Differences in Human Cervical Spine Kinematics for Active and Passive Motions of Symptomatic and Asymptomatic Subject Groups

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Most musculoskeletal disorders of the head and neck regions cannot be identified through imaging techniques; therefore clinician-conducted assessments (passive motions) are used to evaluate the functional ability of these regions. Although active motions do not require interaction with a clinician, these movements can also provide diagnostic indicators of dysfunction. The purpose of this research was to determine whether kinematic measures differed between active and passive motions of participants in symptomatic and asymptomatic groups. Data obtained on cervical lateral flexion range of motion (ROM), coupled axial rotation, and the angular velocity of lateral flexion were statistically analyzed and demonstrated differences between active and passive motions for symptomatic and asymptomatic subjects. Active motions had higher angular velocities ($P < .001$) and larger ROMs, with greater lateral flexions ($P < .05$). The asymptomatic group produced a larger average lateral flexion of 7.9° at an average angular velocity of 2 deg/s greater than the symptomatic group. Trends with regard to group assignment were the same for active and passive motions. This work demonstrates the potential for using kinematic measures of active and passive motions to develop an objective standard for diagnoses of cervical dysfunction and supports validity of the clinician-based analysis to distinguish between participant groups.

Keywords: biomechanics, biomedical engineering, cervical spine, diagnosis, active motion, passive motion

Nonspecific spinal dysfunctions are among the most prevalent human musculoskeletal disorders (MSD), accounting for 80–85% of reported cases. Common symptoms related to these dysfunctions include pain, motion restriction, tenderness to palpation, and temperature variations. These disorders can be caused by degenerative changes or trauma that damages muscles, nerves, joints, tendons, and ligaments. In the United States alone, cervical (neck) dysfunction accounted for 16.4 million health care visits annually, second only to low back dysfunction. Further, consistently high occurrences of cervical dysfunction have been reported throughout multiple decades.

Accurate diagnoses of neck dysfunction are often difficult, even though various techniques are used to investigate specific causes of the abnormality. Medical imaging such as magnetic resonance imaging (MRI), computed axial tomography (CT scan) and radiography (x-ray) have shown success with specific spinal disorders such as disc herniation and vertebral fractures. Although medical imaging typically involves analysis of static postures, dynamic, weight-bearing musculoskeletal assessments using MR and CT imaging techniques are rapidly advancing. However, applications of these imaging techniques are still primarily research based with current focus around optimization of these techniques, in addition to suffering from high costs, lower resolutions, and limited accessibility. As a result, medical imaging is typically limited to static assessments, and therefore many functional cervical disorders cannot be assessed through these techniques. Instead, diagnoses of cervical dysfunctions are regularly accomplished using specific manual
of particular interest to this research are the evaluations of cervical spine dysfunctions made by clinicians using passive diagnostic motions—the use of external (clinician induced) forces to move specific body parts through a range of motion (ROM) for diagnostic purposes. While manual medicine is commonly practiced, current diagnostic techniques are dependent primarily on subjective analyses by the clinician based on training and experience.\textsuperscript{21} Due to this subjectivity, most of these tests lack reliability (precision) and validity (accuracy).\textsuperscript{19,20} One of the challenges associated with manual diagnostic techniques is the paucity of comprehensive studies comparing these passive techniques to volitional motions using objective kinematic comparators, and making assessments across subject groups.

Since passive diagnostic motions are subjective, it is difficult to use this information as the basis for a gold standard. Therefore, objective data that can be related to the diagnostic evaluation must be sought. Subsequently, the use of active self-induced motions that do not require interaction with the clinician, combined with a common set of measures linked to a passive diagnostic test, may provide the basis for a set of objective data. Some studies have evaluated kinematics associated with either active or passive cervical spine function, specifically, ROM.\textsuperscript{22–32} However, scientific studies that dynamically evaluated the movement for both active and passive motions in the same study, across two subject groups are limited. In a systematic review of 46 reliability and 21 validity articles on investigation of active and passive cervical evaluation methods, Williams et al.\textsuperscript{32} found only seven of the studies included both asymptomatic and symptomatic subject groups. Further, the focus of this single study was limited to interobserver reliability, with data reported only for the maximum cervical range of motion. Although 3-dimensional (3D) kinematic measures were collected, no other data comparators were used to assess differences between active and passive motions or groups. There are no reported studies that investigated the differences between both active and passive diagnostic techniques with multiple kinematic comparators across asymptomatic and symptomatic groups.

The study reported here is unique in that 3-dimensional kinematics of cervical spine motions (defined by the movement of the head relative to the thorax) between active and passive motions were compared for multiple kinematic variables across symptomatic and asymptomatic individuals. These kinematic comparators included primary motion (lateral flexion), secondary motion (coupled rotation that occurred during the lateral flexion) and angular velocities. All were statistically analyzed for comparisons between active and passive motions and for comparisons between groups. Thus, the purpose of this research was to determine whether these kinematic measures differed between active and passive movements for participants in symptomatic and asymptomatic groups.

### Methods

#### Screening to Obtain Test Groups

Volunteers were recruited from a university student, faculty, and staff population, as well as from a campus clinical center. Following written consent (IRB approval # 06-464), participants completed two questionnaires to document levels of pain and disability. The first questionnaire was a visual-analog scale (VAS)\textsuperscript{34} where participants documented their pain in the neck region with “0” signifying no pain and “10” indicating severe pain. The second was the Neck Pain and Disability Scale (NPDS).\textsuperscript{35} Following the completion of the consent and questionnaires, a physician (Examiner 1), performed an initial cervical diagnosis (detailed under “Active and passive evaluations”) while blinded to the participant’s results from the pain and disability questionnaires. This assessment was in the form of a standard manual medicine palpatory assessment through cervical lateral flexions (side bending). Based on the initial physician’s assessment, and the results of the VAS questionnaire, two subject groups were established:

**Control Group.** Participants were asymptomatic as determined from the VAS (VAS = 0), and were symmetric for right and left lateral flexion diagnostic motions as determined by Examiner 1. Criteria used to assess symmetry were a subjective assessment of equality of the ROM between right and left sides along with equality of tissue resistance between right and left sides.

**Experimental Group.** Participants were documented as symptomatic as determined from the VAS, (VAS ≥ 3).\textsuperscript{34} Individuals not meeting the criteria for either the Control or Experimental subject groups were dismissed following screening.

#### Participant Pool

Based on the screening of 131 total volunteers, 41 qualified for the study, including 22 Control participants (16 males, 4 females, and 2 who chose not to answer on the questionnaire) and 19 Experimental (14 males and 5 females). The average age was 19.9 (min = 18, max = 23, SD = 1.9) and 27.5 (min = 18, max = 63, SD = 13.1) years respectively for the Control and Experimental groups. The average height and mass for the Control and Experimental groups were 174.9 (10.2) cm and 74.0 (13.7) kg, and 175.9 (12.3) cm and 79.9 (20.9) kg respectively. The average VAS scores for the Control and Experimental group as a result of the screening process were 0 (0) and 4.6 (1.7), respectively.

#### Active and Passive Evaluations

All Control and Experimental participants adhered to the same testing protocol (Figure 1), including, passive cervical evaluations performed by two additional physicians (Examiners 2 and 3), followed by active (volitional) cervical motions.
Examiners 2 and 3 conducted passive diagnostic motions in front of a six-camera motion capture system (Qualysis, Gothenburg, Sweden). Examiners were blinded to participant questionnaire results, each other’s assessments and had limited communication with the participants. Each examiner performed two separate trials of palpatory cervical diagnoses consisting of three right and left lateral flexion’s (Right-Left-Right-Left-Right-Left) per trial (Figure 2) in front of the motion tracking system with Examiner 2 conducting the first examination followed by Examiner 3.

The cervical palpatory diagnostic technique used during participant screening and testing is a highly practiced, standard manual medicine clinical diagnostic motion test.36 All three examiners were practicing osteopathic physicians, specializing in manual medicine, for over 10 years.

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**Figure 1 — Participant testing protocol.**
The procedure was as follows:

1. The examiner aligned himself/herself posterior to a seated participant and asked for the person to remain passive as the diagnostic motions were performed.

2. One of the examiner’s hands was placed gently on a participant’s head, while the contralateral hand was placed lightly on the posterior thoracic midline to stabilize the shoulders (Figure 2).

3. The examiner slowly guided the participant’s head in lateral flexion to the right, bringing the right ear toward the ipsilateral shoulder until a palpable sense of end-range of motion was achieved. The endpoints of ROM were based upon each examiner’s subjective palpatory evaluation where the end range was defined as a tissue texture change that required a substantial increase in force to continue the diagnostic motion.37

4. At the conclusion of motion, the participant’s head was guided back to a neutral location, the examiner’s hand placement was switched, and movement to the contralateral side was conducted.

5. The participant’s head was guided back to the neutral location again, and steps 2–5 were repeated.

Following the cervical palpatory diagnostic procedure, examiners made their clinical evaluations based upon the following predefined assessment criteria.34,36

1. A visual and proprioceptive evaluation of the magnitude and symmetry.
2. A determination of quality of motion, where quality of motion was evaluated on smoothness of motion and tissue resistance.
3. End-feel was considered as any resistance to movement as the participant reached the end range.

Both Examiner 2 and Examiner 3 reported their diagnosis of each subject through written clinical field notes.

The final test in the series was that of active motion. The following written instructions for active motion testing were provided to each participant:

1. Sit with your feet flat on the ground, hands crossed in front of your chest with your back in a comfortably erect posture.
2. Start the motions with your head in a comfortable neutral position (looking straight forward) and with your eyes closed.
3. Hold the starting position for a count of three seconds, and then begin moving your right ear slowly toward your right shoulder.
4. When you reach your “comfortable end range” moving to the right, reverse direction.

This procedure was reiterated verbally before testing.

The endpoints of active ROM were defined as the points of maximum lateral flexion that a subject was “comfortable” achieving without inducing pain.

**Kinematic Data Collection**

To obtain 3-dimensional kinematic data during passive and active motions, retro-reflective markers were attached to the skin via medical tape. A six-camera Qualysis motion tracking system was used to gather the kinematic data. The duration of the trial was not controlled, so that examiners moved at their preferred rates for passive motions, and participants moved at their preferred rates during active motions.

Each passive and active trial started with a 3 s baseline period in which the individuals were instructed to remain still and face forward to establish a subject-specific neutral location. Two markers placed on each temple lateral to the creases of the eyes, and one marker centered on the forehead superior to the brow captured the head motions. Three additional markers were used in a rigid triad configuration and adhered to the participant’s sternum centered inferior to the sternal notch to capture any movement of the participant’s torso (Figure 2).

A global Cartesian coordinate system was oriented such that the X-axis progressed horizontally from the participant’s left to right, the Y-axis from posterior to anterior, and the Z-axis vertically from inferior to superior. The system was calibrated each day before testing, and the system error was less than ±2 mm and ±1°. Trial times ranged from 30 to 65 s, and data were collected at 20 Hz.
Data Analysis

Local coordinate systems were established separately for the head and thorax, and a Matlab toolbox program called KineMat was used to compute the angles of the head relative to the thorax for each trial. This method eliminated torso movements in the calculation of the cervical ranges of motion. The motion angles were determined using Euler angle rotations with the first rotation occurring about the y-axis (lateral flexion), following by rotation about the z-axis (axial rotation), and then x-axis (flexion and extension).

Cervical Range of Motion (ROM). Analyses were conducted on cervical ROM data obtained for primary (lateral flexion) and secondary (axial rotation) movements, as these were the respective movements used in the cervical palpatory diagnostic technique. The maximum right (negative) and left (positive) lateral flexions were identified as an angle greater than 10° (θ > 10°) that was greater than the previous 10 values, and greater than the following 10 values (Figure 3). All angles were based upon the participant’s selected neutral position (0° angle). Secondary ROM values were determined as the axial rotations at the corresponding frames identified for maximum lateral flexion values.

Angular Velocity of Lateral Flexion. The average rate of motion, or angular velocity (deg/s) of each lateral flexion cycle was determined from the slope of calculated linear regressions for the frames identified from the start to the peak of a cycle. This region of the curve corresponded to the portion of the movement where the examiner conducted the passive diagnostic assessment. Assessment occurred from neutral to the end-range but not during the return to neutral.

Statistical Analyses. Statistical analyses were conducted to evaluate: (1) the consistency within an examiner, (2) differences between active and passive motions, and (3) differences between subject groups. One-way repeated-measures ANOVAs with a Bonferroni correction were used to make comparisons between active data and passive data for each participant within each group for lateral flexion ROM, axial rotation ROM, and angular velocity of lateral flexion data. Independent samples t-tests were used for comparisons between groups for lateral flexion ROM, axial rotation ROM, and angular velocity of lateral flexion data of Examiner 2, Examiner 3, and active motion. All analyses were conducted at a 95% confidence level (significance at \( P < .05 \)). For all data comparisons trials one and two were averaged for each participant.

**Figure 3** — Lateral flexion angle for one passive evaluation trial, noting: left range of motion (ROM), right ROM, full ROM, cycle start, and cycle peak.
Results

Comparisons between passive and active lateral flexion ROMs demonstrated significant differences in which average active ROM was consistently greater than the average passive ROM (Figure 4). The average lateral flexion ROMs for Examiner 2, Examiner 3, and active motion respectively of the Control group were 71.4° (11.5), 66.1° (11.5), and 87.4° (12.5), and of the Experimental group were 66.3° (12.0), 58.0° (11.7), and 77.0° (13.5). Average active lateral flexion ROMs were 16.0° and 10.7° greater than passive ROMs for Examiner 2; and 21.3° and 19.0° greater than Examiner 3 for the Control and Experimental groups, respectively ($P < .05$). In both the Control and Experimental group, a trend can be observed in the lateral flexion ROM data such that active motions were greater than Examiner 2’s ROMs which were greater than Examiner 3’s ROM (Figure 4).

From the secondary motion (axial rotations) that occurred at the point of maximal lateral flexion, a trend can be observed in that active motion axial rotations were greater than Examiner 2’s rotations which were greater than Examiner 3’s rotations within both groups (Figure 5).

![Figure 4](image1.png)  
**Figure 4** — Cervical lateral flexion average full range of motion data for active and passive evaluations of the Control and Experimental groups.

![Figure 5](image2.png)  
**Figure 5** — Cervical axial rotation average full range of motion for active and passive evaluations of the Control and Experimental groups.
The average axial rotation ROMs for Examiner 2, Examiner 3, and active motion respectively of the Control group were 19.6° (8.5), 15.4° (8.2), and 21.8° (11.3), and of the Experimental group were 22.6° (11.5), 17.0° (11.5), and 25.0° (19.5). A statistically significant difference was documented for the range of axial rotation motion between active motion and passive motions performed by Examiner 3 in the Control group ($P = .023$) but not for Examiner 2.

Comparisons of angular velocities for passive and active lateral flexion motions for the Control and Experimental groups (Figure 6) demonstrated that the active angular velocities were greater than passive angular velocities for both groups. The average angular velocity of lateral flexion for Examiner 2, Examiner 3, and active motion respectively of the Control group were 11.1 (2.4), 11.7 (3.0), and 17.3 (4.6) deg/s, and of the Experimental group were 9.2 (2.9), 9.8 (2.8), and 15.1 (5.1) deg/s. Differences between active and passive average angular velocities ranged from 5.3 to 6.2 deg/s. Passive motion angular velocities were significantly lower than the active motion velocities for all comparisons ($P < .001$).

Comparisons of average lateral flexion ROMs between Control and Experimental groups indicated that participants in the Control group moved through a greater motion range than those in the Experimental group for both active and passive motions (Figure 4). Differences between Control and Experimental groups were 10.4°, 8.1°, and 5.1° for active motion, Examiner 2, and Examiner 3 comparisons, respectively. In contrast, axial rotations of the Control group were less than that of the Experimental group for both active and passive motions (Figure 5). Significant differences between Control and Experimental groups were documented for lateral flexion ROMs for Examiner 3 ($P = .027$) and active motion ($P = .009$) but not for Examiner 2 ($P = .136$).

Average lateral flexion angular velocities for the Control group were greater than the Experimental group during both active and passive motions (Figure 6). Significant differences between Control and Experimental groups occurred for both Examiner 2 ($P = .033$) and Examiner 3 ($P = .043$) but not active motion ($P = .156$).

In addition, NPDS scores expressed a significant difference in disability levels between the Control and Experimental group with average scores of 2.5 (4.1) and 46.9 (21.0) respectively ($P < .001$). Statistical analyses demonstrated no significant difference between the ages of the Control and Experimental groups.

### Discussion

The purpose of this study was to use 3-dimensional kinematic measures to investigate differences between active and passive movements of the cervical spine across two subject groups (asymptomatic and symptomatic) during diagnostic motions of lateral flexion. Differences in ROMs and rates of movement (angular velocity) were found between groups, and between active and passive motions.

The average ROMs produced by the two examiners during passive diagnostic movements were significantly less than the same active movements produced by the participants themselves for both the Control and Experimental groups. Further, comparisons of the average angular velocity of active and passive motions demonstrated that active motions were conducted at a significantly faster angular velocity, which was anticipated.
as diagnostic evaluations were being conducted by the examiner during passive motions while active motions were volitional and only required the subjects to focus on a prescribed motion. Passive secondary ROMs (axial rotations) occurring at maximum cervical lateral flexions were significantly less than secondary ROMs during active movements, and the standard deviations of the primary and secondary motions were greater for active motions. These larger standard deviations may be a result of the larger active motion performance range as well as the increased variability from conducting the movement actively.

These findings differ from published reports which indicate that average passive cervical ROM values were greater than active motion values. The two potential explanations of differences with reported literature are associated with the experimental intent of this research and the effects of coupled cervical motion. The intent of this study was not to identify maximal motion ranges available during passive head and neck movements. Instead, the examiners used standard, predefined assessment criteria to achieve physiological barriers (not anatomical barriers) of movement. Coupled cervical motion can be associated with geometric constraints that exist between adjacent cervical vertebrae. Further, cervical joint orientation, connecting ligaments and the regional spinal curvature cause inherently connected cervical motions. Thus, coupled movement patterns (the combination of simultaneous flexions, rotations and translations) occurred during all cervical movements. The increased secondary motion that occurred during the active movements, allowed for increased primary motions. This is supported by work conducted by Dvorak et al on the lumbar spine. This physiological phenomenon was observed when comparing diagnostic motions across evaluation techniques within a subject group (Figures 4 and 5); such that for both primary and secondary motions, active ROMs were greater than Examiner 2’s ROMs, which were greater than Examiner 3’s ROMs. This trend was not supported in a comparison across groups, as the Experimental group produced larger secondary ROMs but a smaller primary ROMs. It is likely that the Experimental subjects reached a physiological barrier to their primary motion earlier and subsequently produced an increased secondary motion when the barrier was reached.

In this study, the written and verbal active motion instructions given to the participants did not require them to force movements along the primary (frontal) motion plane. Instead, participants were simply told to move their heads laterally right and left until they reached comfortable motion end ranges. This is clearly indicated through the large standard deviations observed in the axial rotation data. Since coupled motion was not controlled, the secondary motion was highly variable. In the future, exploration of the specific effects of coupled motions on ranges of motion should be addressed through an experimental set-up that requires individuals to maintain the motion in the frontal plane without allowing rotation.

Further, the active and passive data showed the same motion trends with regard to group assignments. Specifically, lateral flexions were lower, secondary rotations were higher, and angular velocities were lower for the Experimental group in comparison with the Control group. These data demonstrate that trends found through active motions of symptomatic and asymptomatic individuals were also identified in passive evaluations. Therefore, relating the active and passive assessments through objective measurements provides the potential for establishing objective standards associated with cervical spine dysfunction.

An additional purpose of this study was to evaluate the efficacy of using 3-dimensional kinematics in a musculoskeletal medicine diagnostic protocol to identify differences between asymptomatic and symptomatic subject groups. To that end, total active and passive generated lateral flexion ROMs for the Control (asymptomatic) group were greater than ROMs for the Experimental (symptomatic) group, with significant differences for one of the two examiners, and for active motions. These findings support previous studies that report reduced cervical ROMs for participants with cervical dysfunction in comparison with healthy individuals.

Further, angular velocities were computed during all passive and active diagnostic motions. Comparisons of the data indicated the Experimental participants moved slower than the Control participants for both passive and active motions.

Recall that the examiners were blinded to whether the participants were in the Control or Experimental group, yet the kinematic data indicated that examiners moved participants in the Experimental group at slower velocities, and produced a decreased ROM for lateral flexion with an associated increase in rotation. Thus, the assessment produced by the examiners also produced kinematics that differed between the Control and Experimental group, even while examiners were blinded to group assignment. It is possible, that visual indicators of age could play a role in examiner assessment; however, this is a limitation that would be present in all studies involving clinical evaluations, unless examiners were blindfolded. Examiner biases based on pain behaviors were limited by placing the examiners posterior to each subject (the standard clinical diagnostic testing position) so that facial expressions were not observed, and verbal communication between the subject and examiner were limited with no subject ever providing a verbal indication of pain during testing. Further, muscle guarding during the diagnostic process was likely minimal as previous literature has indicated that warm-up motions, as performed in the screening process, would reduce this bias. Although the average age of the Experimental group was older than that of the Control group, the difference was not significant. Previous literature indicates differences in cervical ROM based on age differences and therefore future work should strive to obtain age-matched groups.
This work provides support for the validity of the manual medicine palpatory analyses to distinguish between participants with or without cervical dysfunction, and provides initial data to support the physical interaction between a clinician and a patient in the assessment of motion qualities, tissue texture regularities/irregularities, and joint stability. These data also move the research process closer to the development of an accurate, objective, standard to parallel manual medicine techniques.

This study lends support to the clinical practice of manual diagnosis of passive cervical kinematics to determine presence of somatic dysfunction. There are limitations in applying these data to clinical practice, however. Patients with VAS > 0 but < 3, and VAS = 0 but asymmetric motion tests, may or may not be differentiated by this passive lateral flexion test, as these populations were not assessed in this study. The lateral flexion passive or active motion test is not the only diagnostic procedure employed in clinical practice to determine presence of cervical somatic dysfunction. Palpation for tissue texture abnormalities, temperature variation, and tenderness, as well data gathered verbally from the patient are coalesced in the practitioner’s mind to determine presence of somatic dysfunction verses referred pain verses underlying disease pathology. In addition, although subjective data for the clinical diagnosis made by each examiner were obtained for each participant, it was found that examiner’s clinical field notes were not consistent in their reporting methods, making comparisons difficult. Future work should strive to develop documents for clinical palpatory diagnosis that are clinically meaningful and can be related to objective measures.

Alterations of function of the musculoskeletal system can and do lead to symptoms of pain. This study shows that alteration in normal range of motion and differences in rates of movement are objective findings in patients with subjective complaints of neck pain and can be quantified through both passive and active assessments.

The value of this study is that kinematic measures of passive motion can be useful in assessing and improving reliability and validity of these types of diagnostic procedures for the cervical spine, and possibly other body regions. The more reliable and valid diagnostic procedures used, the more likely an accurate diagnosis and appropriate treatment will be used, which will improve clinical outcomes.

In summary, this work begins to evaluate kinematic differences and similarities between active and passive motions, and differences between individuals who are asymptomatic and symptomatic. Further, comparing these results to the clinical diagnoses provides objective evidence for the validity of passive diagnostic motions to categorize individuals with and without cervical pain and somatic dysfunction. Lastly, the relationships between active kinematics, passive kinematics, and group assignment (symptomatic or asymptomatic) demonstrate potential for use in the creation of standards associated with cervical spine dysfunction.

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