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Motor impairment in patients with chronic neck pain: does the traumatic event play a significant role? – A case control study

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ABSTRACT

Background context: Motor impairment is a key-sign in patients with traumatic (WAD) and non-traumatic (INP) neck pain.

Purpose: This study aims at analyzing differences in motor impairment between both groups, and assesses the association with self-reported symptoms.

Study Design: Case control.

Patient Sample: 38 patients with chronic INP, 35 patients with chronic WAD, and 30 healthy pain-free controls were included.

Outcome measures: Mobility (°), Strength (N), Repositioning accuracy (°), endurance (s), sway velocity (cm/s), sway area (cm^2) and neuromuscular control.

Methods: Group differences of motor impairment together with questionnaires to evaluate pain intensity, fear avoidance, pain catastrophizing, symptoms of central sensitization, and disability were analyzed with Analysis of Covariance, including age as a covariate.

Results: Motor impairment was observed in both patient groups with a higher degree in patients with chronic WAD. These impairments were moderately linked to self-reported disability and were in most cases associated with pain, fear-avoidance, and symptoms of central sensitization ($|\rho|$ ranging from 0.28 to 0.59).

Conclusion: Motor impairment should be addressed when treating both groups of patients, keeping in mind the association with self-reported pain and disability, fear-avoidance and central sensitization.

Keywords: chronic pain; whiplash associated disorders; motor control; neck pain

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INTRODUCTION

Neck pain is a world-wide problem which affects approximately 4 in 5 people throughout their lifetime. In addition, up to two-third of these patients will encounter a new episode of neck pain within one year [1]. A large proportion of these patients develop chronic neck complaints, of which many of them without the designation of a specific medical cause and/or some of them after a traumatic event. This traumatic event most often consists of a motor vehicle collision, and these patients are often referred to as patients with whiplash associated disorders (WAD) [2, 3], whilst non-traumatic non-specific neck pain patients are often referred to as patients with idiopathic neck pain (INP).

Chronic neck pain not only has a high socio-economic impact, it does also affect the well-being and physical health of patients. Disability [4], motor impairment [5] and fear avoidance [6] are frequently reported in both groups of neck pain patients. Recent publications on different aspects of motor control including impaired postural control [7], decreased repositioning accuracy [8, 9], decreased mobility [10, 11], decreased muscle strength [12, 13], and impaired neuromuscular control [5, 14], have reported the presence of impairments in patients with chronic neck pain. Impairments, which are furthermore often observed to a larger extent in patients with WAD, indicating both groups might be considered as separate identities [15]. However, the comparison of motor impairment in

patients with INP and WAD is often lacking. This observation has caused a rise in questions on the significant contribution of the trauma in the genesis and severity of these symptoms.

Different theories have tried to elucidate these questions. Many report on peripheral alterations, such as muscular morphological adaptations [16, 17] and joint lesions [18], together with central alterations [19, 20] in reaction to the trauma. These alterations were furthermore identified as indisputable contributing factors disrupting the complex interaction between the incoming sensory signals and the processing by the central nervous system (CNS), inducing a poorly adapted motor strategy [21, 22]. In addition to these biological factors, this complex interaction might be affected by psychosocial factors, such as attitudes and beliefs towards movement, potentially aggravating the observed symptoms [13].

Considering the observed motor impairments together with different related biological and psychological adaptations, it is important to pursue a thorough understanding of underlying mechanisms involved in the development of motor impairment in patients with chronic neck pain in order to eventually steer therapy into the proper direction.

To solve these unanswered questions, this study aims at unravelling the magnitude of these motor impairments in both patient-groups compared to healthy controls by applying a clinically-oriented test protocol that assesses motor impairment together with some standardized questionnaires assessing psychological features. In addition, the interaction of these impairments with symptoms of increased central sensitivity, fear of movement, pain and disability will be explored.

METHODS

Participants

Participants were females aged between 18 and 65 years, that were recruited via internet, flyers and posters. Inclusion criteria for patients with chronic WAD and chronic INP were persistent neck pain (> 3 months) with an average pain intensity of more than 3/10 on the Verbal Numeric Rating Scale (VNRS). All chronic neck pain patients had to report mild/moderate to severe pain-related disability (≥ 10 on the Neck Disability Index (NDI)) [4]. In addition, patients with chronic WAD were only included if they were classifiable as WAD II A, B or C on the modified Quebec Task Force Scale [2, 23]. Finally, patients were stable regarding pain medication intake for at least 4 weeks prior to study participation.

Healthy pain-free women could only participate if they were pain-free on the test day (VNRS < 2/10), had no history of neck-shoulder-arm pain for longer than 8 consecutive days during the last year (average VNRS ≥ 2), no medical consultation for neck-shoulder-arm pain during the last year and no history of a whiplash trauma. Additionally, healthy controls were only included if they had a score of less than 8/50 on the NDI.

General exclusion criteria for all study groups were the presence of major depression or psychiatric illness, neurologic, metabolic, cardiovascular disorders, inflammatory conditions, fibromyalgia, chronic fatigue syndrome, and a history of neck or shoulder girdle surgery. Furthermore, women who were possibly pregnant and women 1 year postnatal were excluded. All participants were asked to stop intake of non-opioid analgesics 48 hours prior to study participation. In addition, participants were asked not to undertake heavy physical exertion, and to refrain from consuming alcohol, caffeine and nicotine on the day of testing.

Questionnaires

i. VNRS

The VNRS-11 was applied to assess pain intensity on the day of testing. Scores range from 0 to 10, with 0 reflecting “no pain at all” and 10 reflecting “the worst pain imaginable”. This rating scale is known as a usable and valid pain rating scale [24].

ii. Disability

The Dutch version of the Neck Disability Index (NDI) assesses self-reported disability [4]. This version serves as a valid and reliable measurement to assess self-reported disability [25, 26]. It consists of 10 items: pain intensity, personal care, lifting, reading, headache, concentration, work, driving, sleeping, and recreation. Each of these items has 6 response categories ranging from 0 to 5 (with 0 “no disability” and 5 “total disability”), resulting in a total score ranging up to 50 with a higher score indicating more self-reported disability [4].

iii. Fear Avoidance

Symptoms of kinesiophobia were evaluated using the Dutch Tampa Scale of Kinesiophobia (TSK), a valid and reliable questionnaire [27, 28] consisting of 17 questions scored on a 4-point scale ranging from 1 (completely disagree) to 4 (completely agree). The total score is calculated as the sum of each individual score after reversing the scores on question 4, 8, 12, and 16 [27]. A higher score indicates a higher amount of kinesiophobia. According to Vlaeyen et al. (1995) a cut-off score of 37 indicates the presence of a high degree of kinesiophobia [29].

iv. Central Sensitization

The Central Sensitization Inventory (CSI) is a self-reported screening instrument to measure clinical symptoms of central sensitization in chronic pain populations, with a good internal consistency, good discriminative power, and excellent test-retest reliability for the Dutch version of the CSI [30]. Scores range from 0 to 100 [30] with a higher score indicating a higher amount of symptoms of central sensitization.

Motor control

Strength was measured with a Hand-held dynamometer (MicroFET 2, Hoggan Health Industries Inc., Biometrics, The Netherlands), a clinically useful apparatus with a good inter- and intra-tester reliability [31]. All measurements were recorded in Newton (N) with a threshold of 3.6N and a sensitivity of 0.4N. The subject was seated and its thorax was stabilized. Places of resistance were the forehead (frontal bone), the occiput, and just above the left and right ear (parietal bone) for flexion, extension, and left and right side bending respectively. Patients were asked to perform 3 consecutive trials with a 10 seconds rest-interval. The maximum of three strength-measures was included in the final dataset.

Mobility was assessed with a dual digital inclinometer (Acumar digital inclinometer, model ACU360; Lafayette Instrument Co, Lafayette, IN), a reliable instrument for measuring active range of motion [32]. This instrument is capable of measuring a range up to 180° with an accuracy of 1°. Subject positioning was identical to the positioning for strength measurements. Patients were asked to perform 3 consecutive flexion, extension, left and right side bending movements, of which the average was calculated and included in the final dataset.

To measure **repositioning accuracy** or joint position error (JPE), subjects were seated at a distance of 90 cm from the wall. A laser-helmet was placed on the subject's head and subjects were blinded. Subjects were asked to maximally move their head in different directions (rotation left/right, and flexion/extension), trying to afterwards reposition their head as close as possible to the original position. Repositioning accuracy was defined as the distance between the starting point and the point indicated by the subject with the horizontal and vertical error resembling the distance parallel and perpendicular to the horizontal axis respectively. After each trial the subject was repositioned in order to realign the laser-pointer with the original position, and each participant was assessed during 10 consecutive trials [33]. Lastly, the obtained distances were reformulated in terms of degrees by applying the following formula: *degrees (°) = tan^{-1} (repositioning error / 90)*. This method achieves a fair to good reliability [34].

Postural control was assessed with an AMTI ACG portable forceplate (50 cm x 50 cm) (Advanced Medical Technology, Inc., Watertown, MA), which was connected to the standard amplifier to record changes in displacement of the Center of Pressure (CoP), allowing the recording of three ground reaction forces and three moments, along the axis in the medio-lateral, anterior–posterior, and vertical directions. CoP-data was acquired via three consecutive measurements of 90 seconds using a sampling frequency of 100 Hz in order to yield reliable results [35]. Using MATLAB R2015a (Mathworks, Inc), the raw data were filtered using a 4th order low pass digital Butterworth filter with a cut-off frequency of 5 Hz and afterwards the following CoP parameters were computed: mean sway velocity (cm^2/s), and the 95% confidence ellipse area (cm^2). Data on each subject was gathered with the subject placed on a firm surface, feet placed at hip width, and eyes closed.

Neuromuscular control was assessed by the craniocervical flexion test (CCFT) and the scapular holding test (SHT), for which a specific form was constructed resulting in a score ranging from 0 to 10 with a lower score indicating more neuromuscular impairment.

The CCFT is a valid [36, 37] and reliable [38] test, which aims at assessing the deep cervical flexors. The first part of the scoring form consisted of the original test as described by Jull et al. (2008) resulting in a score ranging from 0 to 4 (22mmHg to 30mmHg) with the aid of a stabilizer-cuff (*Chattanooga Stabilizer Group Inc., Hoxson, TN*) [39]. In addition, patients were asked to perform the same movement 5 consecutive times trying to reach the level of 26 mmHg. A score ranging from 0 (unable) to 4 (excellent) was given based on fluency, respiration, compensation of superficial muscles, and under or overshooting of the targeted pressure. Lastly, a score ranging from 0 to 2 was given based on the endurance in which patients were asked to hold a normative pressure of 26 mmHg for 10 seconds during 10 consecutive trials. The score was calculated as the amount of successful repetitions multiplied by 0.2. The complete assessment form is represented in **Appendix 1**.

The neuromuscular capacity of scapulothoracic muscles was assessed using the scapular holding test (SHT), performed at the dominant painful side. Subjects were positioned prone with their head in a

neutral position and arms besides their thorax. The first part of the form assesses compensatory movements (elevation, retraction, downwards rotation, tipping, or internal rotation of the scapula), and the quality of contraction of the lower trapezius muscle after the therapists instructed the patient to keep the scapula in this optimal position [40], resulting in a score ranging from 0 to 4. Afterwards, patients were asked to perform the same movement 5 consecutive times trying to reach the scapular setting. The performance of these trials was assessed on fluency, compensatory movements, and under or overshooting from the targeted position, resulting in a score ranging from 0 (worse) to 4 (best). Lastly, a score ranging from 0 to 2 was given based on the endurance in which subjects were asked to hold the scapular setting for 10 seconds during 10 consecutive trials. The score was calculated as the amount of successful repetitions multiplied by 0.2. Information on the reliability of this measurement is however currently lacking. The complete assessment form is represented in **Appendix 2**.

Endurance of the cervical flexor muscles was measured via the protocol described by Olson and colleagues (2006), which features a high inter- and intratester reliability [41]. Participants lay supine in a hook-lying position, hands resting on their abdomen, and were asked to slightly raise the head allowing the tester to slide the widths of the index and middle finger of one hand, one atop the other, under the participant's head at the most posterior aspect of the occiput. The participant is then asked to rest their head on the examiner's fingers. Next, the subject is directed to perform a craniocervical flexion and raise the head just off the tester's fingers resulting in a cervical flexion and hold this position as long as possible. During the test, the examiner gently moves his/her fingers side to side under the subject's head, providing a tactile cue for maintaining proper head position above the plinth. Timing of the duration of the trial started after the subject raises the head off the tester's fingers, and ended when 1 of 4 criteria are met: (1) the subject experiences pain and is unwilling to continue; (2) the subject is unwilling to continue; (3) the examiner determines that the subject loses chin tuck; and (4) the examiner determines that the subject raises the head (flexes the neck while still in chin tuck) such that the tester's fingers no longer maintain contact [41].

Data analysis

The distribution of the continuous data within each group was assessed by histograms, QQ-plots, and the Shapiro-Wilk test. If data was observed to deviate from normality, an appropriate transformation was applied in an attempt to normalize the data. Parametric demographic continuous data were analyzed with ANOVA (F-test) with post-hoc t-tests, non-parametric demographic continuous data were analyzed with the non-parametric Kruskal-Wallis-test with post-hoc non-parametric Wilcoxon-test.

Group-differences in motor impairment and questionnaires were analyzed with an analysis of covariance (ANCOVA), including age as a covariate. To judge the model the residual terms were analyzed on normality, homoscedasticity, and outliers via a normalized residual plot, a squared residual plot together with a Levene's test and the Cook's Distance respectively. Post-hoc pairwise comparison was performed correcting the Family-Wise Error Rate (FWER) at 0.05 by application of the Bonferroni method. The resulting test-statistics of each test were represented with the corresponding p-value.

The associations between motor control variables and questionnaires were analyzed with a correlation analysis (spearman's ρ). Statistical significance was set at $\alpha < 0.01$ (Bonferroni-corrected for 5 clusters: neuromuscular control, mobility, strength, balance, and repositioning accuracy).

All data-analysis was performed using R (version 3.2.4 Revised). To build the statistical models, the functions from the package "stats" [42] were used. For purpose of multiple comparison between groups, the package "multcomp" [43] was used.

RESULTS

Between-Group differences

In total, 103 participants were enrolled in the study, of which 30 were classified as HC, 38 as patients with INP, and 35 as patients with WAD. All groups were comparable for BMI (kg/m^2), education level,

smoking status, and daily computer work. Only age and medication intake was significantly different between the included groups. The difference in age was situated between patients with WAD and HC (Mean difference ± SE: 0.21 ± 0.09; t-value = 2.48; $p < 0.05$), and the proportion of medication takers seems highest in patients with WAD. Pain duration ranged from 3 to 444, and 4 to 300 months in patients with WAD, and INP respectively, indicating similar pain durations in both groups. Patients with WAD did however report higher values of pain on the test-day. **Table 1** gives more information on the demographics of the included groups.

QUESTIONNAIRES

The fitted model based on the NDI-data showed only a significant association between the included groups and **disability**. A higher degree of self-reported disability was observed in both patient-groups with patients suffering from WAD reporting the highest degree of self-reported disability. Similarly only a significant association between the included groups and **kinesiophobia** was observed with an increased amount of kinesiophobia in both patient-groups compared to HC. Of all patients, 33.3% and 40% of patients with INP and WAD respectively, exceeded the critical point of 37. Furthermore, more sensitization seems to be present in patients with WAD compared to both other groups. Patients with INP do however demonstrate an increased amount of sensitization-symptoms compared to HC. All details of the analysis are represented in **table 2**.

MOTOR OUTPUT

Significant group differences were present in all motor tests, except for repositioning error after rotation in all planes, the total and vertical repositioning error after flexion/extension, and the sway velocity (**Table 3 and 4**). A decrease in **strength** was observed in patients suffering from WAD compared to HC and patients with INP in all directions, whilst only a significantly lower strength was observed in patients with INP compared to HC for extension. Similarly, **mobility** was observed to be decreased in all directions in patients with WAD compared to HC. Patients with INP featured only a greater mobility compared to patients with WAD for extension and right side bending, and a decreased mobility compared to HC was observed in the flexion and right side bending direction.

Repositioning accuracy, measured via JPE, was highest in patients with WAD and significantly higher on the horizontal axis after performing flexion-extension compared to HC. Patients with WAD and INP featured a greater sway area compared to HC with the highest sway in patients with WAD. In addition, patients with WAD and INP seem to suffer from **neuromuscular control dysfunction** in comparison with HC. Both patient-groups obtained on average a lower score on both the SHT and CCFT, indicating the presence of altered neuromuscular control strategies. Although a tendency towards greater neuromuscular deficiency in patients with WAD was observed, this did not reach significance. Lastly, the **endurance**-test for the flexor-muscles indicated a decreased endurance for patients with WAD and INP compared to HC.

Correlation analysis

Table 4 shows the result from the spearman correlation analysis, assessing the association between self-reported symptoms and motor performance. All correlations (absolute values) varied between 0.21 and 0.59, indicating only small to moderate associations between the included variables [44]. No association between motor impairment and pain duration was concealed, nor did we observe an association between **repositioning accuracy** and any of the included questionnaires. In contrast, a clear association was found between disability, pain, fear of movement and symptoms of central sensitization, and **mobility and strength**. **Postural control** was observed to show the highest associations with sway area, and in a lesser extent with the sway velocity. Both measures were observed to be significantly correlated with symptoms of central sensitization. In contrast, only the patient's sway area correlated significantly with self-reported disability, and pain. Both **neuromuscular control** tests were associated with self-reported disability, pain, and symptoms of central sensitization. In addition, scapular neuromuscular control showed an association with fear of movement. Lastly, an association was observed between **cervical flexor endurance**, and disability, pain, and symptoms of central sensitization.

DISCUSSION

Motor impairments were observed in both patient-groups with a higher impairment in patients with chronic WAD, ratifying the importance of the prior trauma in the severity of reported symptoms. However, these differences were not analogous for all aspects of motor impairment. Strength was observed to be impaired in all directions in patients with WAD compared to both HC and patients with INP. This is in contrast with patients with INP, who only feature a decreased strength in the extension-direction when compared to HC, but corresponds with previously reported results from our department [12]. Similar findings were observed for AROM, for which a multidirectional impaired AROM was observed in patients with WAD, whilst patients with INP only feature an impaired AROM in the direction of flexion and right side bending, which is in accordance with the current evidence regarding neck flexibility in patients with chronic neck pain [10, 11, 45]. The difference in magnitude of strength and AROM impairments between both patient-groups might be attributed to different aspects. First of all, the higher degree of pain observed in patients with WAD might explain the observed difference, however, only conflicting evidence is available for this association [31]. In addition, condition-specific adaptions might be involved as the cervical musculature in patients with WAD exhibits some specific features, such as fatty infiltration [16]. The observed impaired strength and AROM might not only be associated with tissue alterations and pain, but might also result from a higher degree of fear of movement [13, 29]. Lastly, patients who report symptoms of sensitization in a higher degree might suffer from a larger impairment in strength, as could be observed from these data. This corresponds with the observed impaired exercise-induced analgesia (EIA) in patients with central sensitization, often causing increased pain experience after an active isometric contraction [46].

A significantly decreased repositioning accuracy was only observed in patients with WAD showing an increased error in the horizontal plane after extension/flexion. The diversity of results observed in this study is in accordance with the current literature [47]. Methodological differences do however restrict comparison with the current literature. A recently published meta-analysis reported an

increased, but rather small repositioning error in patients with INP ranging from 0.20° to 0.65° compared to HC [8]. The magnitude of this error makes the clinical relevance of these increased errors questionable, certainly since some authors furthermore suggested the use of a 4.5° deviation threshold to assess an inadequate repositioning accuracy [33]. In contrast, both patient-groups were observed to suffer from an impaired postural control compared to HC, which is in accordance with previously published studies [7]. Impaired postural control is revealed by the normal sway velocity in combination with an increased sway area, suggesting a delayed response of the postural control system on the incoming stimuli. Both postural control and proprioception are the product of an advanced feedback-system, in which incoming proprioceptive information are scrutinized and an adapted response is generated. Both, peripheral [48, 49] and central alterations [50, 51] might thus affect this process. Trauma-induced muscular changes for example affect the muscle spindles, and together with an impaired vestibular function [47, 52], might contribute to the increased repositioning error and postural control deficiency. Interestingly, only a few patients reported symptoms of dizziness and unsteadiness, indicating postural control and repositioning error is only deficient in a specific subgroup of patients [53]. Surprisingly, none of the self-reported symptoms were found to be significantly associated with repositioning accuracy. In contrast, postural control is associated with pain, indicating the feedback system is potentially influenced by the pain experience of the patients.

Likewise, neuromuscular control seems to be affected in both groups, which is similar to early reports on scapular and cranio-cervical neuromuscular control in patients with chronic neck pain [54, 55]. Both, the axio-scapular [14] and deep cervical flexor musculature [54] have been attributed as important dynamic stabilizers which – if dysfunctional – might be associated with the genesis of neck pain or vice versa [5, 56]. More research on this aspect is however inevitable, certainly regarding the contribution of scapular dynamic stability in neck pain [55]. These dysfunctions were surprisingly similar in both patient-groups, illustrating the traumatic event might only play a minor role in

neuromuscular impairment. In addition, patients with WAD and INP suffer from a reduced endurance of the deep and superficial cervical flexors. Both pain and symptoms of central sensitization were observed to be associated with these neuromuscular impairments, indicating a potential primary role for the CNS in regulating motor output [22]. It is known that experimental muscle pain might influence motor units, resulting in a delayed and reduced activity of the deep cervical flexor muscles [57], which corresponds with our current observations.

Our data furthermore suggests a clear association of many self-reported symptoms with motor impairment. Self-reported symptoms might interact with physical factors, and determine the severity of motor impairment, which is currently considered as the result from the complex interaction between sensory input, processing by the CNS, and the generation of an appropriate and adapted output [21, 22]. Pain and/or a trauma might for example induce a state of hypersensitivity [58] by causing direct functional and structural changes in the CNS. Pain could furthermore induce a stress-response, resulting in an increased pain awareness and experience [59], and indirectly induce motor impairment [29]. Different clinical and experimental studies have already explored the causal relationship between pain and motor impairments, of which many have reported pain-induced or pain-related motor impairments [60]. In addition, a trauma might directly induce peripheral adaptations, such as altered muscle and joint receptors, directly or indirectly via an inflammatory response [18, 61].

Therapists working in practice should certainly address this complex interaction, and provide a thorough physical examination to assess the degree of motor impairment in these patients. In addition, these data provide evidence for differences in the degree of impairment in patients with INP and WAD, indicating these groups of patients should indeed be seen as separate identities in practice. To get a patient-specific portray, a clinical assessment, consisting of reliable and valid tests is unbearable. This might ultimately lead to an patient-specific adapted therapy program.

Limitations, strengths, and future research

This study is the first to extensively analyze the differences in motor impairment between patients with INP and WAD. Moreover, in contrast to other studies, this study accounts for age, which has been identified as an important confounding factor [62]. This study did furthermore not only analyze the association between motor impairment and self-reported symptoms of pain and disability, but also the correlation between motor impairment and symptoms of central sensitization and the patient's attitudes and believes towards pain and fear of movement is explored. Furthermore, this study included more than 30 subjects in each group, resulting in a power of 93.2% for the included ANCOVA-analysis to detect large effect sizes.

In addition, some limitations should be mentioned: only females were included in this study, limiting the generalization of our findings. In addition, although a correlation between the different questionnaires might be assumed, this was not assessed. Furthermore, the observational cross-sectional design of this study prohibits the inference on causality. Although this study provides some evidence for clinical motor impairment to a different degree in patients with chronic neck pain, more studies including reliable and valid measurements are required to draw final conclusions. More longitudinal high quality studies are necessary to assess the role of motor impairment in pain and/or disability. Lastly, patients with WAD were only eligible if they met the general inclusion criteria and were classifiable as WAD II (A,B, or C). Patients with INP were only eligible if they met the general inclusion criteria, since a generally accepted condition-specific classification is currently lacking.

Conclusion

To conclude, many of the observed motor impairments were associated with symptoms of disability and pain indicating motor impairment should not be underestimated in the daily clinical practice. Although differences in motor impairment were mostly evident between patients suffering from

WAD and INP, compared to HC, the magnitude of these differences remains unclear. Patients with WAD do often feature these motor impairments in a higher degree, indicating the trauma might be associated with motor impairment.

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Table 1: Overview of summary statistics on the demographic variables of the included groups

		Mean (SD)	Median	Range	Test-statistic (P-value)
Age (years)	**HC**	30.45 (1.15)	28.36	20.01 – 49.01	3.75 (0.03*)
	INP	38.00 (1.41)	37.00	18.00 – 63.00	
	WAD	47.00 (1.11)	38.00	22.00 – 59.00	
BMI (kg/m^2)	**HC**	21.83 (3.81)	21.84	18.07 - 26.75	0.80 (0.45)
	INP	22.75 (7.77)	22.73	18.34 – 29.07	
	WAD	22.30 (3.64)	22.31	16.65 – 32.02	
Pain Duration (months)	**HC**	NA			
	INP	86.97 (84.88)	60	4 – 300	579.5 (0.81†)
	WAD	86.62 (86.66)	60	3 – 444	
Pain intensity on test day	**HC**	NA			
	INP	2 (2.08)	2.85	0 – 7	855 (0.006†)
	WAD	5 (2.70)	4.49	0 – 10	

Education Level	**No degree**	**High School**	**Higher Education**	
HC	0	10 (33.3 %)	20 (66.7%)	2.78 (0.84)
INP	0	11 (30.6%)	25 (69.4%)	
WAD	1 (2.9%)	9 (26.5 %)	24 (70.6%)	
Smoker	**Former smoker**	**Non-smoker**	**Smoker**	
HC	3 (10%)	26 (86.7%)	1 (3.3%)	7.40 (0.12)
INP	10 (32.3%)	20 (64.5%)	1 (3.2%)	
WAD	9 (25.7%)	22 (62.9%)	4 (11.4%)	

Medication	**Yes**	**No**	
HC	3 (10%)	27 (90%)	12.17 (0.002)
INP	7 (18.9%)	30 (81.1%)	
WAD	16 (45.7%)	19 (54.3%)	

Data assumed to be normally distributed was analyzed with ANOVA. (*) Age was log-transformed to obtain normally distributed data, summary measures given are however presented in the original scale. Non-normal data was indicated with †, and group differences were analyzed using the Wilcoxon-test. Test-statistics represent the F-statistic for parametric continuous data, the W-statistic for continuous non-parametric data and the χ^2-statistic. **Abbreviations**: SD: standard deviation; NA: Not applicable.

1 **Table 2:** Descriptives of different motor tests within the included groups.
2

			Mean	Median	Range	IQR	SD
Force (N)	**Flexion**	***HC***	92.51	93.15	56.9 – 159.2	73.72 – 106.1	22.22
		INP	78.41	72.70	42.2 – 122.7	67.82 – 91.6	19.72
		WAD	55.73	52.90	6.2 – 137.4	36.65 – 75.2	31.18
	Extension	***HC***	197.0	199.0	114.7 – 255.8	171.4 – 228.8	41.24
		INP	160.9	164.6	80.9 – 227.3	135.5 – 191.2	40.78
		WAD	117.5	117.4	13.7 – 315.0	67.15 – 167.0	70.62
	Side Bending Left	***HC***	119.60	120.7	68.9 – 187.3	102.9 – 135.3	24.89
		INP	101.70	100.8	47.2 – 160.1	80.95 – 121.8	26.34
		WAD	70.17	70.2	9.0 – 138.8	46.65 – 96.7	35.25
	Side Bending Right	***HC***	119.9	120.8	76.9 – 206.8	97.85 – 134.0	30.36
		INP	108.50	112.0	47.6 – 164.6	93.80 – 128.4	29.56
		WAD	72.85	74.4	7.1 – 146.3	49.55 – 99.4	36.89
Mobility (°)	**Flexion**	***HC***	62.96	64.16	46.67 – 80	56.86 – 69.00	8.73
		INP	55.09	52.50	33.00 – 79	48.33 - 61.97	10.02
		WAD	44.64	46.67	7.67 - 74	32.17 – 57.50	17.39
	Extension	***HC***	73.89	74.44	41.67 – 111.70	67.17 – 82.92	13.62
		INP	64.15	64.34	40.67 – 103.70	53.33 – 74.58	14.78
		WAD	51.50	53.11	5.67 – 91.33	42.50 – 62.84	20.73
	Side Bending Left	***HC***	41.52	42.00	28.00 – 56.67	37.86 – 45.83	7.21
		INP	36.76	36.16	15.33 – 51.67	33.42 – 42.08	7.96
		WAD	33.06	35.56	6.67 – 62.67	23.67 – 40.16	12.59
	Side Bending Right	***HC***	40.68	41.33	21.67 – 50.67	37.42 – 46.30	6.75
		INP	35.23	34.67	20.67 – 52.33	29.75 – 38.28	7.62
		WAD	31.94	34.33	4.67 – 61.00	24.17 – 38.00	12.50
Neuromuscular control	**Endurance Cervical Flexors** (s)	***HC***	38.21	32.68	14.59 – 112.40	23.90 – 46.57	20.27
		INP	34.04	32.73	11.80 – 105.80	26.39 – 41.48	15.53
		WAD	22.38	20.70	0.00 – 84.14	11.46 – 31.48	16.88
	CCFT	***HC***	4.89	4.7	2 – 9.2	3 – 6.3	2.04
		INP	3.63	4.0	0 – 7.4	2 – 4.75	1.87
		WAD	2.56	2	0 – 9.0	1.00 – 3.50	2.06
	SHT	***HC***	6.60	6.5	4.0 – 9.8	5.25 – 7.35	1.46
		INP	5.15	5.0	2 – 9.0	4.00 – 7.00	1.84
		WAD	4.73	4.0	2 – 9.0	4.00 – 6.00	1.68
Balance	**95-Area** (cm^2)	***HC***	1.76	1.86	0.59 – 2.98	1.27 – 2.15	0.61
		INP	2.72	2.54	0.65 – 8.18	1.38 – 3.51	1.66
		WAD	4.11	3.68	0.89 – 13.74	2.10 – 4.93	2.88
	Velocity (cm/s)	***HC***	0.78	0.82	0.39 – 1.21	0.62 – 0.89	0.19
		INP	0.92	0.84	0.50 – 2.06	0.73 – 1.02	0.38
		WAD	0.98	0.94	0.55 – 1.73	0.70 – 1.22	0.31
JPE (°) ***Rotation***	**Horizontal**	***HC***	2.70	2.70	0.85 – 6.06	1.68 – 3.53	1.26
		INP	2.92	2.86	0.71 – 5.93	1.86 – 3.90	1.36
		WAD	3.42	2.86	0.68 – 10.35	1.82 – 4.73	2.25
	Vertical	***HC***	1.67	1.55	0.60 – 3.59	1.19 – 2.04	0.75
		INP	1.82	1.60	0.78 – 5.12	1.08 – 2.11	1.02
		WAD	1.91	1.57	0.71 – 4.10	1.36 – 2.38	0.89
	Total	***HC***	3.46	3.25	1.56 – 7.26	2.30 – 4.34	1.44
		INP	3.81	3.62	1.46 – 7.89	2.90 – 4.61	1.47

		WAD	4.30	3.50	1.65 – 10.50	2.73 – 5.42	2.16
JPE (°) ***Flexion/Extension***	**Horizontal**	***HC***	1.06	1.03	0.32 – 1.90	0.82 – 1.25	0.36
		INP	1.28	1.17	0.39 – 2.84	0.92 – 1.56	0.55
		WAD	1.66	1.38	0.36 – 5.94	1.01 – 2.19	1.08
	Vertical	***HC***	2.64	2.52	0.97 – 6.21	2.07 – 2.97	1.05
		INP	3.05	2.63	1.45 – 6.28	2.31 – 3.53	1.19
		WAD	3.37	2.71	0.61 – 8.21	1.96 – 4.76	1.87
	Total	***HC***	3.04	2.94	1.50 – 6.37	2.57 – 3.42	0.99
		INP	3.50	3.01	1.76 – 6.67	2.74 – 3.89	1.20
		WAD	3.97	3.33	0.75 – 10.16	2.61 – 5.33	2.05

Abbreviations: SD: standard deviation; NA: Not applicable.

Table 3: Overview of statistical tests

			F-test		WAD - INP		WAD - HC		INP - HC	
			Group	***Age***	***Δ ± SE***	**t-value**	***Δ ± SE***	**t-value**	***Δ ± SE***	**t-value**
Sensorimotor control										
Force (N)	*Flexion*		19.21 (< 0.001)	5.79 (0.02)	- 22.47 ± 5.69 **	- 3.95	- 33.66 ± 6.18 **	- 5.45	- 11.19 ± 6.05	- 1.85
	Extension		18.47 (< 0.001)	1.62 (0.20)	- 43.12 ± 12.37 *	- 3.49	- 75.83 ± 13.43 **	- 5.64	- 32.71 ± 13.16 *	- 2.49
	Side Bending Left		24.45 (< 0.001)	2.54 (0.11)	- 31.39 ± 6.81 **	- 4.61	- 47.00 ± 7.40 **	- 6.35	- 15.61 ± 7.25	- 2.15
	Side Bending Right		19.36 (< 0.001)	1.81 (0.18)	- 35.47 ± 7.57 **	- 4.68	- 44.76 ± 8.23 **	- 5.44	- 9.29 ± 8.06	- 1.15
Mobility (°)	*Flexion*		17.68 (< 0.001)	4.74 (0.03)	- 6.51 ± 3.12	- 3.54	- 16.87 ± 3.18 **	- 5.31	- 10.36 ± 2.93 *	- 2.09
	Extension		15.68 (< 0.001)	8.02 (0.005)	- 12.48 ± 3.80 *	- 3.29	- 19.94 ± 4.12 **	- 4.84	- 7.45 ± 4.04	- 1.85
	Side Bending Left		6.84 (0.001)	9.98 (0.002)	- 3.60 ± 2.16	- 1.67	- 6.91 ± 2.34 *	- 2.95	- 3.60 ± 2.16	- 1.44
	Side Bending Right		7.95 (< 0.001)	12.92 (< 0.001)	- 3.17 ± 2.08 *	- 1.53	- 7.04 ± 2.25 *	- 3.12	- 3.87 ± 2.21 *	- 1.75
JPE (log; °)	*Flexion – Extension*	***Total***	1.88 (0.16)	2.13 (0.15)	0.05 ± 0.10	0.48	0.16 ± 0.10	1.50	0.11 ± 0.10	1.11
		Vertical	1.33 (0.27)	2.44 (0.12)	0.01 ± 0.11	0.09	0.12 ± 0.12	1.08	0.12 ± 0.11	1.05
		Horizontal	3.85 (0.02)	0.001 (0.97)	0.18 ± 0.11	1.30	0.33 ± 0.12 *	2.69	0.15 ± 0.12	1.30
	Rotation	***Total***	1.65 (0.20)	9.85 (0.002)	0.08 ± 0.10	0.78	0.12 ± 0.11	1.07	0.04 ± 0.10	0.37
		Vertical	0.63 (0.54)	1.61 (0.21)	0.07 ± 0.11	0.24	0.10 ± 0.12	0.80	0.03 ± 0.12	0.62
		Horizontal	0.67 (0.51)	7.66 (0.006)	0.08 ± 0.12	0.62	0.07 ± 0.14	0.51	-0.01 ± 0.13	- 0.07
Balance	*Sway Area* (cm^2)		10.43 (< 0.001)	3.79 (0.04)	0.77 ± 0.52	2.77	2.15 ± 0.53 **	4.08	1.39 ± 0.50 *	1.49
	Sway Velocity (cm/s)		3.21 (0.05)	6.06 (0.02)	0.05 ± 0.08	0.66	0.16 ± 0.09	1.92	0.11 ± 0.08	1.33
Neuromuscular Control	*CCFT*		10.97 (< 0.001)	0.10 (0.76)	- 1.07 ± 0.47	- 2.29	- 2.29 ± 0.51 **	- 4.52	-1.22 ± 0.50 *	- 2.46
	SHT		11.43 (< 0.001)	8.59 (0.004)	- 0.39 ± 0.39	- 1.01	- 1.60 ± 0.42 **	- 3.81	- 1.2 ± 0.40 *	- 2.99
Endurance (s)	*Head Lift Test*		7.34 (0.001)	0.41 (0.52)	-11.71 ± 4.11	- 2.58	- 16.43 ± 4.50 *	- 3.69	-4.73 ± 4.37 *	- 1.08
Questionnaires										
NDI			136.37 (< 0.001)	0.80 (0.37)	6.17 ± 1.24 **	4.99	20.22 ± 1.29 **	15.74	14.05 ± 1.31 **	10.73
TSK			9.41 (< 0.001)	0.21 (0.65)	- 0.16 ± 1.33	- 0.12	5.13 ± 1.43 *	3.58	5.29 ± 1.44 *	3.72
CSI			62.44 (< 0.001)	2.02 (0.16)	8.94 ± 2.45 *	3.65	27.81 ± 2.68 **	10.37	18.87 ± 2.6 **	7.26

For the F-test, the F-test statistic (p-value) is given. The estimated mean difference between groups (Δ) is given together with its Standard Error (SE) based on an ANCOVA-model with age as a covariate. Significant results are indicated with an asterisk and are marked in grey (for post-hoc comparison; *: $p < 0.05$; **: $p < 0.001$). For the F-test, the F-test statistic (p-value) is given.

Table 4: Correlation analysis

	NDI	Pain (VNRS)	TSK	CSI
Scapular holding test	**-0.42**	**-0.44**	-0.26	**-0.47**
	< 0.001	**< 0.001**	0.010	**< 0.001**
Craniocervical flexion test	**-0.38**	**-0.37**	-0.11	**-0.32**
	< 0.001	**< 0.001**	0.301	**0.001**
Endurance cervical flexors (s)	**-0.35**	**-0.28**	-0.12	**-0.30**
	< 0.001	**0.004**	0.231	**0.003**
Mobility right side bending (°)	**-0.42**	**-0.44**	-0.25	**-0.41**
	< 0.001	**< 0.001**	0.014	**< 0.001**
Mobility left side bending (°)	**-0.37**	**-0.38**	-0.18	**-0.35**
	< 0.001	**< 0.001**	0.075	**< 0.001**
Mobility flexion (°)	**-0.47**	**-0.47**	-0.21	**-0.41**
	< 0.001	**< 0.001**	0.034	**< 0.001**
Mobility extension (°)	**-0.49**	**-0.48**	**-0.30**	**-0.47**
	< 0.001	**< 0.001**	**0.003**	**< 0.001**
Force right side bending (N)	**-0.50**	**-0.41**	**-0.30**	**-0.46**
	< 0.001	**< 0.001**	**0.002**	**< 0.001**
Force left side bending (N)	**-0.59**	**-0.49**	**-0.37**	**-0.51**
	< 0.001	**< 0.001**	**< 0.001**	**< 0.001**
Force flexion (N)	**-0.53**	**-0.41**	**-0.30**	**-0.53**
	< 0.001	**< 0.001**	**0.002**	**< 0.001**
Force extension (N)	**-0.57**	**-0.47**	**-0.35**	**-0.51**
	< 0.001	**< 0.001**	**< 0.001**	**< 0.001**
Sway velocity (cm/s)	0.18	0.24	0.13	**0.32**
	0.122	0.030	0.248	**0.004**
Sway area (cm^2)	**0.38**	**0.35**	0.20	**0.42**
	0.001	**0.001**	0.068	**< 0.001**

Spearman-correlations (ρ) are accompanied by their p-values.

Appendix 1: Assessment-form for the scapular holding test.

Scapular Holding Test			Score	
CONTRACTION OF LOWER TRAPEZIUS	Unclear		0	
	Clear		1	
SUBSTITUTION*	Medial border		SEVERE MODERATE MILD NO	0 1 2 3
	Extension arm			
	Elevation			
	Retraction			
	Downward rotation			
	Anterior tipping			
MOVEMENT PATTERN†	Fluent	Concentric	YES / NO	0 1 2 3 4
		Eccentric	YES / NO	
	Over- or Undershooting		YES / NO	
	Substitution	Medial border	YES / NO	
		Extension arm		
		Elevation		
		Retraction		
		Downward rotation		
		Anterior tipping		
ENDURANCE (10 x 10 s)‡				
Total				/10

(*) The Score in substitution represents the amount of substitution.
(†) For each "YES" in fluency and each "NO" in Over-/undershooting and substitution a score of 1 is given.
(‡) For each 10 seconds-series a score of 0.2 is given.

Appendix 2: Assessment-form for the craniocervical flexion test.

Craniocervical Flexion test			Score	
CCFT (Jull et al. ,2008)*	Unable		0	
	22 mmHg		0	
	24 mmHg		1	
	26 mmHg		2	
	28 mmHg		3	
	30 mmHg		4	
MOVEMENT PATTERN†	Substitution	Scaleni	YES / NO	0 1 2 3 4
		SCM		
	Fluent respiration		YES / NO	
	Fluent	Concentric phase	YES / NO	
		Eccentric phase		
	Over- or Undershooting		YES / NO	
ENDURANCE (10 x 10 s)‡				
Total			/10	

(*) The score is calculated according to the protocol of Jull et al. (2008)
(†) For each "YES" in fluency and fluent respiration, and each "NO" in Over-/undershooting and substitution a score of 1 is given.
(‡) For each 10 seconds-series a score of 0.2 is given.