ORIGINAL REPORT

REDUCED HEAD STEADINESS IN WHIPLASH COMPARED WITH NON-TRAUMATIC NECK PAIN

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Objective: **While sensorimotor alterations have been observed in patients with neck pain, it is uncertain whether such changes distinguish whiplash-associated disorders from chronic neck pain without trauma. The aim of this study was to investigate head steadiness during isometric neck flexion in subjects with chronic whiplash-associated disorders (WAD), those with chronic non-traumatic neck pain and healthy subjects. Associations with fatigue and effects of pain and dizziness were also investigated.**

Methods: **Head steadiness in terms of head motion velocity was compared in subjects with whiplash (*n* = 59), non-traumatic neck pain (*n* = 57) and healthy controls (*n* = 57) during 2 40-s isometric neck flexion tests; a high load test and a low load test. Increased velocity was expected to reflect decreased head steadiness.**

Results: **The whiplash group showed significantly decreased head steadiness in the low load task compared with the other 2 groups. The difference was explained largely by severe levels of neck pain and dizziness. No group differences in head steadiness were found in the high load task.**

Conclusion: **Reduced head steadiness during an isometric holding test was observed in a group of patients with whiplash-associated disorders. Decreased head steadiness was related to severe pain and dizziness.**

Key words: whiplash; isometric hold; head steadiness; neck pain; dizziness.

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INTRODUCTION

The main function of the neck is to work as a stable base of support for the head with simultaneous control of head movements (1). A number of studies have shown alterations in motor control and cervical movement patterns associated with neck pain conditions. There is consistent documentation of reduced standing balance and increased sway in patients with whiplash-associated disorders (WAD) compared with healthy subjects (2–7). Small differences have, however, been found between patients with WAD and non-traumatic neck pain, but only for difficult balance tasks (5). It remains unclear whether WAD can be distinguished from non-traumatic neck pain in terms of more neck-specific motor control strategies (8–10). In patients with chronic neck pain, changes in cervical muscle activation patterns in terms of delayed onset in deep cervical flexors (11, 12) and increased activation of superficial neck muscles (8, 13, 14) have been reported. During dynamic movements, patients with neck pain have shown more jerky cervical movement patterns (15) and irregular motion curves (10) compared with healthy controls. Stiffer neck movement patterns during cervical rotation were related to chronic neck pain but did not distinguish patients with WAD from those with chronic neck pain (16). During specific isometric loading, cranio-cervical flexor muscles have shown decreased contraction steadiness in patients with neck pain (17). These irregularities indicate sensorimotor control impairments in neck pain, but the effect of trauma is uncertain, as is the knowledge of motor control strategies during isometric holding.

Altered motor control is believed to be centrally driven, but may also be a consequence of fatigue. Increased cervical muscle fatigue, as recorded by electromyography (EMG), has been reported among patients with chronic neck pain for both flexor and extensor muscles (18, 19), and cervical fatigue has been related to impaired standing balance in healthy controls as well as in patients with WAD (20, 21). The effect of fatigue on motor control in the neck has not been investigated. Furthermore, dizziness seems to affect motor control in patients with WAD, such as standing balance and head reposition error (22–24).

Evidence thus points to postural disturbances during head motion in patients with neck pain, but with no firm evidence that such disturbances are related to a traumatic origin of neck pain. The purpose of this study was to investigate head steadiness during isometric neck flexion tasks in patients with WAD, patients with non-traumatic chronic neck pain and healthy controls. Altered motor control during movement may reflect normal functional adaptation to pain (25). However, it is more difficult to accept that alterations in head control during isometric tasks have a functional purpose. We hypothesized that if chronic neck pain causes altered or dysfunctional motor control strategies, it should also be reflected in tests of head steadiness during isometric loading, which was investigated in this study by measuring head motion velocity during isometric neck flexion tasks. Healthy subjects were included in order to

obtain an impression of normal head steadiness. In order to study a potential influence of fatigue, the test was performed at both low load and high load. A secondary aim was to study the effect of pain and dizziness, 2 of the most frequent symptoms in WAD, on head movement velocity.

MATERIAL AND METHODS

A cross-sectional study with a total of 173 participants was conducted in the period January 2004 to October 2006. The study groups consisted of persons with WAD that had persisted for more than 6 months, a group of patients with chronic non-traumatic neck pain, and a group of healthy volunteers. All subjects provided written informed consent and the study was conducted in accordance with the Declaration of Helsinki and approved by the regional ethics committee.

WAD group

Participants were recruited successively from patients with WAD referred to the National Center for Spinal Disorders, St Olav's Hospital, Trondheim, Norway. A total of 59 subjects with WAD injury classified as Québec Task Force grades I–II (26), were included, all suffering from neck pain with or without headache after a car collision where they had either been driver or passenger. Symptom duration of between 6 months and 10 years and onset of symptoms within 48 h after the accident were also criteria for inclusion. Subjects were excluded if they had WAD III–IV, had suffered a head injury during the accident or had surgery of the cervical spine. They were also excluded if they had a history of similar symptoms previous to the accident or any known systemic disease that could account for their symptoms.

Chronic neck pain group

Subjects with chronic non-traumatic neck pain ($n = 57$) were recruited by local physiotherapists and general practitioners. Pain duration of at least 6 months and not more than 10 years was required for inclusion. Subjects were excluded if they had any history of neck trauma or any known systemic disease that could explain their symptoms.

Healthy control group

The healthy control group comprised 57 subjects with no previous or current neck pain or history of neck trauma. Participants in this group were recruited from different workplaces and educational institutions.

The study was part of a more comprehensive study also involving diagnostic imaging of the cervical spine (27). Pregnant women and persons with contra-indications to magnetic resonance imaging (MRI) (e.g. pacemaker, magnetic aneurysm clips, etc.) were therefore excluded.

Instrumentation

All cervical movement registrations were made using the 3Space Fastrak (Polhemus, Inc., Colchester, Vermont, USA) with a sampling rate of 120 Hz. The system has been found to reliably record angular and positional data among healthy persons as well as patients with persistent neck pain (28–30). The system includes a transmitter creating an electromagnetic field. A magnetic field sensor, in this study held in place on the subject's forehead with an elastic band, is monitored as it moves in the electromagnetic field. The system measures the position and orientation of the head in 3 dimensions, with respect to the transmitter. Custom-made software based on *Matlab* (SINTEF ICT, Trondheim, Norway) was used to quantify and display the data gathered by the Fastrak system. The software estimated the angular velocity of the neck as the change in the orientation of the sensor between each registration point divided by the time difference (1/120 s) between the registration points. The estimated angular velocity was not direction-specific. This means that the software calculated the magnitude of the angular velocity between the registration points regardless of the direction in which the head was moved. The estimated angular velocity was low-pass filtered at 20 Hz (3rd order Butterworth filter) to remove high-frequency measurement noise. The filter cut-off frequency was chosen based on the conjecture that frequency components above 20 Hz are not physiological.

Testing procedures

The examiner was not blinded to the subjects' group allocation, but all commands were standardized. Two isometric holding tasks were performed and 3-dimensional angular head movement velocity recordings were made throughout the holding-sequences. A 40-s *low load task* was performed with the subject seated in a backwards recumbent position (60°) on a wooden bench with a footrest and a backrest. Head support was adjusted for the subject's comfort, aiming for a neutral resting position of the head and neck. The Fastrak transmitter was placed on the upper part of the wooden backrest above the subject's head. For the test of head steadiness the subject was asked to lift the head slightly (1 cm) from the head support and hold as still as possible for 40 s. A *high load task* was performed in a similar manner and time, but in a supine lying position (0°).

Outcome variables and data management

Individual holding times were registered with a stopwatch. Head angular velocity (°/s) was recorded continuously during the holding period of the 2 tasks, i.e. excluding the head lifting and lowering sequences. In cases where the subjects were not capable of holding for 40 s, the length of the achieved holding sequence was recorded. For each individual, and based on the entire recording time, the 90th percentile angular velocity level was calculated. This was done in order to distinguish higher velocities, possibly due to rapid changes of velocity, which could be concealed by the mean values of angular velocity. Each recording was divided into a first and a second half, and values were compared to investigate a possible effect of fatigue. Likewise, the mean angular velocities of consecutive intervals of 4 s throughout the recordings were quantified to explore time trends in more detail. Subjects with holding times of less than 10 s were excluded from analyses of head motion velocity. Neck pain intensity and levels of dizziness on the day of testing were registered on a self-reported questionnaire. Neck pain was registered on numeric rating scales (NRS), where 0 denoted "no pain" and 10 "worst imaginable pain". Dizziness was registered on a 5-point rating scale, where 1 denoted "no problem" and 5 "severe problems".

Statistical analysis

Holding time in seconds was analysed with the Kaplan-Meier logrank test. Group differences in subject characteristics, mean angular velocity and 90th percentile angular velocity levels were analysed with the Kruskal-Wallis test. Regression analysis of mean angular velocity (dependent variable) was performed using multiple robust regression (Huber's method). Initially, age-adjusted multiple robust regression analyses were run for each variable separately (group, gender, neck pain intensity and dizziness). Secondly, multiple robust regression was used to analyse differences between the 2 pain groups (healthy controls excluded) adjusted for age, dizziness and pain in order to detect whether head steadiness related to a traumatic onset of neck pain (whiplash) or neck pain *per se* (chronic neck pain). Neck pain intensity and dizziness were both recoded into 3 categories for the regression analysis in order to avoid categories with insufficient number of cases. Differences in angular velocity between the first and second halves of each recording were investigated for each study group separately with the non-parametric Wilcoxon signed-rank test for 2 related samples. Group differences were considered significant at the $p < 0.05$ level. Analyses were performed using SPSS 14.0 and NCSS 2007 (Utah, USA).

RESULTS

Seven recordings from the low load task (4 WAD, 3 neck pain) and 10 recordings from the high load task (6 neck pain, 4 healthy controls) were excluded due to technical problems during testing. Ten additional recordings were excluded from the high load task due to a holding time of less than 10 s (9 WAD, 1 neck pain). In the low load task, 164 registrations were left to be analysed (53 WAD, 54 neck pain, 57 healthy). In the high load task, 150 registrations were left to be analysed (47 WAD, 50 neck pain, 53 healthy). In addition, 2 healthy subjects and one patient with WAD had missing data on neck pain and dizziness and one chronic neck pain patient had missing data on neck pain only. Subject characteristics, symptom intensity levels and head motion velocity in the study groups are shown in Table I. Age was significantly higher in the chronic neck pain group, while gender differences were non-significant. Neck pain and dizziness were significantly different between all 3 study groups (Table I).

Holding time

Kaplan-Meier curves were used to illustrate holding times in the groups for both the low load and the high load tasks (Fig. 1). The majority of the subjects in the chronic neck pain group and the healthy control group were able to hold the full 40 s of both tasks. Significantly shorter holding times were found in the WAD group compared with the 2 other groups in both tasks ($p < 0.05$).

Head motion velocity

The mean and 90th percentile head angular velocity levels in the low load and the high load isometric tasks are shown in Table I. Significant overall group differences in angular velocities were found for the low load task but not for the high load task. A strong correlation was found between the mean and the
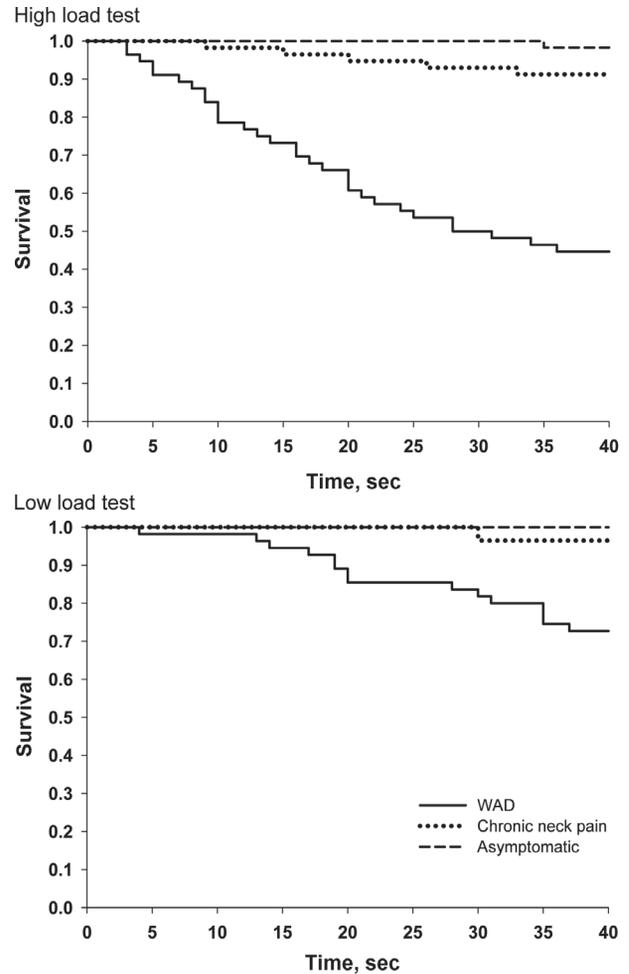

Fig. 1. Holding time for the high load (upper panel) and the low load (lower panel) isometric holding tasks shown as Kaplan-Meier survival curves of the 3 study groups. The tasks were terminated at 40 sec.

Table I. *Subject characteristics, neck pain intensity, dizziness and head motion velocity (angular velocity; °/sec) during isometric flexion tests. Data are group median values with interquartile range (IQR)*

	WAD	Chronic neck pain	Healthy controls	*p*-value*
Characteristics and symptoms				
Gender (female/male)	34/23	38/19	28/29	0.16
Age (years)	37 (30–45.5)	45 (32–54)	37 (28.5–47)	**0.01**
Neck pain† (0–10)‡	6 (4–7)	4 (2.3–5)	0 (0–0)	**<0.01**
Dizziness (1–5)§	2.5 (2–3)	2 (1–2)	1 (1–1)	**<0.01**
Mean head motion velocity				
Low load task	1.20 (0.97–1.50)	1.09 (0.91–1.25)	1.14 (0.95–1.35)	**0.02**
High load task	2.17 (1.91–2.67)	2.00 (1.65–2.61)	2.34 (1.83–2.83)	0.54
90th percentile head motion velocity				
Low load task	2.02 (1.60–2.65)	1.82 (1.53–2.18)	1.94 (1.57–2.36)	**0.02**
High load task	3.76 (3.26–4.72)	3.45 (2.81–4.63)	4.13 (3.17–4.92)	0.44

*Overall group differences, Kruskal-Wallis test. Bold text indicates significant values.
†Neck pain at day of testing.
‡Numeric rating scale: 0=no pain; 10=worst imaginable pain.
§1=no problem with dizziness; 5=severe problems with dizziness.
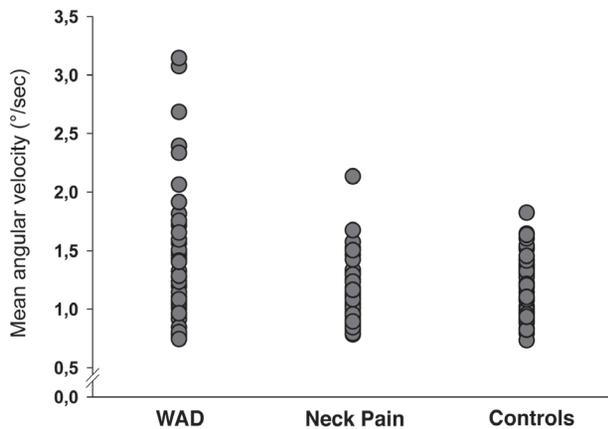WAD: whiplash-associated disorders.

Fig. 2. Individual mean head motion velocities for the low load task displayed for the 3 study groups. A greater range of values is observed within the group with whiplash-associated disorders (WAD).

90th percentile angular velocity levels, and the 90th percentile level did not reveal any additional information. Mean angular velocity was therefore used in the further analyses. A larger range of individual mean angular velocity levels in the low load task was observed in the WAD group compared with the other 2 groups, with a smaller portion of patients with WAD presenting higher velocity values (Fig. 2).

Age-adjusted multiple robust regression was initially run to analyse the separate effects of group, pain intensity and dizziness on mean angular velocity. The multiple regression analyses were run only for the low load task due to overall non-significant group effects for the high load task. The results are presented in the left-hand column of Table II and show significant effects for all variables. The WAD group had significantly higher angular velocity than the other 2 groups. There was a

lower angular velocity with increasing age. Neck pain and dizziness significantly increased head angular velocity, but only with considerable/severe symptom levels. Secondly, group, age and neck pain were included in an adjusted regression model (Table II, second column). Since the healthy control group did not have neck pain, the analysis was run without this group, i.e. between the 2 pain groups only. The effect of group was eliminated when adjusted for neck pain ($p=0.438$), but the effect of neck pain remained significant for the severe category ($p=0.006$). Thirdly, group (healthy controls excluded), age and dizziness were included in an adjusted regression model. The effect of group no longer reached significance ($p=0.085$), but the effect of dizziness was unchanged for the considerable/severe category ($p=0.001$) (Table II; third column).

The final model included group (with the healthy control group excluded), age, pain and dizziness. The results showed significant effects of severe neck pain and considerable/severe dizziness. The effect of group was eliminated. Explained variance (R^2) of the final adjusted model for the two pain groups was 0.29.

For both the low and high load task, each recording was divided into a first and a second half, and mean head angular velocity was computed for each half (Fig. 3). In the high load task, angular velocity in the WAD group increased significantly in the second half compared with the first half. No such differences were found in the other 2 groups. In the low load task, no change in velocity was found in the WAD group, while the neck pain group and the healthy control group showed significantly lower angular velocity in the second half relative to the first half. Fig. 4 shows the low load task divided into 4-s intervals displaying the time trends in 3 study groups in more detail. For the chronic neck pain group and the healthy controls, a steady trend is observed towards gradually lower angular velocity throughout the holding sequence, while the WAD group showed a more steady state.

Table II. *Effects of group, age, neck pain and dizziness on mean head motion velocity (angular velocity; °/second) during the low load isometric flexion test*

Categories	Adjusted (age) 3 study groups		Adjusted (age, pain) 2 study groups*		Adjusted (age, dizziness) 2 study groups*		Adjusted (all variables) 2 study groups*	
	β-estimate	*p*-value†	β-estimate	*p*-value†	β-estimate	*p*-value†	β-estimate	*p*-value†
Group								
WAD	ref		ref		ref		ref	
Neck pain	−0.154	0.011	−0.054	0.438	−0.111	0.085	−0.044	0.511
Healthy	−0.135	0.022	–	–	–	–	–	–
Age	−0.008‡	<0.001	−0.008	0.004	−0.008	0.002	−0.008	0.001
Neck pain§ (categorized)								
NRS=0–3	ref		ref		–	–	ref	
NRS=4–6	0.050	0.498	0.049	0.498	–	–	0.009	0.896
NRS=7–10	0.289	0.001	0.258	0.006	–	–	0.195	0.034
Dizziness								
No problem/slight problem	ref		–	–	ref		ref	
Moderate problem	0.152	0.062	–	–	0.116	0.153	0.099	0.219
Considerable/severe problem	0.350	<0.001	–	–	0.328	0.001	0.292	0.002
	n=161¶		*n*=105¶		*n*=106¶		*n*=105¶	

*Adjusted results for the WAD group and the chronic neck pain group only; †Robust multiple regression using Huber's method (C=1.345); ‡Unadjusted, §Neck pain at day of testing measured on a numerical rating scale (NRS): 0=no pain, 10=worst imaginable pain; ¶minimum number.
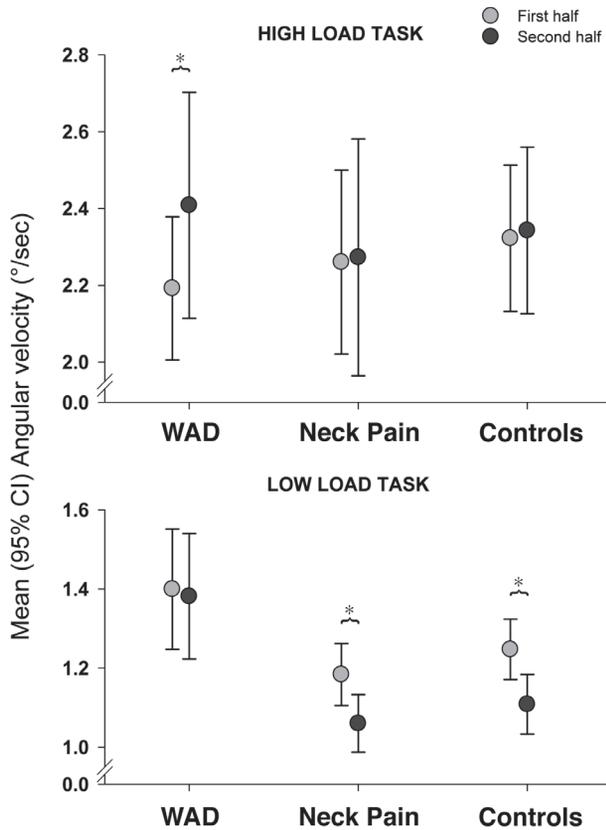WAD: whiplash-associated disorders.

Fig. 3. Mean head motion velocity with 95% confidence interval (CI) of the high load (upper panel) and low load (lower panel) isometric holding tasks estimated for the first and second half of each recording. Asterisks indicate significant differences in head motion velocity ($p<0.05$) between the 2 half sections within each study group. WAD: whiplash-associated disorders.

DISCUSSION

Significantly increased head motion velocity when performing a low load isometric neck flexor holding task was found in the WAD group compared with both patients with chronic
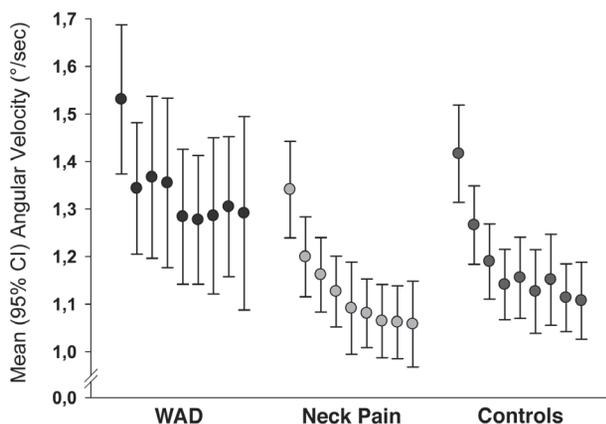

Fig. 4. Head motion velocity (mean, 95% confidence interval (CI)) of the low load isometric holding task shown as consecutive 4-sec intervals throughout the holding sequence. WAD: whiplash-associated disorders.

non-traumatic neck pain and healthy controls. Severe levels of neck pain intensity and dizziness explained the variation in head motion. No differences between groups were found with a high load isometric task. Decreased steadiness with increasing holding time in the WAD group indicates that fatigue may influence head steadiness for the high load task in particular. It was hypothesized that neck pain influences the stability or "head steadiness", with increased head motion during isometric holding tests. Findings from previous studies indicate that neck pain is associated with inhibition and delayed onset in deep neck flexors muscles (11, 12, 31) and increased activation of superficial neck muscles (8, 13, 14). It has been argued that an impaired performance of deep neck flexor muscles can be compensated by superficial muscle activity (32). Particularly neck flexion with head lift from a neutral position, similar to the isometric tasks of this study, might allow the superficial muscles to "mask" deep muscle dysfunction. The 2 isometric tests were expected to challenge deep and superficial cervical muscle groups differently. In a previous study, a supine cervical flexion test against resistance was shown to activate both the deep and the superficial neck flexors (33). Increased resistance against head lift was found to increase the involvement of the superficial neck flexors. The isometric holding tasks in this study cannot be interpreted as specific tests for deep or superficial neck flexor function, but rather as general tests of the ability to sustain steadiness of the head and neck under 2 different load conditions. Although the muscle activation patterns were not investigated in our study, it is possible that both the high load and the low load task would challenge both deep and superficial neck flexors, but with a greater activation of superficial muscles in the high load task. This may account for the differential effects found for the low load and high load tasks. The low load task was considered to be the test that corresponds most closely to normal daily function. Our findings of altered "steadiness" for the low load task may indicate maladaptive or dysfunctional motor control strategies, possibly deep neck flexor dysfunction with insufficient compensational strategies among the patients with WAD. Such hypotheses would need to be confirmed in EMG studies.

Increased head motion velocity was found only in the WAD group in this study. Pain-related motor control alterations in the deep neck flexor muscles have previously been detected in patients with non-traumatic neck pain even at moderate intensity (17). Increased velocity was therefore expected for both pain groups in the study. Surprisingly, the non-traumatic neck pain group showed slightly lower head motion velocity even when compared with the healthy controls, but the differences were small and not statistically significant. A significant age-effect (lower velocity with increasing age) may account for the results, as the differences between the healthy controls and the chronic neck pain group disappeared when adjusted for age. Gender was not found to have any significant effect on head steadiness.

Patients with neck pain have shown increased fatigue of cervical flexors at moderate and low loads (18) and increased fatigue of both flexors and extensors at high loads (19). A relationship between cervical fatigue and impaired postural

control has been demonstrated previously in healthy controls (20) and patients with WAD (21) when studying associations between body sway and EMG signs of fatigue in cervical extensors. No direct measures of fatigue were included in this study. The 40-s holding time in the high load task was expected to be sufficient for most of the patients with WAD to reach fatigue based on findings of holding times among patients with WAD in a previous trial (34). Holding time may serve as an indirect measure of fatigue, and was significantly shorter in the WAD group. The observation of decreased steadiness with increasing holding time during the high load task in the WAD group indicates that fatigue may influence head steadiness. The fact that most of the WAD patients were not able to hold the full 40 s and still showed increased velocity in the second half of the recording merely strengthens an assumption of fatigue in this group. Completely opposite group results were found in the low load task, with a decrease in angular velocity from the first to the second half in both the chronic neck pain and the healthy control groups, while there was no change in the WAD group. The low load task was not expected to cause fatigue in healthy subjects, and from Fig. 4 it appears that the normal course of the low load task is a gradual increase in steadiness. The WAD group, on the contrary, kept an increased velocity quite stable throughout the first and second half. Although decreased head steadiness may point to neck flexor fatigue in patients with WAD, this study design is not suited to explore causal relationships. A more detailed description of "head unsteadiness", such as angular displacements and spectral frequency in different head motion planes, might add important information as to whether the findings are related to fatigue or to centrally driven motor control changes. A limitation in this study is the use of only one sensor and no reference sensor (e.g. at the upper trunk), and this information could not be detected with our set-up.

According to the inclusion criteria, the 2 pain groups were distinguished only by the history of trauma. However, the difference between the 2 pain groups on head motion velocity in the low load task may be associated with symptom variables that were found to relate to WAD in this study, such as higher reported levels of neck pain and dizziness (Table I). The unadjusted results showed a significant effect of both pain and dizziness on angular velocity, but only for the subjects with severe symptom levels. In the adjusted model, however, the effect of group was eliminated, but the effect of neck pain and dizziness remained significant for those with severe symptoms. In other words, decreased head steadiness was found to be associated with high levels of neck pain and dizziness. Neck pain may be a result of altered neuromuscular control in the cervical spine, but evidence from experimental pain studies has shown alterations in motor control strategies initiated by pain (35, 36). Dizziness and unsteadiness could be related to vestibular, visual, vascular or neurovascular mechanisms (37). It is, however, feasible that increased head motion velocity produces abnormal somatosensory input from the cervical spine and thus generates dizziness. Somatosensory alterations from the cervical spine have been found to affect postural stability and head movement control, with associated reports of dizzi-

ness and unsteadiness (38). Although decreased head steadiness in the WAD group was explained by severe pain and dizziness, the causal relationships remain to be answered.

We acknowledge that WAD is a complex condition with other essential contributing factors that are not reported in this study, such as various psychosocial factors (39, 40) and disability benefits (41). Motor control alterations in WAD must therefore fit in as part of a larger picture. The contribution of motor control alterations relative to other important factors in the purpose of diagnostics needs to be studied.

In conclusion, reduced head steadiness in a low load isometric neck flexion test was found in a group of patients with WAD compared with patients with chronic non-traumatic neck pain and healthy controls. The difference was explained largely by severe levels of neck pain and dizziness. Decreased steadiness with increasing holding time in the WAD group during a high load task indicates that fatigue may influence head steadiness.

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