitations

The search criteria for this review was broad to attempt to capture any study that had measured in vivo 3D kinematics in the cervical and thoracic spines. All types of neck pain and all types of functional tasks were included, yet only five studies met the criteria for inclusion. This demonstrates a lack of quantitative studies measuring functional cervical spine movement, despite current guidelines for neck pain stating that clinicians should assess functional movement [24]. The lack of 3D motion analysis studies in neck pain is likely due to the difficulty in objectively quantifying 3D functional movement in the spine compared to measuring neck range of motion in a single plane. Despite 3D motion analysis system being the gold standard to track complex 3D joint movement and can be used to provide real-time feedback [25], it requires expensive equipment, highly specialised skills and is time-consuming analysis. These limitations precludes most clinicians to employ this gold standard methodology within their day-to-day clinical practice. Yet, if there were more laboratory studies in individuals with neck pain, it would assist in better understanding of movement patterns of the cervical and thoracic spine during functional tasks, providing a critical foundation to enhance objective clinical assessments and interventions. Currently, physiotherapists are retraining functional movements in patients with neck pain with very limited scientific evidence of altered 3D motion in these patients. Therefore, more studies are needed that objectively quantify 3D cervical motion in individuals with neck pain. This critical information will provide clinicians with a deeper understanding of neck kinematics during functional movement tasks to better guide treatment outcomes.

Motion analysis methods have their own inherent limitations, as described by previous authors for electromagnetic systems [26], i.e. Fastrack utilised by three studies in this review [12–14], and optical motion capture systems [27,28] utilised by two studies [15,16]. Electromagnetic systems [26] do not have the issues of marker occlusion or tracking problems of optical systems but their accuracy can be affected by surrounding metal within the environment or if the sensors are too close to one another. The maximum sampling rate for electromagnetic systems is lower (120 Hz) than optical systems (200–500 Hz) and decreases with each additional sensor such that the maximum sampling rate possible is equal to 120 Hz divided by the number of sensors [26]. Nevertheless, the varied sampling rates varied among the included studies (Table 2) did not violate the Nyquist sampling theorem, that states the sampling rate must be no less than twice the highest frequency [26], with the highest frequency recoded during functional task less than 20 Hz [29]. The experimental protocols (i.e., camera setup) and modelling [27,28] may also alter the accuracy of kinematic data.

There were additional limitations in the current review. From the quality review, studies had low sample sizes and few accounted for confounding variables suggesting caution in interpreting the review findings. Further, there were strict inclusion criteria for functional movement tasks which meant studies were excluded if they used 2D movements, for example, planar ROM. This is often measured in clinical studies as it can be easily measured in the clinical setting using low-cost low-fidelity tools such as goniometers or the CROM. Their exclusion meant that many clinical studies were excluded from the review. However, the focus of this review was to summarise the evidence for altered cervical kinematics during multi-planar functional movement, as the evidence for differences in single plane cervical ROM in individuals with neck pain has been previously reviewed [30]. The number of functional tasks among the five studies are limited to gaming, typing, standing, walking and reaching. Therefore, it is unknown if kinematics differ in other functional tasks, for example, driving or putting on a seatbelt. There is a need for future studies to examine neck kinematics for additional functional tasks. As non-english studies were excluded it is possible that other functional tasks have been measured that were not captured by this review.

Conclusion

There is Level 3 evidence that cervical kinematics during functional movement differs in individuals with neck pain compared to pain-free individuals. This evidence suggests individuals with neck pain may have greater neck flexion, slower velocity and reduced smoothness of head movement compared to asymptomatic individuals during functional movements. However, the kinematic data reported in three out five included studies have small sample sizes indicating these findings should be interpreted with caution, and there is a need for further research examining cervical spine kinematics during common functional tasks.*Conflict of interest*:

Key messages

- This systematic review found limited Level 3 evidence that individuals with chronic neck pain have slower head velocity, reduced smoothness of movement and increased neck flexion angles during functional reaching tasks compared to asymptomatic individuals.
- Three-dimensional (3D) motion analysis is commonly reported in the assessment of lower limb joint kinematics, however, this is the first review examining the evidence for alterations in 3D kinematics of the cervical spine in individuals with neck pain.
- New knowledge provided by this paper is the specific differences in cervical 3D kinematics in individuals with chronic neck pain compared to asymptomatic individuals. These further improve understanding of neck kinematics, providing clinicians with a foundation to enhance the comprehensiveness of their physical examination and assist in tailoring exercises more effectively for chronic neck pain.

None declared.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.physio.2019.01.007.

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