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Maximal Voluntary Isometric Neck Strength Deficits in Adults With Whiplash-Associated Disorders and Association With Pain and Fear of Movement

The term *whiplash* is commonly used to describe a mechanism of neck injury. It has been defined by Spitzer et al[31] as "an acceleration-deceleration mechanism of energy transfer to the neck." Whiplash-associated disorder (WAD) is the clinical manifestation of a whiplash injury. Such clinical manifestation may include neck pain, headaches, visual disturbances, dizziness, weakness, paraesthesia, concentration and memory disturbances, as well as psychological symptoms.[2] Unfortunately, the prognosis of WAD is difficult to predict due to the wide variability of symptoms encompassed in this condition.[39] Barnsley et al[2] found that 14% to 52% of people who experience whiplash will develop chronic neck problems. In the last 5 years, longitudinal studies have been conducted to identify prognostic factors for the development of chronic WAD, with old age, high initial neck disability scores, impaired neck range of motion, elevated neck muscle activity, sensory hypersensitivity, and psychological distress, predicting poor outcome.[33-37] Despite detailed analyses, these studies have not assessed neck force as a possible outcome of neck disability or as a possible prognostic factor of outcome following WAD. The cervical muscles play an important role in providing stability to the cervical vertebrae.[21] Impairments in neck strength may alter neck stability and, in turn, increase the risk of reinjury in subsequent acceleration-deceleration events.[4,12] Evidence suggests that cervical strength is impaired by the presence

• **STUDY DESIGN:** Controlled laboratory study using a cross-sectional, repeated-measures design.

• **OBJECTIVES:** To quantify maximal voluntary isometric neck forces in healthy subjects and individuals with whiplash-associated disorder (WAD), using an objective measurement system to evaluate the test-retest properties of these strength measurements and to assess the links between neck strength, pain, kinesiophobia, and catastrophizing in patients with WAD.

• **BACKGROUND:** The prognosis of WAD is difficult to predict due to a lack of objective measurement methods and to our limited understanding of the role of psychological factors in the development of chronic WAD symptoms.

• **METHODS AND MEASURES:** Fourteen subjects with chronic WAD grade I or II and an age-matched, healthy group (n = 28) participated in this study. Cervical strength was measured with the Multi-Cervical Unit (MCU) in 6 directions, and pain was measured with a visual analog scale. Individuals in the WAD group completed the Neck Disability Index (NDI), the Tampa Scale for Kinesiophobia (TSK), and the Pain Catastrophizing Scale (PCS).

• **RESULTS:** Significant deficits in strength were observed for the individuals in the WAD group compared to the healthy group, particularly in extension, retraction, and left lateral flexion ($P<.05$). The MCU demonstrated good intratester reliability for the healthy group (ICC = 0.80-0.92) and the WAD group (ICC = 0.85-0.98), and small standard errors of measurement for both groups. No significant association was found between neck strength and NDI, TSK, and PCS.

• **CONCLUSION:** The MCU demonstrated good test-retest properties for healthy subjects and individuals with WAD. Cervical strength was lower in individuals with WAD; however, the strength deficits were not clearly linked with psychological factors. *J Orthop Sports Phys Ther 2009;39(3):179-187. doi:10.2519/jospt.2009.2950*

• **KEYWORDS:** *catastrophizing, cervical spine, kinesiophobia, muscles, neck*

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of cervical disorders[30]; however, very few studies have assessed neck force in individuals with WAD. The importance of the integrity of the neck musculature is also acknowledged in the clinical setting, because an important part of rehabilitation for patients with neck conditions consists of retraining the deficient neck musculature. Several authors have used neck-strengthening interventions[16,17,23,49] and reported positive outcomes related to pain, strength, and self-reported disability in patients with chronic neck pain.

In clinical practice, there is a large demand for validated equipment to objectively measure neck functional capacity to assess the severity of a whiplash injury and the extent of its recovery. In current practice, isometric strength is generally tested with standard manual muscle testing procedures and handheld dynamometers. Although practical, these techniques are rather subjective and have a questionable interrater reliability.[20] Recently, researchers have attempted to validate biomechanical systems to objectively measure cervical isometric force in healthy subjects.[8,12,18,20,24,52] However, no studies have specifically investigated the psychometric properties of cervical isometric force recordings in a population of patients with WAD. Moreover, only 2 studies[28,46] have specifically compared cervical isometric force generated by individuals with a whiplash injury with those recorded from healthy subjects. Vernon et al[46] reported flexion-extension ratios of 0.57 in healthy subjects and 0.46 in symptomatic patients. Within the symptomatic group, the ratios were 0.62 for patients with chronic pain and 0.25 for patients with whiplash, which included subjects with both acute and chronic condition, suggesting a cervical flexor strength deficit in patients with WAD. Conversely, Prushansky et al[28] found a flexion-extension ratio of 0.86 for a sample of patients with chronic WAD, indicating a cervical extensor strength deficit that was correlated with high coefficients of variation, which authors interpreted as an indication of learned pain-avoidance behavior. Unfortunately, neither study reported the force values recorded in the WAD groups, nor the associations with measurements of psychological characteristics that may be associated with pain. Clearly, the amount of neck force deficit and its direction-specificity in WAD is a question that remains to be elucidated.

The Multi-Cervical Unit (BTE Technologies, Inc, Hanover, MD) is a biomechanical system designed to quantify isometric neck force (**FIGURE 1**). Chiu et al[6-8] have conducted several studies involving a previous generation of the MCU (Multi-Cervical Unit, Hanoun Medical Inc, Ontario). They reported good reliability for isometric strength measurements for healthy and subjects with neck pain, with intraclass correlation coefficients (ICCs) ranging from 0.94 to 0.98 and from 0.92 to 0.99, respectively. However, they did not specifically test individuals with a history of whiplash injury. Moreover, no reliability data have been published using the new generation of the system.

Deficits in cervical isometric strength may arise from different conditions such as soft-tissue injury, muscle weakness, disuse, and pain. Some authors have reported negative association between pain and isometric neck force production.[13,51] In addition, kinesiophobia (fear of movement, injury, and/or reinjury) and catastrophizing[41] (exaggerated negative orientation towards noxious stimuli) may also play roles as mediating factors in neck force measurements.[28] Fear-avoidance models have been developed in an attempt to understand the mechanism of chronic pain.[47,48] In these models, fear of pain is the central concept, while confrontation and avoidance are the extreme responses to this fear. Accordingly, it is thought that the fear of pain and injury/reinjury may be more important than the pain itself in individuals with chronic conditions. Most researchers who have studied fear-avoidance behaviors have focused their attention on patients with chronic low back pain.[1,25,44] Although catastrophizing has been previously associated with some functional characteristics in patients with chronic WAD,[32] little is known about the impact of kinesiophobia and catastrophizing on the measurement of neck strength of patients with WAD.

FIGURE 1. The Multi-Cervical Unit (MCU, BTE technologies, Inc, 2006) setup for flexion testing.

The purposes of this study were to quantify maximal voluntary isometric neck forces in healthy subjects and patients with WAD using an objective measurement system, to evaluate the test-retest properties of force measurements in groups of healthy subjects and patients with WAD, and to examine the relationships between neck strength, pain, kinesiophobia, and catastrophizing in patients with WAD.

METHODS

Participants

Fourteen patients with WAD and 28 healthy subjects participated in this study. The WAD group included adults recruited from a rehabilitation and return-to-work program of the institution and from advertisements appearing in local community newspapers. Inclusion criteria were a diagnosis of a grade I or II whiplash injury (Quebec Task Force [QTF] classification system[31]) within the last 2 years and the presence of neck pain for at least 3 months prior to the entry in the study. According to the QTF classification system, WAD grade I refers to neck complaint of pain, stiffness, or tenderness and the absence of musculoskeletal signs, while grade II refers to neck complaint with musculoskeletal signs including decreased range of movement and point tenderness to palpation. Patients with WAD were excluded if their medical chart indicated concomitant diagnoses to the neck (including post accident report, as well as past history prior to the accident), if their primary diagnosis following the accident did not target the neck, or if they sustained a concussion as part of the whiplash accident. The age- and sex-matched group of healthy subjects consisted of adults free of neck or spine injuries, who were not engaged in training specifically targeting the neck musculature. Ethical approval was granted by the Ethics Committee of the rehabilitation institutions of the Centre for Interdisciplinary Research in Rehabilitation (CRIR) of Greater Montreal. Informed consent was obtained from each participant prior to participation in the study. The rights of the subjects were protected at all times during the experiment.

Experimental Procedures

Each subject was tested during 2 separate sessions, held 48 hours apart. Testers were not blinded to the subject's group assignment. Upon their arrival for the first session (day 1), subjects were introduced to the procedures of testing and relevant demographics and medical information were collected. Maximal voluntary isometric force (MVIF) of the cervical spine musculature was measured in 6 directions: flexion, extension, right and left lateral flexions, protraction, and retraction. Three submaximal practice trials were performed for each direction prior to recording. Examiners' guidance and correction was provided as needed during these practice trials. During the testing phase, each subject was asked to perform 3 consecutive trials of 3 seconds each of MVIF in each direction, with a 1-minute rest between each trial and a 2-minute rest between each direction. For each set of 3 trials, subjects were instructed to gradually increase the force to their maximum. Instructions to the subjects were as follows: "Push as hard as you can into the pads…by bringing your chin to your chest [flexion]…by bringing the back of the head to the neck [extension]…by bringing your right (left) ear to your right (left) shoulder [lateral flexion]…by bringing your chin forward as much as possible [protraction]…by bringing your chin as far back as possible [retraction]." The directions were assigned in a random order, and the subjects always began and remained with the cervical spine in the neutral position. For each subject, the mean of the peak values obtained for 3 MVIF trials were calculated for each direction and used for further analysis. Group flexion-extension ratios were computed by averaging the ratios obtained for all subjects at the first experimental session. In addition, percentages of force deficits were calculated for each direction using the formula: [(mean force healthy – mean force WAD)/(mean force healthy)] × 100%.

The protocol was repeated in a second session (day 2) using the same sequence of randomization for directions in order to assess the reliability measurements made with the MCU and to calculate the standard error of measurements (SEM) and the minimal detectable change (MDC) values for each group. Subjects were only allowed to view their force results at the end of the second testing session to avoid bias.

For the individuals in the WAD group, pain was measured before testing and after each block of 3 consecutive trials for each direction during both experimental sessions. Pain at rest and pain after each block of testing consisted of the pain rating that the subject was experiencing at that instant. For those subjects, at the first session, neck disability, kinesiophobia, and pain catastrophizing were also assessed through questionnaires, prior to testing.

Data Acquisition

The MCU was used to measure MVIF produced by the neck in all 6 directions. The MCU is a commercially available biomechanical assessment and training device for the cervical spine that measures active range of motion, as well as isometric force of the neck. The unit consists of an adjustable chair and headpiece that can be adjusted to isolate the cervical region. Subjects were seated in the MCU chair and a proper position of the cervical spine in neutral was obtained by adjusting the height and position of the seat and back of the chair. The headpiece was also adjusted and positioned 15° below the horizontal for flexion, extension, protraction, and retraction testing, and 0° from the horizontal for both lateral flexions. For lateral flexion testing, the headpiece was also rotated by 90°. Pads were positioned just above the upper portion of the eyebrows for flexion and protraction testing, just above the external occipital protuberance for extension and retraction testing, and just above the upper part of the earlobes for lateral flexion testing. In addition, shoulder and waist straps were adjusted to further isolate the cervical spine from the rest of the body. Subjects were asked to keep their arms crossed with their hands resting on opposite shoulders and their feet crossed on the platform throughout all trials. The position of the chair was noted and replicated in the second session.

Pain was assessed for the individuals in the WAD group using the written format of the visual analog scale (VAS). It consisted of a 100-mm horizontal straight line representing a continuum of pain intensity that yielded a score ranging from 0 to 100 mm. The 2 extremities of the line were labeled as "no pain" (left end) and "worse pain imaginable" (right end). Scores obtained were expressed as a proportion of the 100-mm line.

Neck disability was assessed with the Neck Disability Index (NDI) questionnaire.[45] It is a 10-item scale used to measure pain and disability felt during functional activities. It uses a 6-point Likert scale that ranges from 0 (no disability) to 5 (complete disability) for each item. Scoring intervals for interpretation are as follows: 0 to 4, no disability; 5 to 14, mild disability; 15 to 24, moderate disability; 25 to 34, severe disability; above 34, complete disability.[45] The validity and reliability of this scale have previously been demonstrated in studies with various patient populations including those with whiplash.[26,45]

Kinesiophobia was assessed with the Tampa Scale for Kinesiophobia (TSK) questionnaire.[19] It is a 17-item scale developed to measure fear of movement, injury, and reinjury. It uses a 4-point Likert scale that ranges from 1 (strongly disagree) to 4 (strongly agree) for each item, with a high value generally indicating a high degree of fear. The validity and reliability of this scale have also previously been demonstrated in healthy individuals as well as those with chronic pain and neck pain.[9,10,22] The TSK has also been previously used in studies of individuals with WAD.[3,37]

Pain catastrophizing was assessed with the Pain Catastrophizing Scale (PCS) questionnaire.[40,41] It is a 13-item scale presenting descriptors of pain experience. It uses a 5-point Likert scale that ranges from 0 (not at all) to 4 (all the time) for each item. A high score on the PCS indicates a high level of catastrophizing. In addition, a total score of 30 or above represents clinically relevant level of catastrophizing.[40] The validity and reliability of this scale have previously been demonstrated in clinical populations.[41] The PCS has also been used in studies of individuals with WAD.[29]

Statistical Analysis

Descriptive statistics were used to qualify the 2 groups in terms of their demographic characteristics. To assess group differences in MVIF, a repeated-measures ANOVA with a group-by-direction factor was computed with the measures taken on day 1. Post hoc analysis was performed using the Tukey-Kramer test. To assess the test-retest reliability of the MVIF measurements, $ICC_{3,3}$ with 95% confidence intervals (CIs) were calculated from the measures taken on day 1 and day 2 for each direction. The SEM for each force direction was calculated using the following formula[27]: ($SEM = SD \times \sqrt{1- ICC}$), where SD is the mean of the standard deviations recorded on day 1 (test) and day 2 (retest), and ICC is the coefficient calculated between day 1 and day 2. The MDC for a confidence level of 90% was calculated using the following formula[38]: $MDC_{90} = SEM \times \sqrt{2} \times (z\ score)_{90}$.

We also assessed the between-day differences in force measurements in each group separately by performing a repeated-measures ANOVA with a time-by-direction factor. Spearman correlation coefficients with 95% CI were calculated between neck force measurements in each direction, as well as between a composite neck force score calculated from the average force across the 6 directions for each subject, and VAS, NDI, TSK, and PCS scores. Spearman correlations were chosen due to the presence of skewness in the data set. All statistical analyses were performed using Statistica Version 7.0 (Statsoft, Inc, Tulsa, OK) and SPSS 17.0 (SPSS Inc, Chicago, IL) software.

TABLE 1 Demographic Information

	WAD Group (n = 14)	Healthy Group (n = 28)
Age (y)*	36.6 ± 10.8 (24-58)	36.3 ± 11.1 (22-58)
Male, female	8, 6	16, 12
WAD (grade I, II)	2, 12	
Time since accident (mo)*	6.1 ± 4.4 (3-20)	
Pain at rest (/100 mm)*		
Day 1	33.4 ± 18.8	
Day 2	27.4 ± 20.7	
NDI (/50)*	20.0 ± 6.9 (10-33)	
TSK (/68)*	41.0 ± 7.8 (28-53)	
PCS (/52)*	17.0 ± 14.4 (2-44)†	

Abbreviations: NDI, Neck Disability Index; PCS, Pain Catastrophizing Scale; TSK, Tampa Scale for Kinesiophobia; WAD, whiplash-associated disorders.
** Values are presented as mean ± SD (range).*
† n = 13.

RESULTS

Participant Demographics

The WAD group was mainly composed of grade II subjects (n = 12), with an average ± SD time from accident of 6.1 ± 4.4 months (**TABLE 1**). It should be noted that, although the original medical diagnosis on the remaining 2 patients was of WAD grade I, they presented with musculoskeletal signs at entry into the rehabilitation program (corresponding to functional limitations associated with WAD grade II), such that they did not represent outliers in our WAD sample. The mean ± SD rest pain on day 1 for the WAD group was 33.4 ± 18.8 mm (out of 100 mm) and was 27.4 ± 20.7 mm on day 2. Based on the mean ± SD of the NDI score of 20.0 ± 6.9, this sample of subjects with WAD was characterized as being moderately disabled. In addition, they presented with moderate fear of movement (mean ± SD, 41.0 ± 7.8) and low pain catastrophizing (mean ± SD, 17.0 ± 14.4).

MVIF Measures

Values of force output reported in this study (day 1) ranged from 77 to 145 N for healthy subjects and from 30 to 50 N for subjects with WAD, across the different

TABLE 2 Maximal Voluntary Force and Pain Measurements in All Directions*

	WAD Group (n = 14)		Healthy Group (n = 28)	
	Day 1	Day 2	Day 1	Day 2
Flexion				
Force (N)	36.3 ± 28.6	43.4 ± 36.3	83.2 ± 41.0	80.8 ± 35.0
Pain (mm)	43.0 ± 25.1	32.5 ± 21.6		
Extension				
Force (N)	49.6 ± 37.2	62.0 ± 44.1	144.9 ± 65.0	151.4 ± 53.5
Pain (mm)	39.8 ± 20.4	30.6 ± 22.3		
Protraction				
Force (N)	41.0 ± 30.7	47.9 ± 40.9	86.0 ± 39.7	81.2 ± 34.7
Pain (mm)	42.6 ± 24.7	34.2 ± 24.3		
Retraction				
Force (N)	39.7 ± 33.8	57.8 ± 52.2	141.5 ± 69.6	138.9 ± 50.4
Pain (mm)	40.4 ± 20.9	33.4 ± 20.9		
Left LF				
Force (N)	34.1 ± 22.5	42.2 ± 22.7	85.6 ± 43.8	84.2 ± 37.9
Pain (mm)	33.1 ± 27.4	30.6 ± 23.4		
Right LF				
Force (N)	29.6 ± 15.0	37.7 ± 20.7	77.3 ± 37.8	79.6 ± 32.3
Pain (mm)	40.3 ± 25.0	33.9 ± 23.9		
Composite				
Force (N)	38.4 ± 25.3	48.5 ± 33.0	103.1 ± 44.0	102.7 ± 35.7
Pain (mm)	39.8 ± 22.4	32.5 ± 22.1		

Abbreviations: LF, lateral flexion; WAD, whiplash-associated disorders.
** All values are mean ± SD. Pain reported on a visual analog scale, with 0 mm as no pain and 100 mm as the worst pain imaginable.*

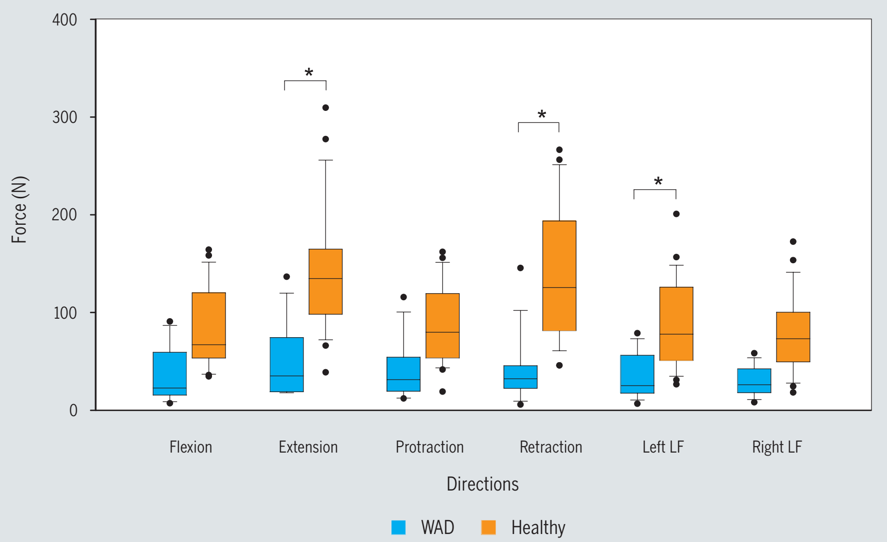

FIGURE 2. Maximal voluntary isometric forces, day 1. The boundaries of each box indicate the 25th and 75th percentiles, the line within each box marks the median, and whiskers (error bars) above and below each box indicate the 90th and 10th percentiles respectively. Filled circles above and below each box represent outliers. *Significant difference between healthy and WAD groups ($P<.05$). Abbreviations: LF, lateral flexion; WAD, whiplash-associated disorders.

directions (**TABLE 2**). The percentage of force deficits for the WAD group on day 1 were 52% for flexion, 66% for extension, 52% for protraction, 72% for retraction, 60% for left lateral flexion, and 62% for right lateral flexion. The flexion-extension ratios yielded mean ± SD values of 0.62 ± 0.27 for the healthy group and 0.76 ± 0.29 for the WAD group. The ANOVA indicated a significant group-by-direction interaction ($F_{5,200}$ = 10.40; $P<.0001$). The Tukey-Kramer post hoc analysis revealed that extension ($P<.0001$), retraction ($P<.0001$), and left lateral flexion ($P = .03$) forces were significantly lower for the WAD group compared to the healthy group. Group differences for right lateral flexion ($P = .06$), flexion ($P = .07$), and protraction ($P = .10$) were not statistically significant (**FIGURE 2**).

Reliability of Force Measures

The ICCs for measurements with the MCU in the different directions ranged from 0.80 to 0.92 for healthy subjects and from 0.85 to 0.98 for subjects with WAD (**TABLE 3**). The SEMs for each direction are indicated in **TABLE 3**. On average, those numbers indicate that one can be 68% confident that a subject's true measurement is between his/her recorded score (±15.5 N for a healthy adult or ±9.1 N for an individual with WAD).[14,15] The SEMs were all greater for the healthy group than for the WAD group, especially in extension (18.7 versus 6.2 N). However, it is important to note that the mean isometric forces exerted by the healthy subjects were larger in amplitude in all directions. Consequently, when expressed with respect to the mean force (as shown by the coefficients of variation in **TABLE 3**), the values between groups are much more similar. The average ± SD MDC_{90} values for force recordings were 36.1 ± 8.9 N for the healthy group and 21.1 ± 9.2 N for the WAD group, with values for each direction indicated in **TABLE 3**. Finally, analysis of the force generated in each direction across the 2 testing sessions indicated no significant direction-by-time interaction for either group. However, there was a significant main effect for time in the

WAD group (P = .011), with the subjects exerting a greater amount of force at the second testing session. There was also a significant main effect for direction, reflecting difference in force production across the 6 directions for both groups.

Association Between MVIF and Pain, NDI, TSK, and PCS

Spearman correlations were computed for the WAD group, between measures of MVIF and pain, NDI, TSK, and PCS (**TABLE 4**). None of the correlations between average force values obtained in each direction and scores on the NDI, TSK, and PCS were statistically significant. The correlations between composite force values computed across all 6 directions and questionnaire scores were not significant either (**TABLE 5**). However, there were significant, moderate positive correlations between the PCS and the NDI (0.61, P = .03), and between the PCS and the TSK (0.65, P = .02).

DISCUSSION

THE FIRST PURPOSE OF THIS STUDY was to quantify isometric maximal neck force output in healthy subjects and those with WAD and to compare results obtained in both groups. The average neck force impairment of subjects with WAD, compared to healthy subjects, ranged from 52% to 72%, with a significant strength deficit in 3 of the 6 directions tested. This impairment is smaller than the one reported by Prushansky et al[28] (90%), who compared neck force measures taken from a WAD group to normative values found in the literature. Our current results are also different from those reported in 2 studies of patients with chronic neck pain,[8,50] where neck strength was significantly lower in patients than in healthy subjects, for all directions. However, Cagnie et al[5] recently reported a significant difference between patients with chronic neck pain and healthy subjects for the extension but not for the flexion direction, which result is similar to the one reported here. Nevertheless, our results should be interpreted

TABLE 3 TEST-RETEST RELIABILITY FOR FORCE MEASURES*

	$ICC_{3,3}$	SEM (N)	MDC_{90} (N)	CoV (%)
WAD group (n = 14)				
Flexion	0.95 (0.83-0.98)	7.5	17.5	18.9
Extension	0.98 (0.93-0.99)	6.2	14.5	11.2
Protraction	0.85 (0.54-0.95)	13.7	31.9	30.9
Retraction	0.89 (0.64-0.96)	14.6	33.9	29.9
Left LF	0.93 (0.77-0.98)	6.2	14.4	16.2
Right LF	0.87 (0.59-0.96)	6.4	14.8	18.9
Composite	0.95 (0.84-0.98)	9.1 ± 3.9	21.1 ± 9.2	21.0 ± 7.8
Healthy group (n = 28)				
Flexion	0.92 (0.83-0.96)	10.7	24.8	13.0
Extension	0.89 (0.77-0.95)	18.7	43.5	12.6
Protraction	0.80 (0.56-0.91)	16.8	39.1	20.1
Retraction	0.88 (0.75-0.95)	20.6	47.8	14.7
Left LF	0.91 (0.80-0.96)	12.5	29.1	14.7
Right LF	0.85 (0.67-0.93)	13.8	32.0	17.5
Composite	0.93 (0.85-0.97)	15.5 ± 3.8	36.1 ± 8.9	15.5 ± 2.9

Abbreviations: ICC, intraclass correlation coefficient; CoV, coefficient of variation; LF, lateral flexion; MDC_{90}, minimal detectable change for a 90% confidence level; SEM, standard error of the measurement; WAD, whiplash-associated disorder.
** Values in parentheses for ICC are 95% confidence interval; values for composite scores for SEM, MDC, and CoV are mean ± SD for the six directions.*

TABLE 4 SPEARMAN CORRELATIONS: FORCE AND PAIN

Correlations	Spearman Correlation Coefficient	*P* Value	95% CI
Flex (force and pain)	−0.42	.14	−0.78-0.16
Ext (force and pain)	−0.41	.15	−0.78-0.18
Prot (force and pain)	−0.44	.12	−0.79-0.14
Ret (force and pain)	−0.32	.27	−0.73-0.27
L LF (force and pain)	−0.17	.56	−0.65-0.41
R LF (force and pain)	−0.04	.89	−0.57-0.51

Abbreviations: CI, confidence interval; Ext, extension; Flex, flexion; L LF, left lateral flexion; Prot, protraction; R LF, right lateral flexion; Ret, retraction.

TABLE 5 SPEARMAN CORRELATIONS: QUESTIONNAIRES

Correlations	Spearman Correlation Coefficient	*P* Value	95% CI
Composite force and NDI	−0.41	.14	−0.78-0.17
Composite force and TSK	0.30	.29	−0.29-0.72
Composite force and PCS	0.26	.39	−0.35-0.72
TSK and NDI	0.17	.55	−0.41-0.65
PCS and NDI	0.61	.03*	0.07-0.87
PCS and TSK	0.65	.02*	0.13-0.89

Abbreviations: CI, confidence interval; NDI, Neck Disability Index; PCS, Pain Catastrophizing Scale; TSK, Tampa Scale for Kinesiophobia.
** $P<.05$*

while keeping in mind that, because of our small sample size, we can only conclude with relative certainty that a group difference exists in 3 directions; the lack of group difference in the remaining directions is much less certain due to lack of statistical power of our analyses.

Our analysis revealed a significant group-by-direction interaction effect on force measurements, suggesting that extension, retraction, and left lateral flexion are most affected by whiplash and this, independently of effort-related pain. Deficits in extension are consistent with other studies (see below) and may also be related to deficits in retraction, because both movements involved the posterior neck musculature. In turn, it is possible that these impairments in the posterior musculature are related to a general lack of protection anterior to the head in motor vehicles, such that these structures are more vulnerable to being overstretched and injured, especially following rear-end impact. Left lateral flexion force deficits are more difficult to explain and could be related to the fact that in our sample, more patients had been involved in driver's-side collisions (n = 3) as opposed to passenger's-side collisions (n = 0). However, care must be taken in evaluating the likelihood of these hypotheses due to the low sample size of our WAD group, which may have precluded group differences to be revealed in the directions of right lateral flexion, flexion, and protraction.

The flexion-extension ratios observed for the 2 groups were 0.62 and 0.76 for healthy subjects and those with WAD, respectively. These ratios illustrate the greater extensor strength deficits identified in the WAD group. The flexion-extension ratio measured in our healthy group was similar to those previously reported.[5,11,18,20,42,43,46] When isometric forces were recorded from subjects with WAD, Vernon et al[46] found a ratio of 0.25 suggesting more loss of neck flexor strength following a whiplash injury. However, results of their study may have been affected by a small sample size (n = 8) and the fact that subjects with both acute and chronic WAD were included. On the other hand, Prushansky et al[28] reported a flexion-extension ratio of 0.86 among 97 patients with chronic WAD, suggesting an even greater loss of extensor strength secondary to WAD. Our ratio supports the latter results in indicating more loss of strength of the neck extensors in individuals with WAD.

The second purpose of this study was to evaluate the psychometric properties of neck force measurements. Our results demonstrate good ICCs, ranging from 0.80 to 0.92 for healthy subjects and from 0.85 to 0.98 in subjects with WAD. These values are similar to previous results reported using the older generation of the MCU system in healthy and patients with chronic neck pain.[8] Similar reliability values for flexion and extension were also found in studies using other systems.[5,50] In our study, the SEM computed for each direction and each group was generally proportional to the mean force exerted by the subjects, yielding similar coefficients of variation for both groups. However, the protraction and retraction directions induced the most measurement error in isometric strength recordings, particularly in the WAD group. This may be due to the fact that these 2 force directions are, in general, harder to conceptualize and to produce for most individuals, and may be even more difficult for patients who experience pain.

A surprising finding concerning our force data analysis was the increased force values from day 1 to day 2 of testing for the individuals in the WAD group. For 4 of the 6 force directions, the force increase was larger than the measurement error. The fact that intertrial covariance was only between 11% and 16% on day 1 and 7% and 13% on day 2, and that patients did not always record their highest force on the third trial of each direction, suggests that the force increments at day 2 do reflect an increase in the amount of force that subjects with WAD were able to produce at retest, rather than a lack of stability in the data, irrespective of force direction. We have observed similar findings in a study assessing upper limb force and power in individuals with neck-shoulder pain. It is possible that subjects were less fearful of aggravating their condition on the second visit, such that they were not as avoidant of a painful response. The increased force values could also reflect a true neuromuscular training effect to occur between visits. Lastly, we believe that subjects may have been better able to conceptualize the tasks during their second visit. Indeed, whiplash has been shown to affect neck position sense such that individuals with WAD display elevated joint position error.[35] Thus, subjects may have benefited from an improved perception of effort direction during their second visit. Although these results point to elements that may have skewed the force data of our WAD sample, they also suggest a behavior that is important for clinicians to understand and address in the clinical setting. Also, it is important to point out that, despite this force increase across sessions in the WAD group, significant group-by-direction interaction and group effects were again observed at visit 2 ($P<.0001$).

The last purpose of this study was to investigate if correlations might exist between MCU measurements of neck force and measurements of pain, neck disability, kinesiophobia, and catastrophizing. The lack of association between the NDI scores and isometric neck force are consistent with the results published by Chiu et al,[6] who reported significant correlations ranging from −0.12 to −0.37 in patients with chronic neck pain. Hakkinen et al[13] also reported negative associations between neck disability and isometric strength (−0.59 to −0.67) in patients with cervical dystonia. Our results also demonstrated nonsignificant association between isometric neck force and pain taken just after the measurements (−0.04 to −0.44), which is similar to the findings of Chiu et al.[6] In their study, the correlations between neck strength recorded with the MCU and pain in subjects with nonspecific chronic neck pain ranged from 0.00 to −0.26. Other researchers have found significant low to moderate negative correlations between these 2 variables[13,51] in other groups of patients with pain. With such correlations, it may be relevant to ask if the force exerted by the individuals with WAD was limited by the pain they felt, or if it was their true physiological force, indicative of muscle weaknesses, or both. In any case, a future recommendation would be to have subjects rate their pain at the moment of force production instead of immediately after the effort. This could be done verbally rather than by putting a mark on the VAS on paper and would ensure simultaneous measures of force and pain, which may increase the correlations between the 2 measures, as the literature suggests that pain ratings at these 2 moments may slightly differ.[51]

Our results revealed no significant correlation between kinesiophobia and neck force output (0.30, $P = .29$), and between pain catastrophizing and neck force (0.26, $P = .39$). These results are in contrast with those observed previously for subjects with low back pain, where fear-avoidance beliefs about physical activity were significantly negatively correlated with isometric low back strength,[1] and seem to contradict the hypothesis raised by Prushansky et al[28] as to the possible nature of the elevated neck strength coefficients of variation in their cohort of individuals with neck pain. However, our results are in agreement with those of Cleland et al[9] and Buitenhuis et al,[3] who suggested that the relationships between measures of fear and avoidance beliefs and measures of pain and disability may be weaker in patients with mechanical neck pain than in patients with chronic low back pain. Further, the small range of scores obtained on the TSK and the large between-subject standard deviation obtained on the PCS for our subjects, with WAD likely affected our correlation results. Finally, it should also be noted that there were only 3 catastrophizers in our WAD group, based on Sullivan's cutoff value of 30/52.[40]

As a whole, because our measures of pain, disability, kinesiophobia, and pain catastrophizing were not significantly associated with isometric neck force in our study, other hypotheses have to be considered to explain neck strength deficits in our sample of subjects with WAD. These include actual muscle weakness related to disuse or to increased inhibition of muscle activity, leading to a submaximal performance during muscle testing, impaired control of the neck musculature, distress, and/or other pain- or fear-related aspects not accounted for by our measures of pain, catastrophizing, and kinesiophobia. Limitations of our study also include a small sample size for the WAD group, which likely limited our ability to find statistically significant differences in strength for 3 of the 6 directions tested and likely limited our ability to find statistically significant association between variables. Future studies should aim at confirming our findings with larger sample sizes. Also, our results are mostly generalizable to a population of patients with chronic WAD of grade II. Consequently, individuals diagnosed with other grades of WAD may present with different findings. Other types of muscle contractions (concentric, eccentric) should also be investigated to better understand the association between neck force and chronic pain. Finally, the use of simultaneous electromyography recording may help provide a better understanding of the mechanisms of neck strength impairment in individuals with chronic WAD, as well as better integration of our results within more complete biopsychosocial models of WAD.[33,36]

CONCLUSION

In this study, we found that individuals with chronic WAD of grade I and II presented with maximal voluntary isometric neck force deficits, especially in the directions of extension, retraction, and left lateral flexion. We have also demonstrated the good test-retest reliability of objective force measurements using the MCU system in healthy subjects and individuals with chronic WAD. Finally, our data indicate no association between neck strength and fear-avoidance behaviors. More research is needed to better understand these relationships. ◉

KEY POINTS

FINDINGS: Deficits in maximal voluntary isometric neck force were identified for individuals with chronic WAD of grade I and II, especially in the directions of extension, retraction, and left lateral flexion. Strength values in this small group of individuals with WAD were not clearly associated with pain, kinesiophobia, or catastrophizing.

IMPLICATION: These findings suggest the need to address cervical spine strength deficits in individuals with chronic WAD.

CAUTION: This study only assessed subjects with WAD of grade I and II. The small number of subjects is a further limitation of the study.

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