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Neck extensor muscle function in individuals with tension-type headache and healthy adults: a cross-sectional study.

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Manuscript title: Neck extensor muscle function in individuals with tension-type headache and healthy adults: a cross-sectional study.

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ABSTRACT

Objectives

To further the understanding of the pathophysiological mechanisms underlying tension-type headache by comparing the endurance and strength of neck extensor muscles under acute muscle fatigue in patients with tension-type headache and healthy adults.

Design

A cross sectional analysis of neck extensor muscles performance.

Setting

Healthy adults and adults with tension-type headache were recruited via social medias and from the *Université du Québec à Trois-Rivières* community and employees.

Participants

Eighty-four participants took part in an isometric neck extensor endurance task performed at 60% of their maximum voluntary contraction. Inclusion criteria for the headache group were to be older than 18 years old and to fulfill the International Headache Society classification's criteria for either frequent episodic or chronic tension-type headache. People presenting with fibromyalgia, recent cervical spine trauma, fracture, infection, surgery or malignant lesion, and the presence of upper limb pain, neurological deficits or spasmodic torticollis were excluded.

Outcome measures

Clinical (self-efficacy, anxiety, neck disability and kinesiophobia) and physical parameters (neck extensors maximum voluntary contraction, endurance time, muscle fatigue) as well as characteristics of headache episodes (intensity, frequency, adverse headache-related impact) were collected for all participants. Surface electromyography

was used to document sternocleidomastoids, upper trapezius and splenius capitis muscle activity and muscle fatigue.

Results

Both groups displayed similar neck extensor muscle endurance capacity with a mean difference of 6.2 seconds (p>0.05) in favor of the control group. However, participants in the headache group showed lower neck extensor muscle strength mainly explained by a 20% lower force production by the individuals with severe headache-related incapacity. Similarly, participants scoring as severely impacted were the ones with higher neck-related disability (F[1,44]=10.77; p=0.002), the more frequent headache episodes (F[1,44]=6.70; p=0.01), and higher maximum headache intensity (F[1,44]=10.81; p=0.002).

Conclusion

A fatigue task consisting of isometric neck extension cannot efficiently differentiate participants with tension-type headache from healthy controls.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- Data related to severity and frequency of headache episodes were retrospectively self-reported based on episodes from the previous month.
- Surface electromyography was used to ensure and quantify muscle fatigue.
- Participants were mostly students and employees of the University community and the results may not be generalizable to different work environments.
- Eighty-four participants were included based on rigorous diagnostic criteria.

BACKGROUND

Headache disorders are a common health issue, with more than 46 % of the adult population suffering from active headache[1]. Among all types, tension-type headache (TTH) is the most widespread type of headache worldwide with a global prevalence of 42%[2]. On average, TTH develops in individuals of 25-30 years of age, its prevalence peeks between 30 to 39 years and affects women slightly more than men, with a prevalence ratio of 5:4[3]. Risks factors to develop chronic tension type headache (CTTH) include analgesic medication overuse, depression, history of migraine and presence other pain syndromes[4]. TTH is characterized by a pressing and tightening pain, of non-pulsating quality and bilateral location of symptoms of mild to moderate intensity with no or little aggravation of pain during physical activity[5, 4]. According to the International Headache Society (IHS), TTH can be further divided into three subcategories based on the frequency of episodes. Infrequent episodic headaches are characterized as occurring one day or less per month, the frequent episodic form corresponds to headaches occurring between 1 to 14 days per month for at least 3 consecutive months (> 12 and < 180 days per year) and the chronic form consists of fifteen days or more with headache per month (> 180 days per year)[2, 3, 6].

Previous studies have shown that myofascial tissues are more sensitive in TTH patients than in healthy patients and that such tenderness is correlated with TTH episode intensity and frequency[7-9]. Moreover, a study reported that 88% of patients with neck pain had TTH and that there was a significant correlation between the number of days with TTH and the number of days with neck pain in a year[10]. Fernández-de-las-Peñas also showed that patients with CTTH had less neck mobility than healthy patients[11, 12]. Neck pain and TTH seem to share similar underlying pathophysiological mechanisms. For instance, forward head posture has been related to both headache and neck pain. In fact, excessive forward head position seems to be associated to cervicogenic headache but also to CTTH[13]. Similarly, both conditions have been associated with shortening of neck extensors muscles[14, 13] and declined endurance and strength of the deep cervical flexors when progressing to the chronic form[15, 16].

Current evidence suggests that increased neck flexor isometric strength helps increase pressure pain threshold tolerance in CTTH[17]. Furthermore, interventions aimed at the cervical region including massage, cervical strengthening, postural techniques, cervical mobilization, progressive stretching or cervical relaxation exercises, have shown to help reduce pain frequency, intensity and duration of headaches[18]. On the other hand, the role cervical extensor muscles play in the pathophysiological mechanism of TTH remains poorly studied, and the hypothesis that there is a relation between endurance and strength of these muscles and intensity and frequency of the TTH has not been explored thoroughly. To the best of our knowledge, no study has investigated neck extensor muscle endurance in patients with TTH using electromyography fatigue parameters.

This study aimed to compare endurance and strength of neck extensor muscles under acute muscle fatigue in patients with TTH and healthy adults. In addition, physical outcomes collected from TTH participants were compared according to levels of adverse headache-related impact. It was hypothesized that, participants with TTH would have significantly lower neck extensor muscles endurance compared to controls and that higher levels of adverse headache impact would be associated to lower physical outcomes. Finally, potential correlations between physical parameters related to the endurance task and the clinical parameters were explored.

METHODS

Design

We conducted a cross-sectional study taking place at the Laboratory of Neuromechanics at l'Université du Québec à Trois-Rivières. Recruitment and testing of participants went from August 2016 to July 2017.

Participants' selection

A cross-sectional study was conducted for which eighty-four participants were conveniently recruited via social medias and from the university community and employees. Inclusion criteria for the headache group was to fulfill the International Headache Society (HIS) classification's criteria for either frequent episodic or chronic tension-type headache based on an estimated number of days with headaches each participants had over the last year (see table 1 for detailed classification criteria). Concomitance of neck pain and other types of headaches was allowed in the headache group as long as pain unrelated to tension-type headaches was not the dominant one. If participants fulfilled the IHS classification criteria for tension-type headache but experienced only 12 episodes a year or less (classified as infrequent episodic TTH), they were allocated to the control group. Similarly, people not suffering from headache but still interested in participating to the research project were allocated to the control group if in addition they had no neck pain or had had less than 3 consecutive days of incapacitating neck pain over the last year.

Exclusion criteria included being under a course of treatment for headache or neck pain, having been diagnosed with fibromyalgia, having a recent history of cervical spine severe trauma, fracture, infection, surgery or malignant lesion, and the presence of upper limb pain, neurological deficits or spasmodic torticollis. Pregnant women were excluded because of the prone position adopted during the experiment. This study has been approved by the ethic committee of human subjects of the Université du Québec à Trois-Rivières (CER-16-225-07.15). All participants provided informed written consent prior to their entry in this study.

Table 1. International Headache Association Classification criteria's for frequent episodic and chronic tension-type headache.

Frequent episodic tension-type headache	Chronic tension-type headache
A. At least 10 episodes of headache occurring on 1-14 days per month on average for >3 months (≥12 and <180 days per year) and fulfilling criteria B-D	**A**. Headache occurring on ≥15 days per month on average for >3 months (≥180 days per year) and fulfilling criteria B-D
B. Lasting from 30 min to 7 days	**B**. Lasting hours to days, or unremitting
C. At least two of the following four characteristics: 1. bilateral location 2. pressing or tightening (non-pulsating) quality 3. mild or moderate intensity 4. not aggravated by routine physical activity such as walking or climbing stairs	
D. Both of the following: 1. no nausea or vomiting 2. no more than one of photophobia or phonophobia	**D**. Both of the following: 1. no more than one of photophobia, phonophobia or mild nausea 2. neither moderate or severe nausea nor vomiting

Clinical data collection

The experimental session began with a history taking to obtain demographic data, information regarding typical episodes of headache and neck pain as well as the completion of validated questionnaires. Mean and maximum pain intensity over the last month for headache and neck pain was assessed using a visual analog scale (VAS). Disability was assessed using the 6-item Headache impact test (HIT-6) questionnaire for headaches[19] and the Neck Disability Index (NDI) for neck pain[20]. Kinesiophobia (Tampa Scale of Kinesiophobia), anxiety (state-trait anxiety inventory (STAI-Y))[21] and self-efficacy[22] were documented as potential factors that could explain the differences found between groups if any.

Electromyography data collection

Surface electromyography (EMG) data were collected bilaterally using bipolar surface electrodes applied over the midsection of the sternocleidomastoids, upper trapezius and splenius capitis muscles (at the vertebral level of C4) and parallel to the fibers orientation, as described by Criswell and Cram[23]. A ground electrode was placed over the left acromion. To avoid inter-rater variability, anatomical structures palpation and placement of electrodes were assessed by the same investigator for all participants. Skin impedance was reduced by shaving body hair, gently abrading the skin with fine-grade sandpaper (Red Dot Trace Prep, 3M, St. Paul, MN, USA), and wiping the skin with alcohol swabs.

EMG activity was recorded using a single differential Delsys Surface EMG sensor with a common mode rejection ratio of 92 dB at 60 Hz, a noise level of 1.2 µV, a gain of 10 V/V ± 1%, an input impedance of 10^{15} Ω, a bandwidth of 20–450 ± 10% (Model DE2.1, Delsys Inc., Boston, MA, USA) and sampled at 2048 Hz with a 12-bit A/D converter (PCI 6024E, National Instruments, Austin, TX, USA). The EMG data were filtered digitally by a 10- to 450-Hz bandpass, zero-lag, and fifth-order Butterworth filter. Data were collected using the OT Bioelettronica custom software (OT Bioelettronica; Torino, Italy) and processed using Matlab (R2007b MathWorks, Natick, MA, USA).

Following skin preparation and electrodes placement participants were asked to lay prone with the head and neck past the edge of the table. The cervico-thoracic junction was stabilized to ensure minimal recruitment of scapular and thoracic muscles throughout the task. The strap length was then adjusted over the protuberantia occipitalis with the participant's head in a neutral horizontal position as depicted in figure 1. One maximum voluntary contraction (MVC) trial was performed to allow participants to get familiar with the isometric extension contraction required during the endurance task and a further two trials were conducted afterwards. Participants were asked to slowly build up the force to maximal strength within two seconds, and then exert maximal pressure for about three seconds and thereafter slowly relax. Participants were verbally encouraged to perform maximally. From the greater of the 2 contractions, the target force (and visual feedback) for the endurance task was set at 60 per cent of the MVC deployed. The feedback was displayed on a computer screen placed on the floor and for ease of identification the 1 bar graph became green when the target was reached or stayed red if under the target and became blue if over the 60 per cent mark. Participants were instructed to maintain the neck extension for as long as possible and were verbally encouraged throughout the task. The test was stopped when participants felt no longer able to maintain the position or if we considered that they were unable to stabilize the positioning at the 60% mark because of fatigue. Within seconds of the end of the endurance task participants were asked to score their perceived level of effort using a Borg's scale[24] and to perform one last maximum voluntary contraction. The development of any post-experimental headache was documented and its intensity recorded using a numerical rating scale.

[Insert figure 1. about here]

Figure 1. Isometric neck extensor muscles endurance test performed in the prone position with visual feedback.

Data and statistical analyses

Muscle fatigue was assessed using the pre- and post-experiment (fatigue task) assessment differences in maximum voluntary contraction. In addition, the root mean square (RMS) mean slope and the median frequency (MDF) mean slope were calculated from adjacent non-overlapping EMG signal epochs of 0.5s for each muscle throughout the task.

As data were all normally distributed, differences between groups, for all variables were assessed using T-tests for independent samples. Physical outcomes of participants with

TTH were compared based on their level of adverse headache-related impact using one-way ANOVAs. Correlations between physical (endurance time and MVC before the task) and clinical parameters (kinesiophobia, anxiety, self-efficacy, and pain frequency and intensity) were evaluated using Pearson's correlation coefficient. Analyses were performed using STATISTICA statistical package version 10 (Statsoft, Tulsa, OK), and the level of significance was set at $P < .05$.

RESULTS

Baseline demographics

T-tests for independent samples confirmed that both groups were similar for age, height, weight and scores for the fear of movement, and self-efficacy questionnaires. Only the anxiety level differed between the groups with the participants with TTH ranking at low and the control group at minimal anxiety (P=0.03). The headache group included 44 female participants and the control group 40. Outcomes related to headache and neck pain differed between the two groups. Participants in the headache group had higher disability related to the presence of both headaches and neck pain, with the headache impact-test questionnaire (mean±SD= 54.6±8.5) scoring at some impact on daily life functioning and the Neck Disability Index (mean±SD= 7.1±4.4) at mild disability. Similarly, headache intensity and frequency were higher in the headache group with a mean intensity of 4.6 on the VAS, which is considered moderate, and a mean frequency of 8 episodes per month. Neck pain was also reported more frequently and of greater intensity in the headache group and although neck pain episodes were reported almost as frequently as headaches the intensity was rated lower than headache episodes with a mean score of 3.1 out of 10, which is considered mild [25]. Greater headache (r= -0.29; p=0.006) or neck-related disability (r=-0.24; p=0.03), anxiety (r= -0.28; p=0.01) and higher maximum headache pain intensity (r=-0.27; p=0.01) were negatively correlated to the maximum voluntary contraction prior to the endurance task.

Endurance task

Values for MCVs both prior and after the neck extensor muscles endurance task were significantly lower in participants with TTH than in the control group (p=0.04 and p=0.01 respectively). Fatigue occurred in all muscles with EMG data analysis showing a positive RMS slope, confirming the recruitment of additional motor units as the task went on (values ranging from 1109.8 up to 6245.9 Hz/s, p>0.05). Fatigue was also confirmed in both groups by a mean negative median frequency slope found for all muscles (values ranging from -0.11 up to -0.30 Hz/sec, p>0.05). The mean scores for the perceived amount of effort put into the task were slightly above 15 in both groups (p>0.05). Finally, a 7% decrease in MVC was observed after the endurance task in the control group compared to 9% in the TTH group (p>0.05) whereas the mean time for the endurance task was similar in both groups (mean difference= 6.2 seconds, p>0.05). Results for all clinical and physical parameters are presented in table 2.

Table 2. Participants' results for clinical and physical parameters evaluated.

	Variables	Control group (n=40) Mean±SD	Headache group (n=44) Mean±SD	*P*
Demographics	Age (years)	29.8±10.9	27.6±10.3	0.34
	F : M	19 : 21	32 : 12	-
	Years w/ headache	0.8±3.9	10.7±8.7	<0.001*
	Weight (kg)	72.3±15.5	67.4±11.5	0.10
	Height (m)	1.7±0.1	1.6±0.1	0.08
	IMC (kg/m^2)	24.5±4.0	24.1±3.9	0.64
	Kinesiophobia (17-68)	26.8±6.1	28.5±6.2	0.20
	Self-efficacy (10-40)	35.8±.3.9	34.7±3.6	0.18
	Anxiety (20-80)	33.1±10.6	38.0±10.2	0.03*
Headache	Frequency (per month)	0.5±1.0	8.0±7.8	<0.001*
	Mean intensity (/10)	1.9±1.8	4.6±1.2	<0.001*
	Maximum intensity (/10)	3.3±2.6	7.1±1.7	<0.001*
	HIT-6 (36-78)	42.6±5.6	54.6±8.5	<0.001*
Neck pain	Frequency (per month)	2.7±6.3	7.2±9.2	0.01*
	Mean intensity (/10)	1.6±1.4	3.1±1.7	<0.001*
	Maximum intensity (/10)	2.6±2.3	4.6±2.3	<0.001*
	NDI (/50)	2.0±2.7	7.1±4.4	<0.001*
Endurance task	MVC before (N)	111.3±38.7	95.9±30.4	0.04*
	MVC after (N)	104.0±33.9	87.7±24.8	0.01*
	Endurance time (sec)	68.1±32.3	61.9±20.1	0.30
	Perceived effort (6-20)	15.0±1.7	15.2±1.7	0.68

F= female; M= male; IMC= body mass index; HIT-6= headache impact test; NDI= neck disability index; MVC= maximum voluntary contraction. *= statistically significant difference

Performance of headache participants

Participants with TTH were divided into levels of adverse headache impact based on their score obtained on the HIT-6 questionnaire (minimum possible score is 36 and maximum possible score is 78). Categories are as followed; level 1) little to no impact with score= ≤49; level 2) some impact with score= 50-55; level 3) substantial impact with score= 56-59; and level 4) severe impact with score= ≥60.

Comparing results of physical outcomes across levels of headache adverse impact showed that individuals categorized into levels 1 to 3 behaved differently than those into the level 4. Results of clinical and physical parameters that differed based on levels of adverse headache-related impact are presented in Table3. Indeed, participants in the headache group had significantly lower pre-endurance MVC compared to the control group but that was mainly explained by the individuals with severe headache-related incapacity (mean±SD=80.1N±19.4) who produced a mean MVC 20.0% lower than the individuals in the other 3 categories (mean±SD= 100.1N±32.3). Similarly, participants scoring as severely impacted on the HIT-6 questionnaire were the ones with the smallest decrease in MVC after the endurance task ($F[1,44]=9.40$; $p=0.004$), the higher neck-related disability ($F[1,44]=10.77$; $p=0.002$), the more frequent headache episodes ($F[1,44]=6.70$; $p=0.01$), and the higher maximum headache intensity ($F[1,44]=10.81$; $p=0.002$). Figure 2 shows the main results based on headache-related impact categories.

Table 3. Results of physical and clinical parameters that differ between levels of headache-related impact as measured by the HIT-6 questionnaire.

Variables	Little to no impact N=12	Some impact N=12	Substantial impact N=11	Severe impact N=9
Prior MVC (N)	101.3 ± 29.6	94.5 ± 30.4	104.6 ± 36.9	80.1 ± 19.4
Decrease in MVC (%)	-11.9 ± 7.9	-6.5 ± 5.9	-5.6 ± 7.9	-1.0 ± 8.2
NDI (/50)	4.4 ± 2.4	7.4 ± 3.9	6.9 ± 3.3	10.6 ± 6.0
Headache frequency (n/ per month)	4.9 ± 6.7	5.8 ± 4.3	9.8 ± 9.1	12.5 ± 9.3
Max headache intensity (/10)	6.5 ± 2.3	6.5 ± 1.4	7.2 ± 1.1	8.6 ± 0.8

MVC= maximum voluntary contraction; NDI= neck disability index.

[Insert Figure 2. About here]

Figure 2. Clinical and physical parameters broke-down by levels of adverse headache-related impact as measured by the HIT-6 questionnaire. A) Maximum intensity of headache episodes; B) Frequency of headache episodes; C) Decrease in MVC after the endurance task; D) Neck-related incapacity.

DISCUSSION

Endurance task

The purpose of this study was to compare endurance of neck extensor muscles under acute muscle fatigue in patients with TTH and healthy adults. The results showed that participants with TTH had similar endurance (length of task) and muscle fatigue (EMG parameters) compared to healthy participants.

The current research protocol was based on the premise that TTH and neck pain are, from a physiological and clinical standpoint, intricately linked. The development of chronic neck pain (CNP) has been previously associated with changes in neck muscle endurance with studies reporting lower cervical muscle endurance in patients with CNP compared with asymptomatic subjects[26]. Although neck extensors endurance have been scarcely studied, compared to neck flexors, recent evidence suggests a decreased resistance to fatigue ranging from 21% to 76% in neck pain patients compared to controls[27-29].

The lack of difference between groups regarding the endurance test could be explained by the fact that participant with TTH produced lower MVC than controls during the baseline evaluation. Lower neck extensor strength, in such experimental conditions, can be due to higher levels of fear of movement, lower amount of effort put into the task, or development of pain during the task. Nonetheless, kinesiophobia scores were similar and low (score < 37 are considered low) in both groups and Borg's perceived exertion scores were slightly above 15 in both groups, which corresponds to a "hard" level of effort[24]. Finally, among those who reported headache after the endurance test, the mean change in pain intensity from baseline was low (control group N=3; mean change in pain intensity= 1.6±0.6; TTH group N=13; mean change in pain intensity= 1.3±2.1; p=0.77). More studies are needed to identify the determinants of the lower neck extensor muscle strength in TTH individuals.

A recent study by Kahlaee et al. reported that the multifidus and semispinalis cervicis muscles, considered deep neck extensor muscles, had lower force production capacity and smaller cross-sectional area in chronic neck pain patients than in control participants. Furthermore, muscle thickness was negatively correlated with levels of pain and disability[29]. A difference in force production between the neck flexor and extensor muscles has also been considered a potential contributing factor of chronic neck and CTTH development. As such, Madsen et al. reported a 12% decrease in neck extension/flexion strength ratio in the TTH population[30] and a 26% difference in extension strength between TTH and healthy subject[31]. In addition, it has been reported that in the presence of chronic pain, adipose tissue takes place of active muscular filaments, thus affecting muscular tension capabilities and ultimately strength[32]. Similarly, previous studies have shown that the dysfunction in neck extensor muscles force production, displayed by individuals with neck pain, translates into muscle fiber type changes[33], especially with an increased number of intermediate fibers type (type IIC) which alters the muscle function [34]. For instance, forward head posture is commonly observed in patients with neck pain and such posture is believed to put a greater load on the neck extensors to compensate for neck flexors weaknesses[13]. As type II fibers are associated to power and strength and that forward head posture induces a greater load on the neck extensors, it seems that type II fibers are modified towards type I fibers to maintain head posture[35]. Similar to neck pain patients, patients with TTH seem to have reduced neck extensors muscular activity. Altogether, these findings support the theory that inhibition type alterations occur in the deep neck muscles in the presence of CNP and tension-type headache patients[36].

Of interest, none of the parameters related to the fatigue task (endurance time and muscle fatigability) were correlated to the participants symptomatology.

Performance of participants with headache

Another aim of this study was to compare the results of the TTH participants based on the 4 levels of adverse headache-related impact (from the Headache Impact Test-6). Among headache sufferers, those with "high adverse headache-related impact" produced less maximum neck extensor force and lost minimal strength during the fatigue task than those in the "little to no impact" to the "substantial adverse headache-related impact" categories. In addition, participants scoring at high levels of adverse headache-related impact had greater neck-related disability, reported greater pain severity and suffered from headache more frequently than their counterparts. Overall, participants in the lower three categories of adverse headache-related impact did not behave differently than the control group. These findings suggest that patients with severe headache incapacity display physiological changes that may be mediated by associated psychological factors that were not captured in the present study or that may be triggered as the condition progresses to a more chronic stage.

Limitations

This study is not without limitations. Data related to severity and frequency of headache episodes were self-reported based on episodes from the previous month, which may be subject to recollection bias. A prospective data collection would have allowed for a more precise estimate of these clinical variables.

CONCLUSION

The results from the present study indicate that a fatigue task consisting of isometric neck extension cannot efficiently differentiate participants with TTH from healthy controls. In addition, parameters related to neck extensor muscles fatigability are not correlated with the severity of headache symptoms. However, neck extensor strength appears to be lower in individuals with TTH, and this may simplify the identification and assessment of physiological changes occurring over time in these patients. Furthermore, force production may only be associated with symptomatology of patients that are categorized with high level of headache-related incapacity. Future studies should further investigate the relationship between levels of headache-related disability and physiological changes.

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Author Contributions: Research area and study design: AAM and MD; data acquisition: AAM, MH, MPG, MEH; data analysis and interpretation: AAM, MH and MD; statistical analysis: AAM and MD, supervision and mentorship: MD. Manuscript writing: AAM, MH, MEH, MPG. MD takes responsibility that this study was been reported, transparently and honestly.

Competing interests: None to declare.

Ethics approval: This study has been approved by the ethic committee of human subjects of the Université du Québec à Trois-Rivières (CER-16-225-07.15).

Data sharing statement: No additional data are available.

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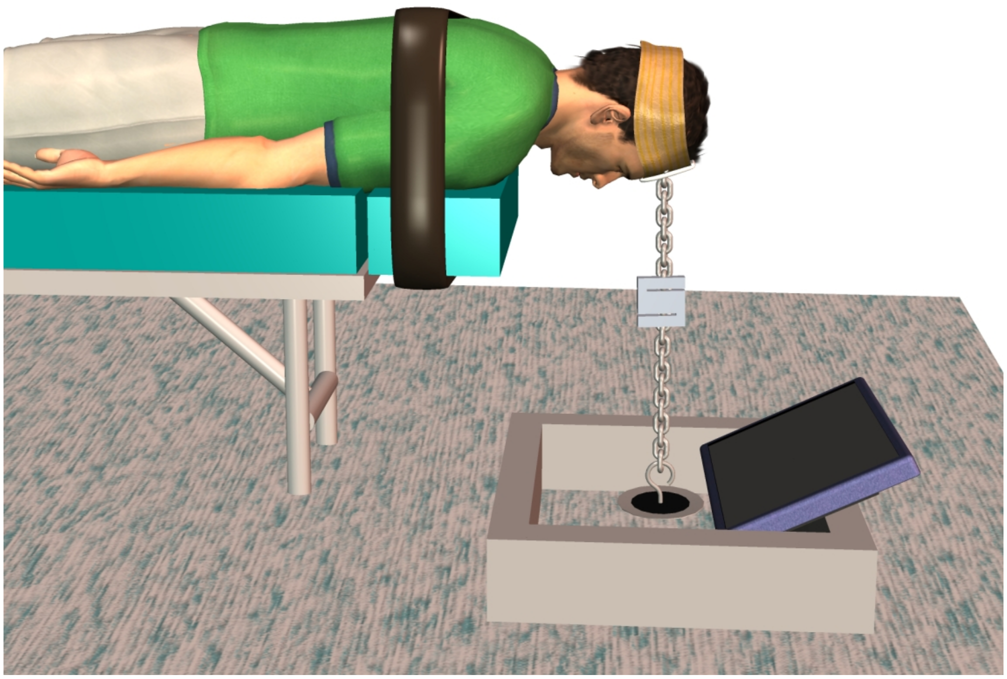
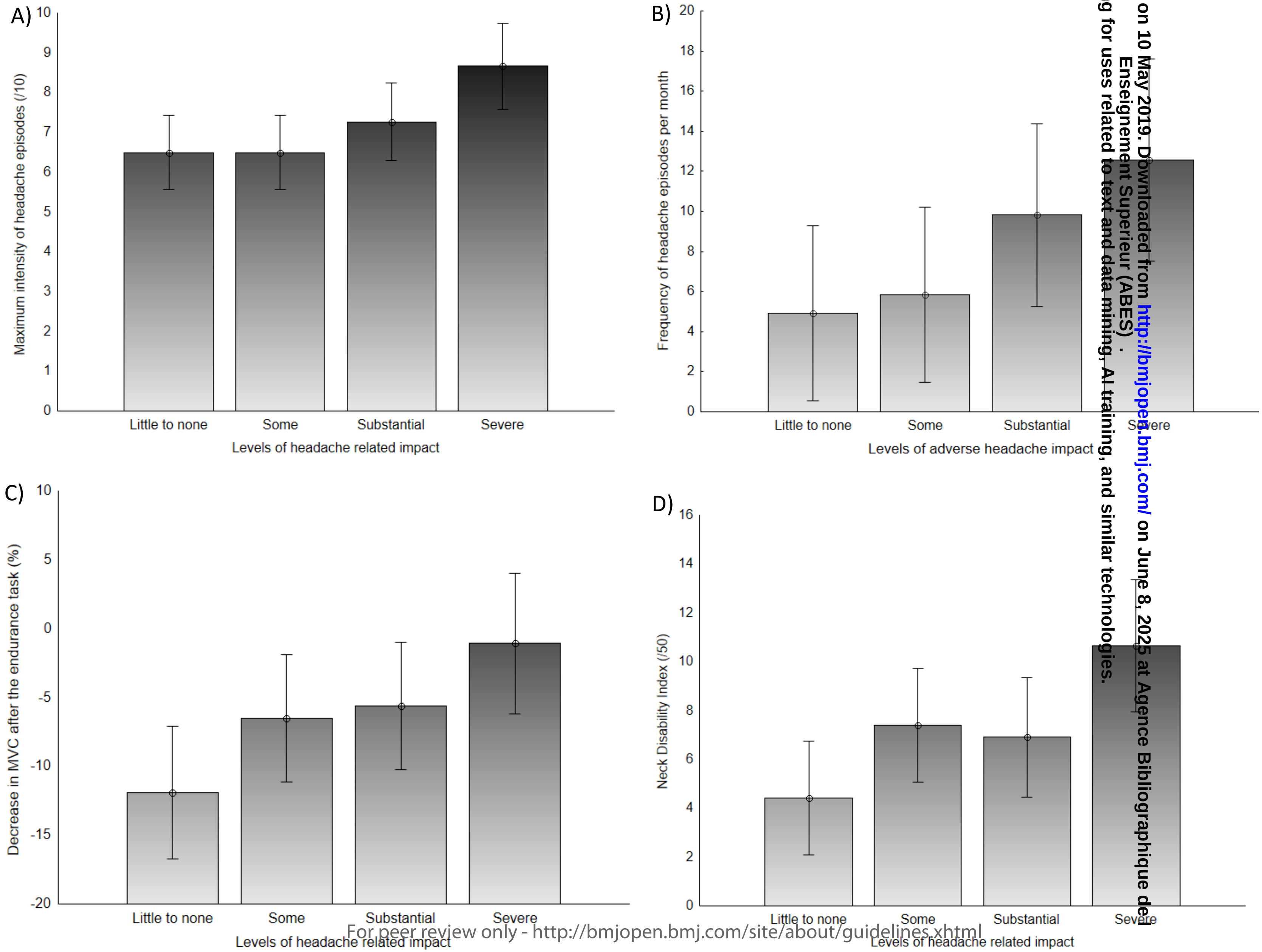


Figure 1. Isometric neck extensor muscles endurance test performed in the prone position with visual feedback.

228x228mm (200 x 200 DPI)


A)
Maximum intensity of headache episodes (/10)
Little to none
Some
Substantial
Severe
Levels of headache related impact
B)
Frequency of headache episodes per month
Little to none
Some
Substantial
Severe
Levels of adverse headache impact
C)
Decrease in MVC after the endurance task (%)
Little to none
Some
Substantial
Severe
Levels of headache related impact
D)
Neck Disability Index (/50)
Little to none
Some
Substantial
Severe
Levels of headache related impact

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	p 1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	p. 1-2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	pp. 3,4,5
Objectives	3	State specific objectives, including any prespecified hypotheses	p. 5
Methods			
Study design	4	Present key elements of study design early in the paper	p 6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	p6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	pp. 6-7
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	pp. 7-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	N/A.
Bias	9	Describe any efforts to address potential sources of bias	p8
Study size	10	Explain how the study size was arrived at	N/A.
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	N/A
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	p.11
		(*b*) Describe any methods used to examine subgroups and interactions	
		(*c*) Explain how missing data were addressed	
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	P.P. 11-12
		(b) Give reasons for non-participation at each stage	N/A
		(c) Consider use of a flow diagram	N/A
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	pp 11-12
		(b) Indicate number of participants with missing data for each variable of interest	
Outcome data	15*	Report numbers of outcome events or summary measures	
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	pp. 13-14
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	pp 13-14

Discussion			
Key results	18	Summarise key results with reference to study objectives	p.15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	p.19
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	pp.17–19
Generalisability	21	Discuss the generalisability (external validity) of the study results	
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	p. 20.

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Neck extensor muscle function does not differ between individuals with tension-type headache and asymptomatic individuals: a Canadian cross-sectional study.

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Neck extensor muscle function does not differ between individuals with tension-type headache and asymptomatic individuals: a Canadian cross-sectional study.

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ABSTRACT

Aim

To further the understanding of the pathophysiological mechanisms underlying tension-type headache (TTH) by comparing the endurance and strength of neck extensor muscles under acute muscle fatigue in participants with TTH and asymptomatic participants.

Methods

We conducted a cross sectional analysis of neck extensor muscle performance. Asymptomatic participants and participants with TTH were recruited via social media platforms and from the Université du Québec à Trois-Rivières community and employees. A total of forty-four participants with TTH and forty asymptomatic participants took part in an isometric neck extensor endurance task performed at 60% of their maximum voluntary contraction. Inclusion criteria for the headache group were to be older than 18 years old and to fulfill the International Headache Society classification's criteria for either frequent episodic or chronic tension-type headache. Clinical (self-efficacy, anxiety, neck disability and kinesiophobia) and physical parameters (neck extensors maximum voluntary contraction, endurance time, muscle fatigue) as well as characteristics of headache episodes (intensity, frequency, and adverse headache-related impact) were collected for all participants. Surface electromyography was used to document sternocleidomastoids, upper trapezius and splenius capitis muscle activity and muscle fatigue.

Results

Both groups displayed similar neck extensor muscle endurance capacity with a mean difference of 6.2 seconds ($p>0.05$) in favor of the control group (control=68.1±32.3;

TTH=61.9±20.1). However, participants in the headache group showed lower neck extensor muscle strength mainly explained by a 20% lower force production by the individuals with severe headache-related incapacity (controls=111.3±38.7N; TTH=95.9±30.4N). Similarly, among participants with TTH, those scoring as severely impacted by headaches were the ones with higher neck-related disability (F[1,44]=10.77; p=0.002), the more frequent headache episodes (F[1,44]=6.70; p=0.01), and higher maximum headache intensity (F[1,44]=10.81; p=0.002).

Conclusion

A fatigue task consisting of isometric neck extension cannot efficiently differentiate participants with TTH from asymptomatic participants.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- Data related to severity and frequency of headache episodes were retrospectively self-reported based on episodes from the previous month.
- Surface electromyography was used to ensure and quantify muscle fatigue.
- Participants were mostly students and employees of the University community and the results may not be generalizable to different work environments.
- Eighty-four participants were included based on rigorous diagnostic criteria.

BACKGROUND

Headache disorders are a common health issue, with more than 46 % of the adult population suffering from active headache[1]. Among all types, tension-type headache (TTH) is the most widespread type of headache worldwide with a global prevalence of

42%[2]. On average, TTH develops in individuals of 25-30 years of age, its prevalence peeks between 30 to 39 years and affects women slightly more than men, with a prevalence ratio of 5:4[3]. Risks factors to develop chronic tension type headache (CTTH) include analgesic medication overuse, depression, history of migraine and presence of other pain syndromes[4]. TTH is characterized by a pressing and tightening pain, of non-pulsating quality and bilateral location of symptoms of mild to moderate intensity with no or little aggravation of pain during physical activity[5]. According to the International Headache Society (IHS), TTH can be further divided into three subcategories based on the frequency of episodes. Infrequent episodic headaches are characterized as occurring one day or less per month, the frequent episodic form corresponds to headaches occurring between 1 to 14 days per month for at least 3 consecutive months (> 12 and < 180 days per year) and the chronic form consists of fifteen days or more with headache per month (> 180 days per year)[2, 3, 5].

Previous studies have shown that myofascial tissues are more sensitive in TTH patients than in healthy patients and that such tenderness is correlated with TTH episode intensity and frequency[6-8]. Similarly, nociceptive hypersensitivity has been reported at both cephalic and extracephalic locations in patients with CTTH [9]. The clinical phenomenon of spread and pain referral for which pain is perceived as originating from a distant receptive field rather than the affected tissue, is common in primary headaches [10]. A mechanism that could explain this finding is the combination of convergence of trigeminal and cervical afferents on to neurons in the trigeminocervical complex of the brain stem, sensitization of supraspinal neurons and decreased antinociceptive activity from supraspinal structures [11, 10]. In line with this concept, a study reported that of patients with neck pain 88% had concomitant TTH and that there was a significant correlation between the number of days with TTH and the number of days with neck pain in a year[12].

Current evidence regarding musculoskeletal physical outcomes in TTH such as neck mobility and muscle strength is mixed. As such, Fernández-de-las-Peñas showed that patients with ETTH or CTTH have less neck mobility than controls [13-15] while other authors reported no difference in global cervical ranges of motion between these two groups [16, 17, 14]. Similarly, TTH have been associated with shortening in muscle length [18, 19] and declined strength of the extensor muscles when progressing to the chronic form [20, 21] while no difference between TTH and healthy participants has also been found [16]. On the other hand, evidence both in favor [20] and against [16, 21] a decrease in flexion strength has been reported. Lastly, limited evidence is available regarding neck muscle endurance with one study reporting less neck flexor endurance in TTH compared to controls [22].

Current evidence suggests that increased neck flexor isometric strength helps increase pressure pain threshold tolerance in CTTH[23]. Furthermore, interventions aimed at the cervical region including massage, cervical strengthening, postural techniques, cervical mobilization, progressive stretching or cervical relaxation exercises, have shown to help reduce pain frequency, intensity and duration of headaches[24]. On the other hand, the role cervical extensor muscles play in the pathophysiological mechanism of TTH remains unclear, and the hypothesis that there is a relation between endurance and strength of these muscles and intensity and frequency of the TTH has not been explored thoroughly. To the best of our knowledge, no study has investigated neck extensor muscle endurance in patients with TTH using electromyography fatigue parameters.

This study aimed to compare endurance and strength of neck extensor muscles under acute muscle fatigue in participants with TTH and asymptomatic participants. In addition, data collected from TTH participants regarding neck extensor muscle strength and endurance were compared according to levels of adverse headache-related impact. It was hypothesized that, participants with TTH would have similar neck extensor strength and significantly lower neck extensor muscle endurance compared to controls and that higher levels of adverse headache impact would be associated to lower muscle strength and endurance. Finally, potential correlations between physical variables related to the endurance task (muscle strength, endurance and muscular activity) and the clinical variables (anxiety, kinesiophobia, self-efficacy, neck disability, levels of adverse headache-related impact, neck pain and headache pain intensity) were explored.

METHODS

Design

The study was conducted at the Laboratory of Neuromechanics at the Université du Québec à Trois-Rivières (Canada). Recruitment and testing of participants went from August 2016 to July 2017.

Patient and Public Involvement

No patients or public members were involved in the research development process or the conduct of this study.

Participants' selection

A cross-sectional study was conducted for which eighty-four participants were conveniently recruited via social media platforms and from the university community and employees. Inclusion criteria for the headache group was to fulfill the International Headache Society (HIS) classification's criteria for either frequent episodic or chronic tension-type headache based on an estimated number of days with headaches each participant had over the last year (see table 1 for detailed classification criteria). Concomitance of neck pain and other types of headaches was allowed in the headache group as long as pain unrelated to tension-type headaches was not the dominant one. If participants fulfilled the IHS classification criteria for tension-type headache but experienced only 12 episodes a year or less (classified as infrequent episodic TTH), they were allocated to the control group. Similarly, people not suffering from headache but still interested in participating to the research project were allocated to the control group if in addition they had no neck pain or had had less than 3 consecutive days of incapacitating neck pain over the last year.

Exclusion criteria included being under a course of treatment for headache or neck pain, having been diagnosed with fibromyalgia, having a recent history of cervical spine severe trauma, fracture, whiplash, medication overuse, infection, surgery or malignant lesion, and the presence of upper limb pain, neurological deficits or spasmodic torticollis. Pregnant women were excluded because of the prone position adopted during the experiment. This study was approved by the ethic committee of human subjects of the Université du Québec à Trois-Rivières (CER-16-225-07.15). All participants provided informed written consent prior to their entry in the study.

Table 1. International Headache Association Classification criteria's for frequent episodic and chronic tension-type headache.

Frequent episodic tension-type headache	Chronic tension-type headache
A. At least 10 episodes of headache occurring on 1-14 days per month on average for >3 months (≥12 and <180 days per year) and fulfilling criteria B-D	**A**. Headache occurring on ≥15 days per month on average for >3 months (≥180 days per year) and fulfilling criteria B-D
B. Lasting from 30 min to 7 days	**B**. Lasting hours to days, or unremitting
C. At least two of the following four characteristics: 1. bilateral location 2. pressing or tightening (non-pulsating) quality 3. mild or moderate intensity 4. not aggravated by routine physical activity such as walking or climbing stairs	
D. Both of the following: 1. no nausea or vomiting 2. no more than one of photophobia or phonophobia	**D**. Both of the following: 1. no more than one of photophobia, phonophobia or mild nausea 2. neither moderate or severe nausea nor vomiting

Data collection

Clinical outcome measures

The experimental session began with a history taking to obtain demographic data, information regarding typical episodes of headache and neck pain as well as the completion of validated questionnaires. Mean and maximum pain intensity over the last month for headache and neck pain was assessed using a visual analog scale (VAS). Disability was assessed using the 6-item Headache impact test (HIT-6) questionnaire for headaches[25] and the Neck Disability Index (NDI) for neck pain[26]. Kinesiophobia (Tampa Scale of Kinesiophobia), anxiety (state-trait anxiety inventory (STAI-Y))[27] and self-efficacy[28] were documented as potential factors that could explain the differences found between groups if any.

Physical outcome measures

Surface electromyography (muscle activity)

Surface electromyography (EMG) data were collected bilaterally using bipolar surface electrodes applied over the midsection of the sternocleidomastoids, upper trapezius and splenius capitis muscles (at the vertebral level of C4) and parallel to the fibers orientation, as described by Criswell and Cram[29]. A ground electrode was placed over the left acromion. To avoid inter-rater variability, anatomical structures palpation and placement of electrodes were assessed by the same investigator for all participants. Skin impedance was reduced by shaving body hair, gently abrading the skin with fine-grade sandpaper (Red Dot Trace Prep, 3M, St. Paul, MN, USA), and wiping the skin with alcohol swabs.

EMG activity was recorded using a single differential Delsys Surface EMG sensor with a common mode rejection ratio of 92 dB at 60 Hz, a noise level of 1.2 µV, a gain of 10 V/V ± 1%, an input impedance of 10^{15} Ω, a bandwidth of 20–450 ± 10% (Model DE2.1, Delsys Inc., Boston, MA, USA) and sampled at 2048 Hz with a 12-bit A/D converter (PCI 6024E, National Instruments, Austin, TX, USA). The EMG data were filtered digitally by a 10- to 450-Hz bandpass, zero-lag, and fifth-order Butterworth filter. Data were collected using the OT Bioelettronica custom software (OT Bioelettronica; Torino, Italy) and processed using Matlab (R2007b MathWorks, Natick, MA, USA).

Neck extensor muscle maximum voluntary contraction

Following skin preparation and electrodes placement participants were asked to lay prone with the head and neck past the edge of the table. The cervico-thoracic junction was stabilized to ensure minimal recruitment of scapular and thoracic muscles throughout the task. The strap length was then adjusted over the protuberantia occipitalis with the participant's head in a neutral horizontal position as depicted in figure 1. One maximum voluntary contraction (MVC) trial was performed to allow participants to get familiar with the isometric extension contraction required during the endurance task and a further two trials were conducted afterwards. Participants were asked to slowly build up the force to maximal strength within two seconds, and then exert maximal pressure for about three seconds and thereafter slowly relax. Participants were verbally encouraged to perform maximally. From the greater of the 2 contractions, the target force (and visual feedback) for the endurance task was set at 60 per cent of the MVC deployed.

Neck extensor muscle endurance task

The feedback was displayed on a computer screen placed on the floor and for ease of identification the 1 bar graph became green when the target was reached or stayed red if under the target and became blue if over the 60 per cent mark. Participants were instructed to maintain the neck extension for as long as possible and were verbally encouraged throughout the task. The test was stopped when participants mentioned that they were no longer able to maintain the position because of fatigue or when they were unable to maintain the head in a neutral horizontal position or if they failed to maintain within ±5% from the 60% feedback mark on 3 occasions. Within seconds of the end of the endurance task participants were asked to score their perceived level of effort using a Borg's scale[30] and to perform one last maximum voluntary contraction. The development of any post-experimental headache was documented and its intensity recorded using a numerical rating scale.

[Insert figure 1. about here]

Figure 1. Isometric neck extensor muscles endurance test performed in the prone position with visual feedback.

Data and statistical analyses

Muscle fatigue was assessed using the pre- and post-experiment (fatigue task) assessment differences in maximum voluntary contraction. In addition, the root mean square (RMS) mean slope and the median frequency (MDF) mean slope were calculated from adjacent non-overlapping EMG signal epochs of 0.5s for each muscle throughout the task.

As data were all normally distributed, differences between groups, for all variables were assessed using T-tests for independent samples. Physical outcomes of participants with TTH were compared based on their level of adverse headache-related impact using one-way ANOVAs. Correlations between physical (endurance time and MVC before the task) and clinical parameters (kinesiophobia, anxiety, self-efficacy, and pain frequency and intensity) were evaluated using Pearson's correlation coefficient. Analyses were performed using STATISTICA statistical package version 10 (Statsoft, Tulsa, OK), and the level of significance was set at *P* < .05.

RESULTS

Baseline demographics

T-tests for independent samples confirmed that both groups were similar for age, height, weight and scores for the fear of movement, and self-efficacy questionnaires. Only the anxiety level differed between the groups with the participants with TTH ranking at low and the control group at minimal anxiety (*P*=0.03). The headache group included 44 participants and the control group 40. Reasons for participants exclusion are presented in figure 2.

[Insert figure 2. about here]

Figure 2. Flowchart of participants enrollment and reasons for exclusion.

Variables related to headache and neck pain differed between the two groups. Participants in the headache group had higher disability related to the presence of both headaches and neck pain, with the headache impact-test questionnaire (mean±SD= 54.6±8.5 for the TTH group; 42.6±5.6 for the control group) scoring at some impact on daily life functioning and the Neck Disability Index (mean±SD= 7.1±4.4 for the TTH group; 2.0±2.7 for the control group) at mild disability. Similarly, headache intensity and frequency were higher in the headache group with a mean intensity of 4.6 on the VAS, which is considered moderate (1.9 for the control group), and a mean frequency of 8 episodes per month (<1 per month for the control group). Neck pain was also reported more frequently and of greater intensity in the headache group and although neck pain episodes were reported almost as frequently as headaches the intensity was rated lower than headache episodes with a mean score of 3.1 out of 10, which is considered mild [31].

Endurance task

Values for MCVs both prior and after the neck extensor muscles endurance task were significantly lower in participants with TTH than in the control group ($p=0.04$ and $p=0.01$ respectively). Fatigue occurred in all muscles with EMG data analysis showing a positive RMS slope, confirming the recruitment of additional motor units as the task went on (values ranging from 1109.8 up to 6245.9 Hz/s, $p>0.05$). Fatigue was also confirmed in both groups by a mean negative median frequency slope found for all muscles (values ranging from -0.11 up to -0.30 Hz/sec, $p>0.05$). The mean scores for the perceived amount of effort put into the task were slightly above 15 in both groups ($p>0.05$). Finally, a 7% decrease in MVC was observed after the endurance task in the control group compared to 9% in the TTH group ($p>0.05$) whereas the mean time for the endurance task was similar in both groups (mean difference= 6.2 seconds, $p>0.05$). Greater headache ($r= -0.29$; $p=0.006$) or neck-related disability ($r=-0.24$; $p=0.03$), anxiety ($r= -0.28$; $p=0.01$) and higher maximum headache pain intensity (r=-

288 0.27; p=0.01) were negatively correlated to the maximum voluntary contraction prior to
289 the endurance task. Results for all clinical and physical variables are presented in table 2.

290

291 Table 2. Participants' results for clinical and physical variables.

	Variables	Control group (n=40) Mean±SD	Headache group (n=44) Mean±SD	*p*
Demographics	Age (years)	29.8±10.9	27.6±10.3	0.34
	F : M	19 : 21	32 : 12	0.01*
	Years w/ headache	0.8±3.9	10.7±8.7	<0.001*
	Weight (kg)	72.3±15.5	67.4±11.5	0.10
	Height (m)	1.7±0.1	1.6±0.1	0.08
	IMC (kg/m^2)	24.5±4.0	24.1±3.9	0.64
	Kinesiophobia (17-68)	26.8±6.1	28.5±6.2	0.20
	Self-efficacy (10-40)	35.8±.3.9	34.7±3.6	0.18
	Anxiety (20-80)	33.1±10.6	38.0±10.2	0.03*
Headache	Frequency (per month)	0.5±1.0	8.0±7.8	<0.001*
	Mean intensity (/10)	1.9±1.8	4.6±1.2	<0.001*
	Maximum intensity (/10)	3.3±2.6	7.1±1.7	<0.001*
	HIT-6 (36-78)	42.6±5.6	54.6±8.5	<0.001*
Neck pain	Frequency (per month)	2.7±6.3	7.2±9.2	0.01*
	Mean intensity (/10)	1.6±1.4	3.1±1.7	<0.001*
	Maximum intensity (/10)	2.6±2.3	4.6±2.3	<0.001*
	NDI (/50)	2.0±2.7	7.1±4.4	<0.001*
	NDI (/50)†	1.5±2.6	5.0±4.4	<0.001*
Endurance task	MVC before (N)	111.3±38.7	95.9±30.4	0.04*
	MVC after (N)	104.0±33.9	87.7±24.8	0.01*
	Endurance time (sec)	68.1±32.3	61.9±20.1	0.30
	Perceived effort (6-20)	15.0±1.7	15.2±1.7	0.68

292

293 F= female; M= male; IMC= body mass index; HIT-6= headache impact test; NDI= neck disability
294 index; MVC= maximum voluntary contraction; *= statistically significant difference; †= NDI score
295 calculated without the headache question (item 5).

296

297 **Performance of headache participants**

298 Participants with TTH were divided into levels of adverse headache impact based on their score obtained on the HIT-6 questionnaire (minimum possible score is 36 and maximum possible score is 78). Categories are as followed; level 1) little to no impact with score= ≤49; level 2) some impact with score= 50-55; level 3) substantial impact with score= 56-59; and level 4) severe impact with score= ≥60.

303 Comparing results of physical outcomes across levels of headache adverse impact showed that individuals categorized into levels 1 to 3 behaved differently than those into the level 4. Results of clinical and physical parameters that differed based on levels of adverse headache-related impact are presented in Table3. Participants in the headache group had significantly lower pre-endurance MVC compared to the control group but that was mainly explained by the individuals with severe headache-related incapacity (mean±SD=80.1N±19.4) who produced a mean MVC 20.0% lower than the individuals in the other 3 categories (mean±SD= 100.1N±32.3). Similarly, participants scoring as severely impacted on the HIT-6 questionnaire were the ones with the smallest decrease in MVC after the endurance task ($F[1,44]=9.40$; $p=0.004$), the higher neck-related disability ($F[1,44]=10.77$; $p=0.002$), the more frequent headache episodes ($F[1,44]=6.70$; $p=0.01$), and the higher maximum headache intensity ($F[1,44]=10.81$; $p=0.002$). None of the variables related to the fatigue task (endurance time and muscle fatigability) were correlated to the participants' symptomatology.

317 Figure 3 shows the main results based on headache-related impact categories.

Table 3. Results of physical and clinical parameters that differ between levels of headache-related impact as measured by the HIT-6 questionnaire.

Variables	Little to no impact N=12	Some impact N=12	Substantial impact N=11	Severe impact N=9
Prior MVC (N)	101.3 ± 29.6	94.5 ± 30.4	104.6 ± 36.9	80.1 ± 19.4
Decrease in MVC (%)	-11.9 ± 7.9	-6.5 ± 5.9	-5.6 ± 7.9	-1.0 ± 8.2
NDI (/50)	4.4 ± 2.4	7.4 ± 3.9	6.9 ± 3.3	10.6 ± 6.0
Headache frequency (n/ per month)	4.9 ± 6.7	5.8 ± 4.3	9.8 ± 9.1	12.5 ± 9.3
Max headache intensity (/10)	6.5 ± 2.3	6.5 ± 1.4	7.2 ± 1.1	8.6 ± 0.8

MVC= maximum voluntary contraction; NDI= neck disability index.

[Insert Figure 3. About here]

Figure 3. Clinical and physical outcomes broke-down by levels of adverse headache-related impact as measured by the HIT-6 questionnaire. A) Maximum intensity of headache episodes; B) Frequency of headache episodes; C) Decrease in MVC after the endurance task; D) Neck-related incapacity.

DISCUSSION

The purpose of this study was to compare endurance and strength of neck extensor muscles under acute muscle fatigue in individuals with TTH and asymptomatic participants. The results showed that participants with TTH had similar endurance (length of task) and rate of muscle fatigue (EMG RMS and MDF mean slopes) while presenting slightly less isometric strength in extension compared to asymptomatic participants.

The current research protocol was based on the premise that TTH and neck pain are, from a physiological and clinical standpoint, intricately linked. The development of chronic neck pain (CNP) has been previously associated with changes in neck muscle endurance with recent evidence suggesting a decreased resistance to fatigue ranging from 21% to 76% in neck pain patients compared to controls[32-34]. However, our results combined with previously published contradictory evidence do not support this observation in TTH participants.

The lack of difference between groups regarding the endurance test could be explained by the fact that participant with TTH produced lower MVC than controls during the baseline evaluation. Lower neck extensor strength, in such experimental conditions, can be due to higher levels of fear of movement, lower amount of effort put into the task, or development of pain during the task. Nonetheless, kinesiophobia scores were similar and low (score < 37 are considered low) in both groups and Borg's perceived exertion scores were slightly above 15 in both groups, which corresponds to a "hard" level of effort[30]. In addition, among those who reported headache after the endurance test, the mean change in pain intensity from baseline was low (control group N=3; mean change in pain intensity= 1.6±0.6; TTH group N=13; mean change in pain intensity= 1.3±2.1; p=0.77).

However, Madsen et al. reported that concomitance of neck pain in patients with TTH has a negative influence on force production which could be explained by a modulation of muscle activity aimed at avoiding painful experiences characterized by an increased activity in antagonist muscles and a decreased activity in agonist muscles [35]. An imbalance in force production between the neck flexor and extensor muscles has also been considered a potential contributing factor of CTTH development. As such, Madsen et al. reported a 12% decrease in neck extension/flexion strength ratio in the TTH population[36] and a 26% difference in extension strength between TTH and healthy subjects[21]. In addition, TTH patients have been found to have significantly lower neck extension force steadiness compared to healthy controls [35]. Our results showed a statistically significant 15% decrease in extension strength compared to the control group. However, individuals with severe headache-related impact had the lowest decrease in MVC post-experiment. Although surprising, this observation could be explained by high levels of pericranial tenderness expected in those with greater headache frequency and intensity, which could have influenced their performance given the nature of the experimental setting. Although the strap on which participants exerted pressure while performing the extension task was padded to avoid discomfort, and that no participants reported such discomfort, it cannot be excluded that pain or discomfort during the task may have played a role in participants' performance.

In addition, muscular fiber type changes have been hypothesized as an adaptive response to conditions such as injuries, presence of pain, nerve pathology or inflammatory processes [37] and have been reported in TTH [38]. Fiber type conversion is characterized by an increase in the proportion of slow twitch fibers which in turn led to a reduction in MVC amplitude in headache sufferers [38]. Modification to muscular fibers distribution, characterized by an increased number of intermediate fibers (type IIC), occurs in subsequent stages (from either slow twitch or fast twitch fibers) and is believed to start within the first year of symptoms onset and terminate 1 to 2 years later

[39]. The combination of data obtained from surface EMG for muscle fatigue (RMS and MDF mean slopes) and the endurance time which was similar in both our TTH and asymptomatic participants suggests that there is no morphologic difference in neck extensor muscle fiber types between the two groups. These results are in accordance with the findings from the study by Biyouki et al. which reported minimal differences in muscles activity between CTTH and controls at rest [40]. Results could however be different in the case of CTTH.

Forward head posture has been commonly reported in patients with neck pain(13), ETTH [15], and CTTH [18] and is reported to put greater load on the shortened neck extensors muscle in compensation to neck flexors muscle weakness [41, 18].Forward head posture is associated with shortening of posterior cervical extensor muscles and such modification has been hypothesized to be responsible for the activation of a number of trigger points found in TTH. Nociceptive inputs from those trigger point have been reported to contribute to the generation of a continuous afferent signal into the trigeminal nerve leading to central sensitization [18, 11]. Similar to neck pain patients, patients with TTH seem to have reduced neck extensors muscular activity. Altogether, these findings support the theory that inhibition type alterations occur in the deep neck muscles in the presence of CNP and tension-type headache patients[42].

Performance of participants with headache

Another aim of this study was to compare the results of the TTH participants based on the 4 levels of adverse headache-related impact (from the Headache Impact Test-6).

Among headache sufferers, those with “high adverse headache-related impact” produced less maximum neck extensor force and lost minimal strength during the fatigue task than those in the “little to no impact” to the “substantial adverse headache-related impact” categories. In addition, participants scoring at high levels of adverse headache-related impact had greater neck-related disability, reported greater pain severity and suffered from headache more frequently than their counterparts. Overall, participants in the lower three categories of adverse headache-related impact did not behave differently than the control group. These findings suggest that patients with severe headache incapacity display physiological changes that may be mediated by associated psychological factors that were not captured in the present study or that may be triggered as the condition progresses to a more chronic stage.

Limitations

This study is not without limitations. Data related to severity and frequency of headache episodes were self-reported based on episodes from the previous month, which may be subject to recollection bias. A prospective data collection would have allowed for a more precise estimate of these clinical variables. In addition, the testing apparatus provided information regarding neck extensor muscle strength and endurance from a prone position, and considering that most waking hours are spent upright, the task may not be fully representative of the daily complex neck muscle interactions and postures. Similarly, the characterization of the chosen neck muscles as purely extensors may not exactly reflect the function of these muscles and does not take into consideration their stabilizing role which again may be different in bearing and non-weight bearing positions.

CONCLUSION

The results from the present study indicate that a fatigue task consisting of isometric neck extension cannot efficiently differentiate participants with TTH from controls. In addition, parameters related to neck extensor muscles fatigability are not correlated with the severity of headache symptoms. However, neck extensor strength appears to be lower in individuals with TTH, and this may simplify the identification and assessment of physiological changes occurring over time in these patients. Furthermore, force production may only be associated with symptomatology of patients that are categorized with high level of headache-related incapacity. Future studies should further investigate the relationship between levels of headache-related disability and physiological changes.

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Competing interests: None to declare.

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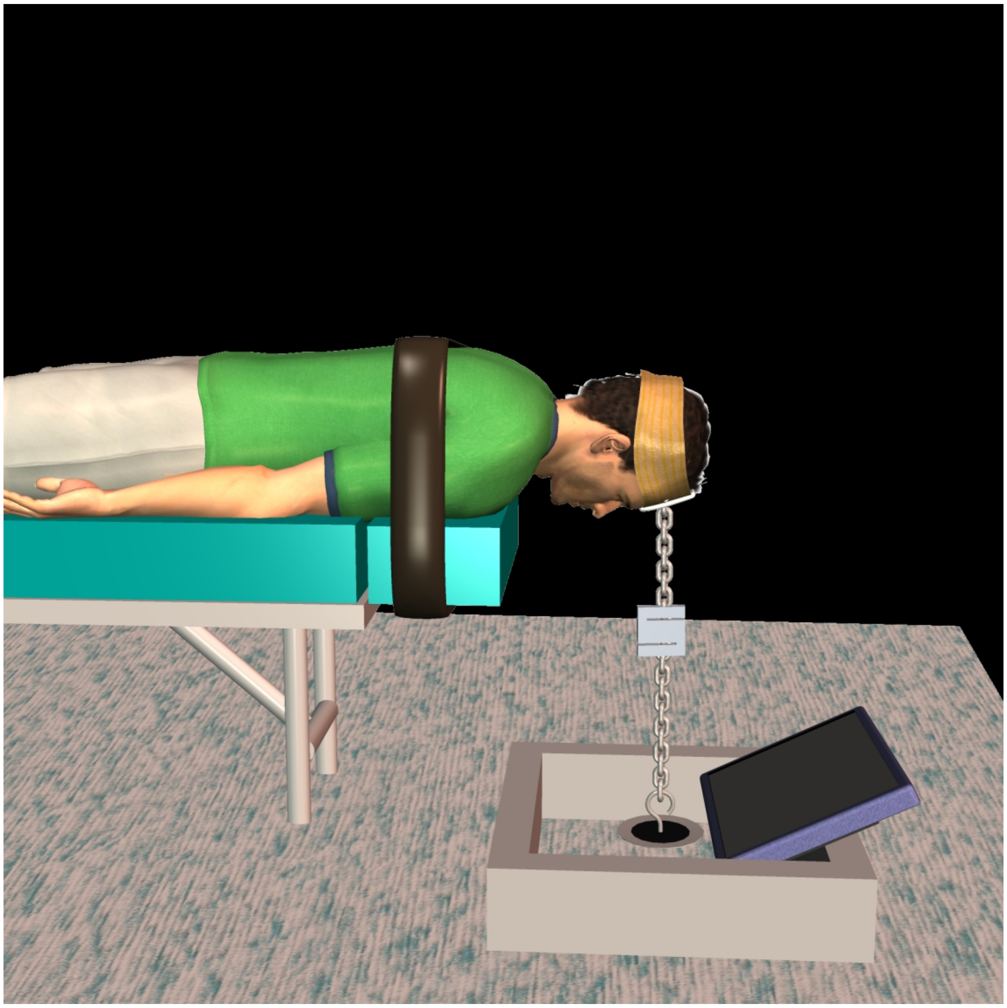

Figure 1. Isometric neck extensor muscles endurance test performed in the prone position with visual feedback.

152x152mm (300 x 300 DPI)

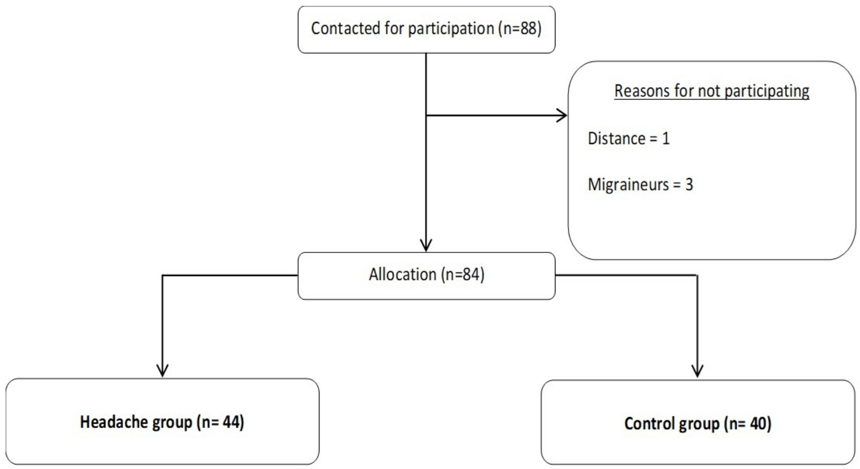

Figure 2. Flowchart of participants enrollment and reasons for exclusion.

108x60mm (300 x 300 DPI)

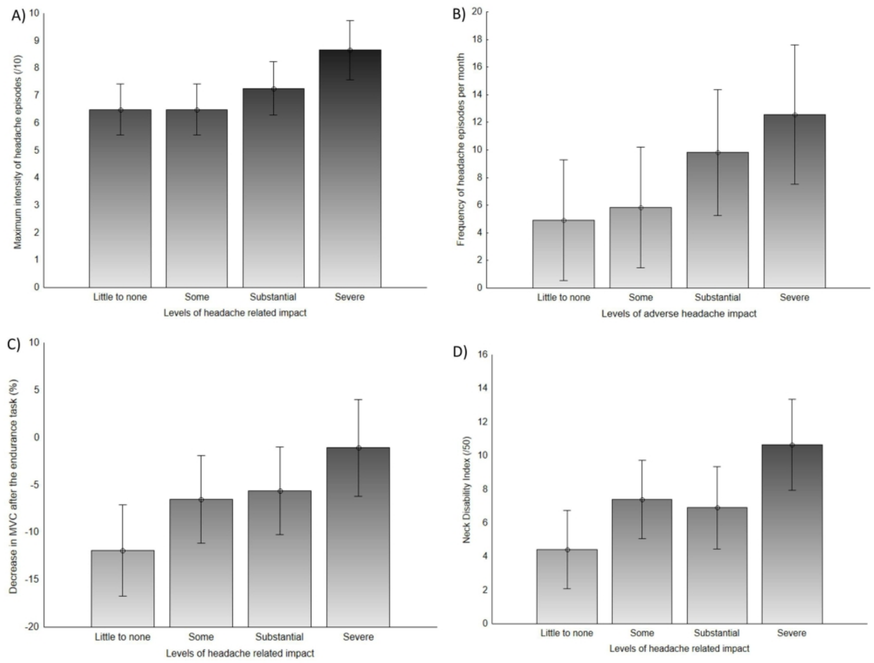

Figure 3. Clinical and physical parameters broke-down by levels of adverse headache-related impact as measured by the HIT-6 questionnaire. A) Maximum intensity of headache episodes; B) Frequency of headache episodes; C) Decrease in MVC after the endurance task; D) Neck-related incapacity.

254x190mm (300 x 300 DPI)

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	p 1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	p. 1-2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	pp. 3,4,5
Objectives	3	State specific objectives, including any prespecified hypotheses	p. 5
Methods			
Study design	4	Present key elements of study design early in the paper	p 6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	p 6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	pp. 6-7
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	pp 7-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group N/A	
Bias	9	Describe any efforts to address potential sources of bias	p 8
Study size	10	Explain how the study size was arrived at N/A	
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why N/A	
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	p. 11
		(*b*) Describe any methods used to examine subgroups and interactions	
		(*c*) Explain how missing data were addressed	
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	pp. 11-12
		(b) Give reasons for non-participation at each stage N/A	
		(c) Consider use of a flow diagram N/A	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	pp 11-12
		(b) Indicate number of participants with missing data for each variable of interest	
Outcome data	15*	Report numbers of outcome events or summary measures	
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	pp. 13-14
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	pp 13-14

Discussion			
Key results	18	Summarise key results with reference to study objectives	p.15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	p.19
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	pp.17–19
Generalisability	21	Discuss the generalisability (external validity) of the study results	
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	p. 20.

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

Neck extensor muscle function does not differ between individuals with tension-type headache and asymptomatic individuals: a Canadian cross-sectional study.

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Keys words: Headache; Electromyography; Muscle fatigue; Endurance; Strength.

ABSTRACT

Aim

To further the understanding of the pathophysiological mechanisms underlying tension-type headache (TTH) by comparing the endurance and strength of neck extensor muscles under acute muscle fatigue in participants with TTH and asymptomatic participants.

Methods

We conducted a cross sectional analysis of neck extensor muscle performance. Asymptomatic participants and participants with TTH were recruited via social media platforms and from the Université du Québec à Trois-Rivières community and employees. A total of forty-four participants with TTH and forty asymptomatic participants took part in an isometric neck extensor endurance task performed at 60% of their maximum voluntary contraction. Inclusion criteria for the headache group were to be older than 18 years old and to fulfill the International Headache Society classification's criteria for either frequent episodic or chronic tension-type headache. Clinical (self-efficacy, anxiety, neck disability and kinesiophobia) and physical parameters (neck extensors maximum voluntary contraction, endurance time, muscle fatigue) as well as characteristics of headache episodes (intensity, frequency, and associated disability) were collected for all participants. Surface electromyography was used to document sternocleidomastoids, upper trapezius and splenius capitis muscle activity and muscle fatigue.

Results

Both groups displayed similar neck extensor muscle endurance capacity with a mean difference of 6.2 seconds ($p>0.05$) in favor of the control group (control=68.1±32.3;

TTH=61.9±20.1). However, participants in the headache group showed lower neck extensor muscle strength partially explained by a 20% lower force production by the individuals with severe headache-related incapacity (controls=111.3±38.7N; TTH=95.9±30.4N). Similarly, among participants with TTH, those scoring as severely impacted by headaches were the ones with higher neck-related disability ($F[1,44]=10.77$; $p=0.002$), the more frequent headache episodes ($F[1,44]=6.70$; $p=0.01$), and higher maximum headache intensity ($F[1,44]=10.81$; $p=0.002$).

Conclusion

A fatigue task consisting of isometric neck extension cannot efficiently differentiate participants with TTH from asymptomatic participants.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- Data related to severity and frequency of headache episodes were retrospectively self-reported based on episodes from the previous month.
- Surface electromyography was used to ensure and quantify muscle fatigue.
- Participants were mostly students and employees of the University community and the results may not be generalizable to different work environments.
- Eighty-four participants were included based on rigorous diagnostic criteria.

BACKGROUND

Headache disorders are a common health issue, with more than 46 % of the adult population suffering from active headache [1]. Among all types, tension-type headache (TTH) is the most widespread type of headache worldwide with a global prevalence of

42%[2]. On average, TTH develops in individuals of 25-30 years of age, its prevalence peeks between 30 to 39 years and affects women slightly more than men, with a prevalence ratio of 5:4[3]. Risks factors to develop chronic tension type headache (CTTH) include analgesic medication overuse, depression, history of migraine and presence of other pain syndromes[4]. TTH is characterized by a pressing and tightening pain, of non-pulsating quality and bilateral location of symptoms of mild to moderate intensity with no or little aggravation of pain during physical activity[5]. According to the International Headache Society (IHS), TTH can be further divided into three subcategories based on the frequency of episodes. Infrequent episodic headaches are characterized as occurring one day or less per month, the frequent episodic form corresponds to headaches occurring between 1 to 14 days per month for at least 3 consecutive months (> 12 and < 180 days per year) and the chronic form consists of fifteen days or more with headache per month (> 180 days per year)[2, 3, 5].

Previous studies have shown that myofascial tissues are more sensitive in TTH patients than in healthy patients and that such tenderness is correlated with TTH episode intensity and frequency [6-8]. Similarly, nociceptive hypersensitivity has been reported at both cephalic and extracephalic locations in patients with CTTH [9]. The clinical phenomenon of spread and pain referral for which pain is perceived as originating from a distant receptive field rather than the affected tissue, is common in primary headaches [10]. A mechanism that could explain this finding is the combination of convergence of trigeminal and cervical afferents on to neurons in the trigeminocervical complex of the brain stem, sensitization of supraspinal neurons and decreased antinociceptive activity from supraspinal structures [11, 10]. In line with this concept, a study reported that of patients with neck pain 88% had concomitant TTH and that there was a significant correlation between the number of days with TTH and the number of days with neck pain in a year[12].

Current evidence regarding musculoskeletal physical outcomes in TTH such as neck mobility and muscle strength is mixed. As such, Fernández-de-las-Peñas showed that patients with episodic tension-type headache (ETTH) or CTTH have less neck mobility than controls [13-15] while other authors reported no difference in global cervical ranges of motion between these two groups [16, 17, 14]. Similarly, TTH have been associated with shortening in muscle length [18, 19] and declined strength of the extensor muscles when progressing to the chronic form [20, 21] while no difference between TTH and healthy participants has also been found [16]. On the other hand, evidence both in favor [20] and against [16, 21] a decrease in flexion strength has been reported. Lastly, limited evidence is available regarding neck muscle endurance with one study reporting less neck flexor endurance in TTH compared to controls [22].

Current evidence suggests that increased neck flexor isometric strength helps increase pressure pain threshold tolerance in CTTH [23]. Furthermore, interventions aimed at the cervical region including massage, cervical strengthening, postural techniques, cervical mobilization, progressive stretching or cervical relaxation exercises, have shown to help reduce pain frequency, intensity and duration of headaches[24]. On the other hand, the role cervical extensor muscles play in the pathophysiological mechanism of TTH remains unclear, and the hypothesis that there is a relation between endurance and strength of these muscles and intensity and frequency of the TTH has not been explored thoroughly. To the best of our knowledge, no study has investigated neck extensor muscle endurance in patients with TTH using electromyography fatigue parameters.

Aim

This study aimed to compare endurance and strength of neck extensor muscles under acute muscle fatigue in participants with TTH and asymptomatic participants. In addition, data collected from TTH participants regarding neck extensor muscle strength and endurance were compared according to levels of headache-related impact (herein defined as headache-associated disability). Based on findings from other chronic painful spinal conditions reporting morphological changes in muscle fiber types, it was hypothesized that, participants with TTH would have similar neck extensor strength and significantly lower neck extensor muscle endurance compared to controls and that higher levels of headache-related impact would be associated to lower muscle strength and endurance. Finally, potential correlations between physical variables related to the endurance task (muscle strength, endurance and muscular activity) and the clinical variables (anxiety, kinesiophobia, self-efficacy, neck and headache-related disability, neck pain and headache pain intensity) were explored.

METHODS

Design

The study was conducted at the Laboratory of Neuromechanics at the Université du Québec à Trois-Rivières (Canada). Recruitment and testing of participants went from August 2016 to July 2017.

Patient and Public Involvement

No patients or public members were involved in the research development process or the conduct of this study.

Participants' selection

A cross-sectional study was conducted for which eighty-four participants were conveniently recruited via social media platforms and from the university community and employees. Inclusion criteria for the headache group was to fulfill the International Headache Society (HIS) classification's criteria for either frequent episodic or chronic TTH based on an estimated number of days with headaches each participant had over the last year (see table 1 for detailed classification criteria). Concomitance of neck pain and other types of headaches was allowed in the headache group as long as pain unrelated to TTH was not the dominant one. If participants fulfilled the IHS classification criteria for TTH but experienced only 12 episodes a year or less (classified as infrequent episodic TTH), they were allocated to the control group. Similarly, people not suffering from headache but still interested in participating to the research project were allocated to the control group if in addition they had no neck pain or had had less than 3 consecutive days of incapacitating neck pain over the last year.

Exclusion criteria included being under a course of treatment for headache or neck pain, having been diagnosed with fibromyalgia, having a recent history of cervical spine severe trauma, fracture, whiplash, medication overuse, infection, surgery or malignant lesion, and the presence of upper limb pain, neurological deficits or spasmodic torticollis. Pregnant women were excluded because of the prone position adopted during the experiment. This study was approved by the ethic committee of human subjects of the Université du Québec à Trois-Rivières (CER-16-225-07.15). All participants provided informed written consent prior to their entry in the study.

Table 1. International Headache Association Classification criteria for frequent episodic and chronic tension-type headache.

Frequent episodic tension-type headache	Chronic tension-type headache
A. At least 10 episodes of headache occurring on 1-14 days per month on average for >3 months (≥12 and <180 days per year) and fulfilling criteria B-D	**A**. Headache occurring on ≥15 days per month on average for >3 months (≥180 days per year) and fulfilling criteria B-D
B. Lasting from 30 min to 7 days	**B**. Lasting hours to days, or unremitting
C. At least two of the following four characteristics: 1. bilateral location 2. pressing or tightening quality (non-pulsating) 3. mild or moderate intensity 4. not aggravated by routine physical activity such as walking or climbing stairs	**C**. At least two of the following four characteristics: 1. bilateral location 2. pressing or tightening quality (non-pulsating) 3. mild or moderate intensity 4. not aggravated by routine physical activity such as walking or climbing stairs
D. Both of the following: 1. no nausea or vomiting 2. no more than one of photophobia or phonophobia	**D**. Both of the following: 1. no more than one of photophobia, phonophobia or mild nausea 2. neither moderate or severe nausea nor vomiting

Data collection

Clinical outcome measures

The experimental session began with a history taking to obtain demographic data, information regarding typical episodes of headache and neck pain as well as the completion of validated questionnaires. Mean and maximum pain intensity over the last month for headache and neck pain was assessed using a visual analog scale (VAS). Disability was assessed using the 6-item Headache impact test (HIT-6) questionnaire for headaches[25] and the Neck Disability Index (NDI) for neck pain[26]. Kinesiophobia (Tampa Scale of Kinesiophobia), anxiety (state-trait anxiety inventory (STAI-Y))[27] and self-efficacy[28] were documented as potential factors that could explain the differences found between groups if any.

Physical outcome measures

Surface electromyography (muscle activity)

Surface electromyography (EMG) data were collected bilaterally using bipolar surface electrodes applied over the midsection of the sternocleidomastoids, upper trapezius and splenius capitis muscles (at the vertebral level of C4) and parallel to the fibers orientation, as described by Criswell and Cram[29]. A ground electrode was placed over the left acromion. To avoid inter-rater variability, anatomical structures palpation and placement of electrodes were assessed by the same investigator for all participants. Skin impedance was reduced by shaving body hair, gently abrading the skin with fine-grade sandpaper (Red Dot Trace Prep, 3M, St. Paul, MN, USA), and wiping the skin with alcohol swabs.

EMG activity was recorded using a single differential Delsys Surface EMG sensor with a common mode rejection ratio of 92 dB at 60 Hz, a noise level of 1.2 µV, a gain of 10 V/V ± 1%, an input impedance of 10^{15} Ω, a bandwidth of 20–450 ± 10% (Model DE2.1, Delsys Inc., Boston, MA, USA) and sampled at 2048 Hz with a 12-bit A/D converter (PCI 6024E, National Instruments, Austin, TX, USA). The EMG data were filtered digitally by a 10- to 450-Hz bandpass, zero-lag, and fifth-order Butterworth filter. Data were collected using the OT Bioelettronica custom software (OT Bioelettronica; Torino, Italy) and processed using Matlab (R2007b MathWorks, Natick, MA, USA).

Neck extensor muscle maximum voluntary contraction

Following skin preparation and electrodes placement participants were asked to lay prone with the head and neck past the edge of the table. The cervico-thoracic junction was stabilized to ensure minimal recruitment of scapular and thoracic muscles throughout the task. The strap length was then adjusted over the protuberantia occipitalis with the participant's head in a neutral horizontal position as depicted in figure 1. One maximum voluntary contraction (MVC) trial was performed to allow participants to get familiar with the isometric extension contraction required during the endurance task and a further two trials were conducted afterwards. Participants were asked to slowly build up the force to maximal strength within two seconds, and then exert maximal pressure for about three seconds and thereafter slowly relax. Participants were verbally encouraged to perform maximally. From the greater of the 2 contractions, the target force (and visual feedback) for the endurance task was set at 60 per cent of the MVC deployed.

Neck extensor muscle endurance task

The feedback was displayed on a computer screen placed on the floor and for ease of identification the 1 bar graph became green when the target was reached or stayed red if under the target and became blue if over the 60 per cent mark. Participants were instructed to maintain the neck extension for as long as possible and were verbally encouraged throughout the task. The test was stopped when participants mentioned that they were no longer able to maintain the position because of fatigue or when they were unable to maintain the head in a neutral horizontal position or if they failed to maintain within ±5% from the 60% feedback mark on 3 occasions. Within seconds of the end of the endurance task participants were asked to score their perceived level of effort using a Borg's scale[30] and to perform one last maximum voluntary contraction. The development of any post-experimental headache was documented and its intensity recorded using a numerical rating scale.

[Insert figure 1. about here]

Figure 1. Isometric neck extensor muscles endurance test performed in the prone position with visual feedback.

Data and statistical analyses

Muscle fatigue was assessed using the pre- and post-experiment (fatigue task) assessment differences in maximum voluntary contraction. In addition, the root mean square (RMS) mean slope and the median frequency (MDF) mean slope were calculated from adjacent non-overlapping EMG signal epochs of 0.5s for each muscle throughout the task.

Differences between groups were assessed using T-tests for independent samples. Physical and clinical outcomes of participants with TTH were compared based on their level of headache-related impact using one-way ANOVAs. Correlations between physical (endurance time and MVC before the task) and clinical parameters (kinesiophobia, anxiety, self-efficacy, neck and headache-related disability, and pain frequency and intensity) were evaluated using Pearson's correlation coefficient. Analyses were performed using STATISTICA statistical package version 10 (Statsoft, Tulsa, OK), and the level of significance was set at $\alpha = .05$.

RESULTS

Baseline demographics

T-tests for independent samples confirmed that both groups were similar for age, height, weight and scores for the fear of movement, and self-efficacy questionnaires. Only the anxiety level differed between the groups with the participants with TTH ranking at low and the control group at minimal anxiety (*P*=0.03). The headache group included 44 participants and the control group 40. Reasons for participant exclusion are presented in figure 2.

[Insert figure 2. about here]

Figure 2. Flowchart of participants' enrollment and reasons for exclusion.

Variables related to headache and neck pain differed between the two groups. Participants in the headache group had higher disability related to the presence of both headaches and neck pain, with the headache impact-test questionnaire (mean±SD= 54.6±8.5 for the TTH group; 42.6±5.6 for the control group) scoring at some impact on daily life functioning and the Neck Disability Index (mean±SD= 7.1±4.4 for the TTH group; 2.0±2.7 for the control group) at mild disability. Similarly, headache intensity and frequency were higher in the headache group with a mean intensity of 4.6 on the VAS, which is considered moderate (1.9 for the control group), and a mean frequency of 8 episodes per month (<1 per month for the control group). Neck pain was also reported more frequently and of greater intensity in the headache group and although neck pain episodes were reported almost as frequently as headaches the intensity was rated lower than headache episodes with a mean score of 3.1 out of 10, which is considered mild [31].

Endurance task

Values for MCVs both prior and after the neck extensor muscles endurance task were significantly lower in participants with TTH than in the control group (p=0.04 and p=0.01 respectively). Fatigue occurred in all muscles with EMG data analysis showing a positive RMS slope, confirming the recruitment of additional motor units as the task went on (values ranging from 1109.8 up to 6245.9 Hz/s, p>0.05). Fatigue was also confirmed in both groups by a mean negative median frequency slope found for all muscles (values ranging from -0.11 up to -0.30 Hz/sec, $p>0.05$). The mean scores for the perceived amount of effort put into the task were slightly above 15 in both groups ($p>0.05$). Finally, a 7% decrease in MVC was observed after the endurance task in the control group compared to 9% in the TTH group ($p>0.05$) whereas the mean time for the endurance task was similar in both groups (mean difference= 6.2 seconds, $p>0.05$). Greater headache ($r= -0.29$; $p=0.006$) or neck-related disability ($r=-0.24$; $p=0.03$), anxiety ($r= -0.28$; $p=0.01$) and higher maximum headache pain intensity ($r=-0.27$; $p=0.01$) were negatively correlated to the maximum voluntary contraction prior to the endurance task. Results for all clinical and physical variables are presented in table 2.

Table 2. Participants' results for clinical and physical variables.

	Variables	Control group (n=40) Mean±SD	Headache group (n=44) Mean±SD	*p*
Demographics	Age (years)	29.8±10.9	27.6±10.3	0.34
	F : M	19 : 21	32 : 12	0.01*
	Years w/ headache	0.8±3.9	10.7±8.7	<0.001*
	Weight (kg)	72.3±15.5	67.4±11.5	0.10
	Height (m)	1.7±0.1	1.6±0.1	0.08
	IMC (kg/m^2)	24.5±4.0	24.1±3.9	0.64
	Kinesiophobia (17-68)	26.8±6.1	28.5±6.2	0.20
	Self-efficacy (10-40)	35.8±.3.9	34.7±3.6	0.18
	Anxiety (20-80)	33.1±10.6	38.0±10.2	0.03*
Headache	Frequency (per month)	0.5±1.0	8.0±7.8	<0.001*
	Mean intensity (/10)	1.9±1.8	4.6±1.2	<0.001*
	Maximum intensity (/10)	3.3±2.6	7.1±1.7	<0.001*
	HIT-6 (36-78)	42.6±5.6	54.6±8.5	<0.001*
Neck pain	Frequency (per month)	2.7±6.3	7.2±9.2	0.01*
	Mean intensity (/10)	1.6±1.4	3.1±1.7	<0.001*
	Maximum intensity (/10)	2.6±2.3	4.6±2.3	<0.001*
	NDI (/50) (%)	2.0±2.7 (4.0)	7.1±4.4 (14.2)	<0.001*
	NDI (/45)† (%)	1.5±2.6 (3.3)	5.0±4.4 (11.1)	<0.001*
E	MVC before (N)	111.3±38.7	95.9±30.4	0.04*

MVC after (N)	104.0±33.9	87.7±24.8	0.01*
Endurance time (sec)	68.1±32.3	61.9±20.1	0.30
Perceived effort (6-20)	15.0±1.7	15.2±1.7	0.68

F= female; M= male; IMC= body mass index; HIT-6= headache impact test; NDI= neck disability index; MVC= maximum voluntary contraction; *= statistically significant difference; †= NDI score calculated without the headache question (item 5).

Performance of headache participants

Participants with TTH were divided into levels of headache-related impact based on their score obtained on the HIT-6 questionnaire (minimum possible score is 36 and maximum possible score is 78). Categories are as followed; level 1) little to no impact with score= ≤49; level 2) some impact with score= 50-55; level 3) substantial impact with score= 56-59; and level 4) severe impact with score= ≥60.

Comparing results of physical outcomes across levels of headache-related impact showed that individuals categorized into levels 1 to 3 behaved differently than those into the level 4. Results of clinical and physical parameters that differed based on levels of headache-related impact are presented in Table 3. Participants in the headache group had significantly lower pre-endurance MVC compared to the control group but that was in part explained by the fact that there was a greater proportion of females in the TTH group and also by the fact that the individuals with severe headache-related incapacity (mean±SD=80.1N±19.4) produced a mean MVC 20.0% lower than the individuals in the other 3 categories (mean±SD= 100.1N±32.3). Similarly, participants scoring as severely impacted on the HIT-6 questionnaire were the ones with the smallest decrease in MVC after the endurance task ($F[1,44]=9.40$; $p=0.004$), the higher neck-related disability ($F[1,44]=10.77$; $p=0.002$), the more frequent headache episodes ($F[1,44]=6.70$; $p=0.01$), and the higher maximum headache intensity ($F[1,44]=10.81$; $p=0.002$). None of the variables related to the fatigue task (endurance time and muscle fatigability) were correlated to the participants' symptomatology.

Figure 3 shows the main results based on headache-related impact categories.

Table 3. Results of physical and clinical parameters that differ between levels of headache-related impact as measured by the HIT-6 questionnaire.

Variables	Little to no impact N=12	Some impact N=12	Substantial impact N=11	Severe impact N=9
F:M	9:3	9:3	7:4	7:2
Prior MVC (N)	101.3 ± 29.6	94.5 ± 30.4	104.6 ± 36.9	80.1 ± 19.4
Decrease in MVC (%)	-11.9 ± 7.9	-6.5 ± 5.9	-5.6 ± 7.9	-1.0 ± 8.2
NDI (/50)	4.4 ± 2.4	7.4 ± 3.9	6.9 ± 3.3	10.6 ± 6.0
Headache frequency (n/ per month)	4.9 ± 6.7	5.8 ± 4.3	9.8 ± 9.1	12.5 ± 9.3
Max headache intensity (/10)	6.5 ± 2.3	6.5 ± 1.4	7.2 ± 1.1	8.6 ± 0.8

F= female; M= male; MVC= maximum voluntary contraction; NDI= neck disability index.

[Insert Figure 3. About here]

Figure 3. Clinical and physical outcomes broke-down by levels of headache-related impact as measured by the HIT-6 questionnaire. A) Maximum intensity of headache episodes; B) Frequency of headache episodes; C) Decrease in MVC after the endurance task; D) Neck-related incapacity.

DISCUSSION

The purpose of this study was to compare endurance and strength of neck extensor muscles under acute muscle fatigue in individuals with TTH and asymptomatic participants. The results showed that participants with TTH had similar endurance (length of task) and rate of muscle fatigue (EMG RMS and MDF mean slopes) while presenting slightly less isometric strength in extension compared to asymptomatic participants.

The current research protocol was based on the premise that TTH and neck pain are, from a physiological and clinical standpoint, intricately linked. The development of chronic neck pain (CNP) has been previously associated with changes in neck muscle endurance with recent evidence suggesting a decreased resistance to fatigue ranging from 21% to 76% in neck pain patients compared to controls [32-34]. However, our results combined with previously published contradictory evidence do not support this observation in TTH participants.

The lack of difference between groups regarding the endurance test could be explained by the fact that participant with TTH produced lower MVC than controls during the baseline evaluation. However, it should be noted that only 20% of subject with TTH showed a significantly reduced force production and contributed to this difference between the TTH and control group. Lower neck extensor strength, in such experimental conditions, can be due to higher levels of fear of movement, lower amount of effort put into the task, or development of pain during the task. Nonetheless, kinesiophobia scores were similar and low (score < 37 are considered low) in both groups and Borg's perceived exertion scores were slightly above 15 in both groups, which corresponds to a "hard" level of effort[30]. In addition, among those who reported headache after the endurance test, the mean change in pain intensity from baseline was low (control group N=3; mean change in pain intensity= 1.6±0.6; TTH group N=13; mean change in pain intensity= 1.3±2.1; p=0.77).

However, Madsen et al. reported that concomitance of neck tenderness in patients with TTH has a negative influence on force production which could be explained by a modulation of muscle activity aimed at avoiding painful experiences characterized by an increased activity in antagonist muscles and a decreased activity in agonist muscles [35]. An imbalance in force production between the neck flexor and extensor muscles has also been considered a potential contributing factor of CTTH development. As such, Madsen et al. reported a 12% decrease in neck extension/flexion strength ratio in the TTH population [36] and a 26% difference in extension strength between TTH and healthy subjects [21]. In addition, TTH patients have been found to have significantly lower neck extension force steadiness compared to healthy controls [35]. Our results showed a statistically significant 15% decrease in extension strength compared to the control group. However, individuals with severe headache-related impact had the lowest decrease in MVC post-experiment. Although surprising, this observation could be explained by high levels of pericranial tenderness expected in those with greater headache frequency and intensity, which could have influenced their performance given the nature of the experimental setting. Although the strap on which participants exerted pressure while performing the extension task was padded to avoid discomfort, and that no participants reported such discomfort, it cannot be excluded that pain or discomfort during the task may have played a role in participants' performance.

In addition, muscular fiber type changes have been hypothesized as an adaptive response to conditions such as injuries, presence of pain, nerve pathology or inflammatory processes [37] and have been reported in TTH [38]. Fiber type conversion is characterized by an increase in the proportion of slow twitch fibers which in turn led to a reduction in MVC amplitude in headache sufferers [38]. Modification to muscular fibers distribution, characterized by an increased number of intermediate fibers (type IIC), occurs in subsequent stages (from either slow twitch or fast twitch fibers) and is believed to start within the first year of symptoms onset and terminate 1 to 2 years later [39]. The combination of data obtained from surface EMG for muscle fatigue (RMS and MDF mean slopes) and the endurance time which was similar in both our TTH and asymptomatic participants suggests that there is no morphologic difference in neck extensor muscle fiber types between the two groups. These results are in accordance with the findings from the study by Biyouki et al. which reported minimal differences in muscles activity between CTTH and controls at rest [40]. Results could however be different in the case of CTTH.

The absence of a clear cervical musculoskeletal impairment in the majority of subjects tested in this study revive the debate around the hypothesis that neck pain may be part of TTH pain pattern, rather than reflecting a local cause in the cervical spine. Although central sensitization pathways and the afferents from the trigeminocervical complex

395 [10, 11] have both been identified as possible mechanisms underlying pain pattern presentation in headaches uncertainty persists around the nature of the role played by neck pain, if any, in TTH presentation [41]. Despite the lack of association between neck muscular dysfunction and clinical portrait found in the present study, future studies should aim to identify a core set of outcome measures, similar to the one developed in migraine patients [42], to help clarify the origin or cause of neck pain in TTH.

401 **Performance of participants with headache**

402 Another aim of this study was to compare the results of the TTH participants based on the four levels of headache-related impact (from the Headache Impact Test-6). Among headache sufferers, those with "high headache-related impact" produced less maximum neck extensor force and lost minimal strength during the fatigue task than those in the "little to no impact" to the "substantial headache-related impact" categories. In addition, participants scoring at high levels of headache-related impact had greater neck-related disability, reported greater pain severity and suffered from headache more frequently than their counterparts. Overall, participants in the lower three categories of headache-related impact did not behave differently than the control group. These findings suggest that patients with severe headache incapacity display physiological changes that may be mediated by associated psychological factors that were not captured in the present study or that may be triggered as the condition progresses to a more chronic stage.

415 **Limitations**

This study is not without limitations. Data related to severity and frequency of headache episodes were self-reported based on episodes from the previous month, which may be subject to recollection bias. A prospective data collection would have allowed for a more precise estimate of these clinical variables. In addition, the testing apparatus provided information regarding neck extensor muscle strength and endurance from a prone position, and considering that most waking hours are spent upright, the task may not be fully representative of the daily complex neck muscle interactions and postures. Similarly, the characterization of the chosen neck muscles as purely extensors may not exactly reflect the function of these muscles and does not take into consideration their stabilizing role which again may be different in bearing and non-weight bearing positions. Furthermore, an interim sample size calculation was conducted to ensure sufficient power to detect differences between the TTH and asymptomatic participants, but the uneven and small number of participants included in the ANOVAs for the four subcategories from the HIT-6 is likely to be underpowered and therefore the results of this analysis should be interpreted with caution.

CONCLUSION

The results from the present study indicate that a fatigue task consisting of isometric neck extension cannot efficiently differentiate participants with TTH from controls. In addition, parameters related to neck extensor muscles fatigability are not correlated with the severity of headache symptoms. However, neck extensor strength appears to be lower in individuals with TTH, and this may simplify the identification and assessment of physiological changes occurring over time in these patients. Furthermore, force production may only be associated with symptomatology of patients that are categorized with high level of headache-related incapacity. Future studies should further investigate the relationship between levels of headache-related disability and physiological changes.

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Author Contributions: Research area and study design: AAM and MD; data acquisition: AAM, MH, MPG, MEH; data analysis and interpretation: AAM, MH and MD; statistical analysis: AAM and MD, supervision and mentorship: MD. Manuscript writing: AAM, MH, MEH, MPG. MD takes responsibility that this study was been reported, transparently and honestly.

Competing interests: None to declare.

Ethics approval: This study has been approved by the ethic committee of human subjects of the Université du Québec à Trois-Rivières (CER-16-225-07.15).

Data sharing statement: No additional data are available.

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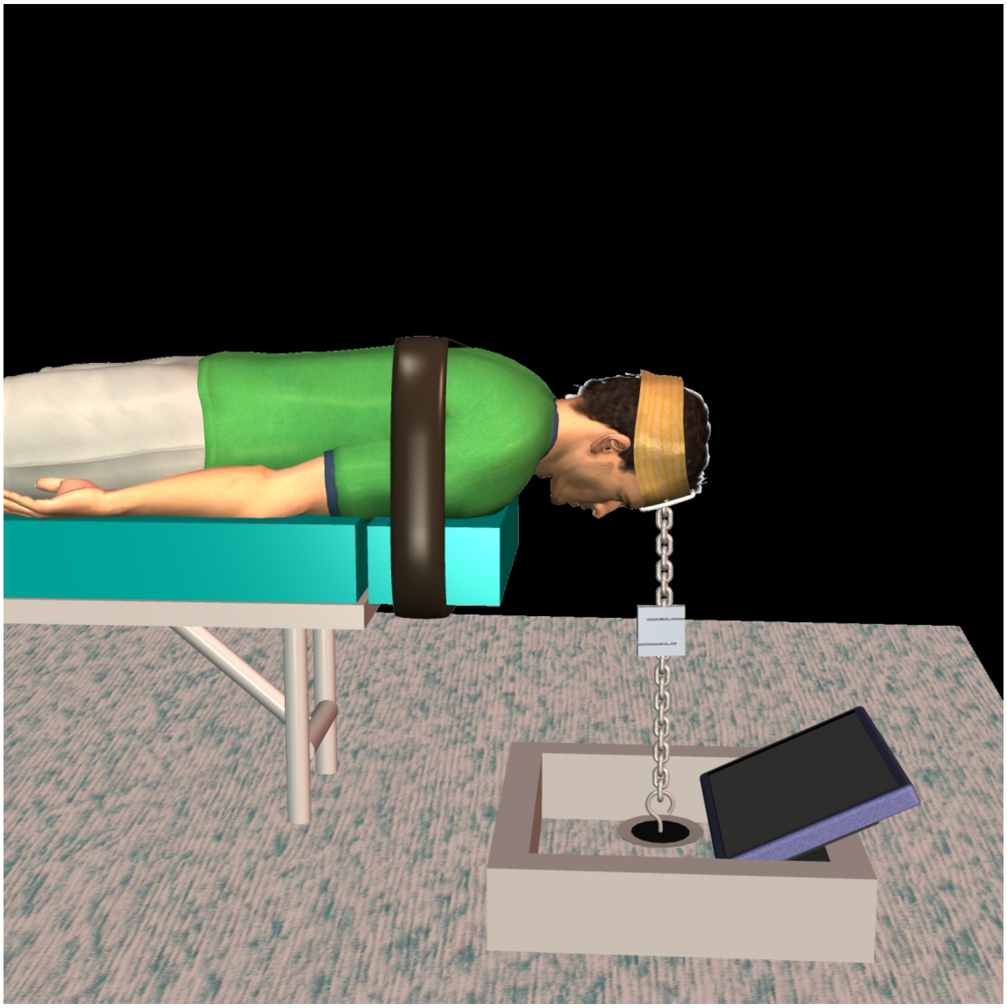

Figure 1. Isometric neck extensor muscles endurance test performed in the prone position with visual feedback.

152x152mm (300 x 300 DPI)

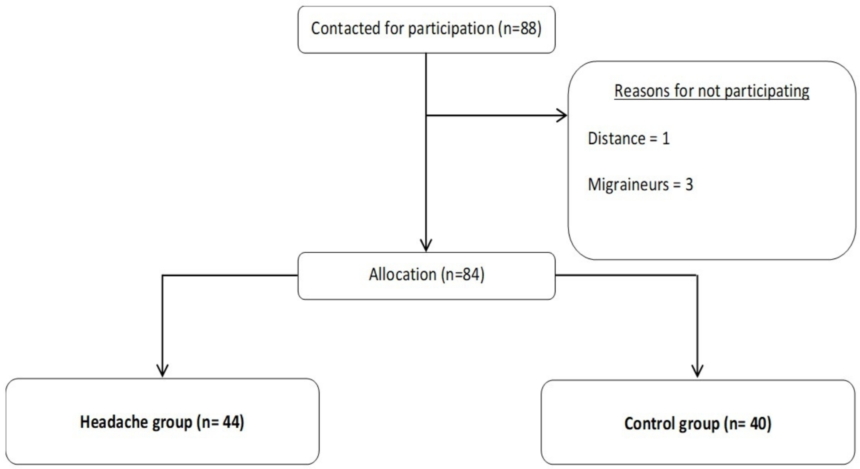

Figure 2. Flowchart of participants enrollment and reasons for exclusion.

108x60mm (300 x 300 DPI)

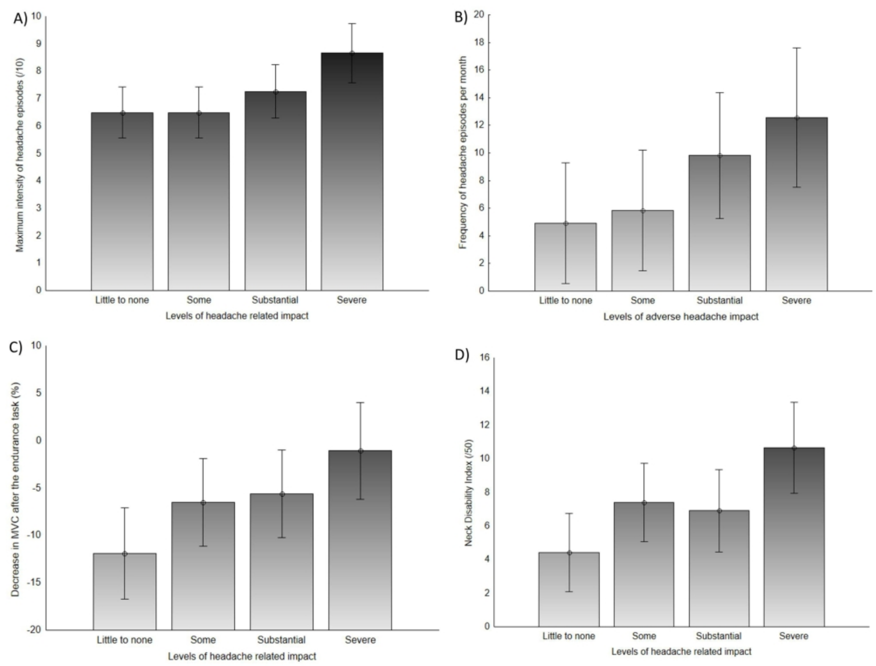

Figure 3. Clinical and physical parameters broke-down by levels of adverse headache-related impact as measured by the HIT-6 questionnaire. A) Maximum intensity of headache episodes; B) Frequency of headache episodes; C) Decrease in MVC after the endurance task; D) Neck-related incapacity.

254x190mm (300 x 300 DPI)

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	p 1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	p. 1-2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	pp. 3,4,5
Objectives	3	State specific objectives, including any prespecified hypotheses	p. 5
Methods			
Study design	4	Present key elements of study design early in the paper	p 6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	p 6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	pp. 6-7
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	pp. 7-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	N/A
Bias	9	Describe any efforts to address potential sources of bias	p 8
Study size	10	Explain how the study size was arrived at	N/A
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	N/A
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	p 11
		(*b*) Describe any methods used to examine subgroups and interactions	
		(*c*) Explain how missing data were addressed	
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	pp. 11-12
		(b) Give reasons for non-participation at each stage	N/A
		(c) Consider use of a flow diagram	N/A
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	pp 11-12
		(b) Indicate number of participants with missing data for each variable of interest	
Outcome data	15*	Report numbers of outcome events or summary measures	
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	pp. 13-14
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	pp 13-14

1

Discussion			
Key results	18	Summarise key results with reference to study objectives	p.15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	p.19
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	p.p. 17–19
Generalisability	21	Discuss the generalisability (external validity) of the study results	
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	p. 20.

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Comparing neck extensor muscle function in asymptomatic Canadian adults and adults with tension-type headache: a cross-sectional study.

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Comparing neck extensor muscle function in asymptomatic Canadian adults and adults with tension-type headache: a cross-sectional study.

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ABSTRACT

Aim

To further the understanding of the pathophysiological mechanisms underlying tension-type headache (TTH) by comparing the endurance and strength of neck extensor muscles under acute muscle fatigue in participants with TTH and asymptomatic participants.

Methods

We conducted a cross sectional analysis of neck extensor muscle performance. Asymptomatic participants and participants with TTH were recruited via social media platforms and from the Université du Québec à Trois-Rivières community and employees. A total of forty-four participants with TTH and forty asymptomatic participants took part in an isometric neck extensor endurance task performed at 60% of their maximum voluntary contraction. Inclusion criteria for the headache group were to be older than 18 years old and to fulfill the International Headache Society classification's criteria for either frequent episodic or chronic tension-type headache. Clinical (self-efficacy, anxiety, neck disability and kinesiophobia) and physical parameters (neck extensors maximum voluntary contraction, endurance time, muscle fatigue) as well as characteristics of headache episodes (intensity, frequency, and associated disability) were collected for all participants. Surface electromyography was used to document, upper trapezius, splenius capitis, and sternocleidomastoids muscle activity and muscle fatigue.

Results

Both groups displayed similar neck extensor muscle endurance capacity with a mean difference of 6.2 seconds ($p>0.05$) in favor of the control group (control=68.1±32.3; TTH=61.9±20.1). Similarly, participants in the headache group showed comparable neck extensor muscle strength (95.9±30.4N) than that of the control group (111.3±38.7N).

Among participants with TTH, those scoring as severely incapacitated by headaches were the ones with higher neck-related disability ($F[1,44]=10.77$; $p=0.002$), the more frequent headache episodes ($F[1,44]=6.70$; $p=0.01$), and higher maximum headache intensity ($F[1,44]=10.81$; $p=0.002$).

Conclusion
A fatigue task consisting of isometric neck extension cannot efficiently differentiate participants with TTH from asymptomatic participants.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- Data related to severity and frequency of headache episodes were retrospectively self-reported based on episodes from the previous month.
- Surface electromyography was used to ensure and quantify muscle fatigue.
- Participants were mostly students and employees of the University community and the results may not be generalizable to different work environments.
- Eighty-four participants were included based on standardized diagnostic criteria.

BACKGROUND

Headache disorders are a common health issue, with more than 46 % of the adult population suffering from active headache [1]. Among all types, tension-type headache (TTH) is the most widespread type of headache worldwide with a global prevalence of 42%[2]. On average, TTH develops in individuals of 25-30 years of age, its prevalence peaks between 30 to 39 years and affects women slightly more than men, with a prevalence ratio of 5:4[3]. Risks factors to develop chronic tension type headache (CTTH) include analgesic medication overuse, depression, history of migraine and presence of other pain syndromes[4]. TTH is characterized by a pressing and tightening pain, of non-pulsating quality and bilateral location of symptoms of mild to moderate intensity with no or little aggravation of pain during physical activity[5]. According to the International Headache Society (IHS), TTH can be further divided into three subcategories based on the frequency of episodes. Infrequent episodic headaches are characterized as occurring one day or less per month, the frequent episodic form corresponds to headaches occurring between 1 to 14 days per month for at least 3 consecutive months (> 12 and < 180 days per year) and the chronic form consists of fifteen days or more with headache per month (> 180 days per year)[2, 3, 5].

Previous studies have shown that myofascial tissues are more sensitive in TTH patients than in healthy patients and that such tenderness is correlated with TTH episode intensity and frequency [6-8]. Similarly, nociceptive hypersensitivity has been reported at both cephalic and extracephalic locations in patients with CTTH [9]. The clinical phenomenon of spread and pain referral for which pain is perceived as originating from a distant receptive field rather than the affected tissue, is common in primary headaches [10]. A mechanism that could explain this finding is the combination of convergence of trigeminal and cervical afferents on to neurons in the trigeminocervical complex of the brain stem, sensitization of supraspinal neurons and decreased antinociceptive activity from supraspinal structures [11, 10]. In line with this concept, a study reported that of patients with TTH 88% had concomitant neck pain and that there was a significant correlation between the number of days with TTH and the number of days with neck pain in a year[12].

Current evidence regarding musculoskeletal physical outcomes in TTH such as neck mobility and muscle strength is mixed. As such, Fernández-de-las-Peñas showed that patients with episodic tension-type headache (ETTH) or CTTH have less neck mobility than controls [13-15] while other authors reported no difference in global cervical ranges of motion between these two groups [16, 17, 14]. Similarly, TTH have been associated with shortening in muscle length [18, 19] and declined strength of the extensor muscles when progressing to the chronic form [20, 21] while no difference between TTH and healthy participants has also been found [16]. On the other hand, evidence both in favor [20] and against [16, 21] a decrease in flexion strength has been reported. Lastly, limited evidence is available regarding neck muscle endurance with one study reporting less neck flexor endurance in TTH compared to controls [22].

Current evidence suggests that increased neck flexor isometric strength helps increase pressure pain threshold tolerance in CTTH [23]. Furthermore, interventions aimed at the cervical region including massage, cervical strengthening, postural techniques, cervical mobilization, progressive stretching or cervical relaxation exercises, have shown to help reduce pain frequency, intensity and duration of headaches[24]. On the other hand, the role cervical extensor muscles play in the pathophysiological mechanism of TTH remains unclear, and the hypothesis that there is a relation between endurance and strength of these muscles and intensity and frequency of the TTH has not been explored thoroughly. To the best of our knowledge, this study is the first to investigate neck extensor muscle endurance in patients with TTH using electromyography fatigue parameters, but also the first to explore such parameters in TTH participants according to levels of headache-related disability.

Aim

This study aimed to compare endurance and strength of neck extensor muscles under acute muscle fatigue in participants with TTH and asymptomatic participants. It was hypothesized that overall, participants with TTH would have similar neck extensor strength and significantly lower neck extensor muscle endurance compared to controls. It was also hypothesized that subgroups of patients with higher levels of headache-related disability would present lower muscle strength and endurance.

Finally, potential correlations between physical variables related to the endurance task (muscle strength, endurance and muscular activity) and the clinical variables (anxiety, kinesiophobia, self-efficacy, neck and headache-related disability, neck pain and headache pain intensity) were explored.

METHODS

Design

The study was conducted at the Laboratory of Neuromechanics at the Université du Québec à Trois-Rivières (Canada). Recruitment and testing of participants went from August 2016 to July 2017.

Patient and Public Involvement

No patients or public members were involved in the research development process or the conduct of this study.

Participants' selection

A cross-sectional study was conducted for which eighty-four participants were conveniently recruited via social media platforms and from the university community and employees. Inclusion criteria for the headache group was to fulfill the International Headache Society (IHS) classification's criteria [5] for either frequent episodic or chronic TTH based on an estimated number of days with headaches each participant had over the last year (see table 1 for detailed classification criteria). Concomitance of neck pain and other types of headaches was allowed in the headache group as long as pain unrelated to TTH was not the dominant one. If participants fulfilled the IHS classification criteria for TTH but experienced only 12 episodes a year or less (classified as infrequent episodic TTH), they were allocated to the control group. Similarly, people not suffering from headache but still interested in participating in the research project were allocated to the control group if in addition they had no neck pain or had had less than 3 consecutive days of incapacitating neck pain over the last year.

Exclusion criteria included being under a course of treatment for headache or neck pain, having been diagnosed with fibromyalgia, having a recent history of cervical spine severe trauma, fracture, whiplash, medication overuse, infection, surgery or malignant lesion, and the presence of upper limb pain, neurological deficits or spasmodic torticollis. Pregnant women were excluded because of the prone position adopted during the experiment. This study was approved by the ethic committee of human subjects of the

Université du Québec à Trois-Rivières (CER-16-225-07.15). All participants provided informed written consent prior to their entry in the study.

Table 1. International Headache Association Classification criteria for frequent episodic and chronic tension-type headache [5].

Frequent episodic tension-type headache	Chronic tension-type headache
A. At least 10 episodes of headache occurring on 1-14 days per month on average for >3 months (≥12 and <180 days per year) and fulfilling criteria B-D	**A**. Headache occurring on ≥15 days per month on average for >3 months (≥180 days per year) and fulfilling criteria B-D
B. Lasting from 30 min to 7 days	**B**. Lasting hours to days, or unremitting
C. At least two of the following four characteristics: 1. bilateral location 2. pressing or tightening quality (non-pulsating) 3. mild or moderate intensity 4. not aggravated by routine physical activity such as walking or climbing stairs	**C**. At least two of the following four characteristics: 1. bilateral location 2. pressing or tightening quality (non-pulsating) 3. mild or moderate intensity 4. not aggravated by routine physical activity such as walking or climbing stairs
D. Both of the following: 1. no nausea or vomiting 2. no more than one of photophobia or phonophobia	**D**. Both of the following: 1. no more than one of photophobia, phonophobia or mild nausea 2. neither moderate or severe nausea nor vomiting

Data collection

Clinical outcome measures

The experimental session began with a history taking to obtain demographic data, information regarding typical episodes of headache and neck pain as well as the completion of validated questionnaires. Mean and maximum pain intensity over the last month for headache and neck pain was assessed using a visual analog scale (VAS).

Disability was assessed using the 6-item Headache impact test (HIT-6) questionnaire for headaches[25] and the Neck Disability Index (NDI) for neck pain[26]. Kinesiophobia (Tampa Scale of Kinesiophobia), anxiety (state-trait anxiety inventory (STAI-Y))[27] and self-efficacy[28] were documented as potential factors that could explain the differences found between groups if any.

Physical outcome measures

Surface electromyography (muscle activity)

Surface electromyography (EMG) data were collected bilaterally using bipolar surface electrodes applied over the midsection of the sternocleidomastoids, upper trapezius and splenius capitis muscles (at the vertebral level of C4) and parallel to the fibers orientation, as described by Criswell and Cram[29]. A ground electrode was placed over the left acromion. To avoid inter-rater variability, anatomical structures palpation and placement of electrodes were assessed by the same investigator for all participants. Skin impedance was reduced by shaving body hair, gently abrading the skin with fine-grade sandpaper (Red Dot Trace Prep, 3M, St. Paul, MN, USA), and wiping the skin with alcohol swabs.

EMG activity was recorded using a single differential Delsys Surface EMG sensor with a common mode rejection ratio of 92 dB at 60 Hz, a noise level of 1.2 μV, a gain of 10 V/V ± 1%, an input impedance of 10^{15} Ω, a bandwidth of 20–450 ± 10% (Model DE2.1, Delsys Inc., Boston, MA, USA) and sampled at 2048 Hz with a 12-bit A/D converter (PCI 6024E, National Instruments, Austin, TX, USA). The EMG data were filtered digitally by a 10- to 450-Hz bandpass, zero-lag, and fifth-order Butterworth filter. Data were collected using the OT Bioelettronica custom software (OT Bioelettronica; Torino, Italy) and processed using Matlab (R2007b MathWorks, Natick, MA, USA).

Neck extensor muscle maximum voluntary contraction

Following skin preparation and electrodes placement participants were asked to lay prone with the head and neck past the edge of the table. The cervico-thoracic junction was stabilized to ensure minimal recruitment of scapular and thoracic muscles throughout the task. The strap length was then adjusted over the protuberantia occipitalis with the participant's head in a neutral horizontal position as depicted in figure 1. One maximum voluntary contraction (MVC) trial was performed to allow participants to get familiar with the isometric extension contraction required during the endurance task and a further two trials were conducted afterwards. Participants were asked to slowly build up the force to maximal strength within two seconds, and then exert maximal pressure for about three seconds and thereafter slowly relax. Participants were verbally encouraged to perform maximally. From the greater of the 2 contractions, the target force (and visual feedback) for the endurance task was set at 60 per cent of the MVC deployed.

Neck extensor muscle endurance task

The feedback was displayed on a computer screen placed on the floor and for ease of identification the 1 bar graph became green when the target was reached or stayed red if under the target and became blue if over the 60 per cent mark. Participants were instructed to maintain the neck extension for as long as possible and were verbally encouraged throughout the task. The test was stopped when participants mentioned that they were no longer able to maintain the position because of fatigue or when they were unable to maintain the head in a neutral horizontal position or if they failed to maintain within ±5% from the 60% feedback mark on 3 occasions. Within seconds of the end of the endurance task participants were asked to score their perceived level of effort using a Borg's scale[30] and to perform one last maximum voluntary contraction. The development of any post-experimental headache was documented, and its intensity recorded using a numerical rating scale.

[Insert figure 1. about here]

Figure 1. Isometric neck extensor muscles endurance test performed in the prone position with visual feedback.

Data and statistical analyses

Muscle fatigue was assessed using the pre- and post-experiment (fatigue task) assessment differences in maximum voluntary contraction. In addition, the root mean square (RMS) mean slope and the median frequency (MDF) mean slope were calculated from adjacent non-overlapping EMG signal epochs of 0.5s for each muscle throughout the task.

Differences between groups were assessed using T-tests for independent samples. Physical and clinical outcomes of participants with TTH were compared based on their level of headache-related disability using one-way ANOVAs. Correlations between physical (endurance time and MVC before the task) and clinical parameters (kinesiophobia, anxiety, self-efficacy, neck and headache-related disability, and pain frequency and intensity) were evaluated using Pearson's correlation coefficient. Analyses were performed using STATISTICA statistical package version 10 (Statsoft, Tulsa, OK), and the level of significance was set at α = .05.

RESULTS

Baseline demographics

T-tests for independent samples confirmed that both groups were similar for age, height, weight and scores for the fear of movement, and self-efficacy questionnaires. However, the TTH group had a greater proportion of female participants (72.9%) compared to the control group (47.5%). In addition, the anxiety level differed between the groups with the participants with TTH ranking at low and the control group at minimal anxiety (p=0.03). The headache group included 44 participants and the control group 40. Reasons for participant exclusion are presented in figure 2.

[Insert figure 2. about here]

Figure 2. Flowchart of participants' enrollment and reasons for exclusion.

Variables related to headache and neck pain differed between the two groups. Participants in the headache group had higher disability related to the presence of both headaches and neck pain, with the headache impact test questionnaire (mean±SD= 54.6±8.5 for the TTH group; 42.6±5.6 for the control group) scoring at some disability on daily life functioning and the Neck Disability Index (mean±SD= 7.1±4.4 for the TTH group; 2.0±2.7 for the control group) at mild disability. Similarly, headache intensity and frequency were higher in the headache group with a mean intensity of 4.6 on the VAS, which is considered moderate (1.9 for the control group), and a mean frequency of 8 episodes per month (<1 per month for the control group). Neck pain was also reported more frequently and of greater intensity in the headache group and although neck pain episodes were reported almost as frequently as headaches the intensity was rated lower than headache episodes with a mean score of 3.1 out of 10, which is considered mild [31].

Endurance task

Since male:female ratios were different between the control and TTH groups, ANCOVAs were conducted for strength and endurance variables. Both baseline and post-fatigue values of MCVs were significantly lower in participants with TTH than in the control group (p=0.04 and p=0.01 respectively). However, when controlled for baseline group differences in male:female ratios, the difference in neck muscle extension strength remained significant at the post-fatigue measurement ($F_{1,84}$= 134.7, p< 0.001) but was no longer significant at baseline ($F_{1,84}$=0.14, p=0.71). In addition, the difference in male:female ratios between groups did not impact the time to fatigue in the endurance task ($F_{1,84}$= 0.17, p=0.68). Fatigue occurred in all muscles with EMG data analysis showing a positive RMS slope, confirming the recruitment of additional motor units as the task went on (values ranging from 1109.8 up to 6245.9 Hz/s, p>0.05). Fatigue was also confirmed in both groups by a mean negative median frequency slope found for all muscles (values ranging from -0.11 up to -0.30 Hz/sec, p>0.05). As it was expected, SCM muscles showed the least contribution during the endurance task as shown by their low levels of muscle fatigue (lowest amongst all measured muscles). The mean scores for the perceived amount of effort put into the task were slightly above 15 in both groups (p>0.05). Finally, a 7% decrease in MVC was observed after the endurance task in the control group compared to 9% in the TTH group (t_{82}=0.5, p=0.06) whereas the mean time for the endurance task was similar in both groups (mean difference= 6.2 seconds, p>0.05). Greater headache (r= -0.29; p=0.006) or neck-related disability (r=-0.24; p=0.03), anxiety (r= -0.28; p=0.01) and higher maximum headache pain intensity (r=-0.27; p=0.01) were negatively correlated to the baseline maximum voluntary contraction. Results for all clinical and physical variables are presented in table 2.

Table 2. Participants' results for clinical and physical variables.

	Variables	Control group (n=40) Mean±SD	Headache group (n=44) Mean±SD	*p*
Demographics	Age (years)	29.8±10.9	27.6±10.3	0.34
	F : M	19 : 21	32 : 12	0.01*
	Years w/ headache	0.8±3.9	10.7±8.7	<0.001*
	Weight (kg)	72.3±15.5	67.4±11.5	0.10
	Height (m)	1.7±0.1	1.6±0.1	0.08
	IMC (kg/m^2)	24.5±4.0	24.1±3.9	0.64
	Kinesiophobia (17-68)	26.8±6.1	28.5±6.2	0.20
	Self-efficacy (10-40)	35.8±.3.9	34.7±3.6	0.18
	Anxiety (20-80)	33.1±10.6	38.0±10.2	0.03*
Headache	Frequency (per month)	0.5±1.0	8.0±7.8	<0.001*
	Mean intensity (/10)	1.9±1.8	4.6±1.2	<0.001*
	Maximum intensity (/10)	3.3±2.6	7.1±1.7	<0.001*
	HIT-6 (36-78)	42.6±5.6	54.6±8.5	<0.001*
Neck	Frequency (per month)	2.7±6.3	7.2±9.2	0.01*
	Mean intensity (/10)	1.6±1.4	3.1±1.7	<0.001*

pai	Maximum intensity (/10)	2.6±2.3	4.6±2.3	<0.001*
	NDI (/50) (%)	2.0±2.7 (4.0)	7.1±4.4 (14.2)	<0.001*
	NDI (/45)† (%)	1.5±2.6 (3.3)	5.0±4.4 (11.1)	<0.001*
Endurance task	MVC before (N)	111.3±38.7	95.9±30.4	0.04*
	MVC after (N)	104.0±33.9	87.7±24.8	0.01*
	Endurance time (sec)	68.1±32.3	61.9±20.1	0.30
	Perceived effort (6-20)	15.0±1.7	15.2±1.7	0.68

F= female; M= male; IMC= body mass index; HIT-6= headache impact test; NDI= neck disability index; MVC= maximum voluntary contraction; *= statistically significant difference; †= NDI score calculated without the headache question (item 5).

Performance of headache participants

Participants with TTH were divided into levels of headache-related disability based on their score obtained on the HIT-6 questionnaire (minimum possible score is 36 and maximum possible score is 78). Categories are as followed; level 1) little to no disability with score= ≤49; level 2) some disability with score= 50-55; level 3) substantial disability with score= 56-59; and level 4) severe disability with score= ≥60.

Comparing results of physical outcomes across levels of headache-related disability showed that individuals categorized into levels 1 to 3 behaved differently than those into the level 4. Results of clinical and physical parameters that differed based on levels of headache-related disability are presented in Table 3. Participants with severe headache-related disability produced a mean MVC 20.0% lower (mean±SD=80.1N±19.4) than the individuals in the other 3 categories (mean±SD= 100.1N±32.3). Similarly, participants scoring as severely incapacitated on the HIT-6 questionnaire were the ones with the smallest decrease in MVC after the endurance task (F[1,44]=9.40; p=0.004), the higher neck-related disability (F[1,44]=10.77; p=0.002), the more frequent headache episodes (F[1,44]=6.70; p=0.01), and the higher maximum headache intensity (F[1,44]=10.81; p=0.002). Among the physical and clinical outcomes, lower baseline MVC (r=0.43, p=0.05), neck pain-related disability (r=0.47, p=0.02), frequency of headache episodes (r=0.42, p=0.05), and maximum intensity of headache episodes (r=0.45, p=0.03) were moderately but significantly correlated with HIT-6 scores.

Figure 3 shows the main results based on headache-related disability categories.

Table 3. Results of physical and clinical parameters that differ between levels of headache-related disability as measured by the HIT-6 questionnaire.

Variables	Little to no disability N=12	Some disability N=12	Substantial disability N=11	Severe disability N=9
F:M	9:3	9:3	7:4	7:2
Prior MVC (N)	101.3 ± 29.6	94.5 ± 30.4	104.6 ± 36.9	80.1 ± 19.4
Decrease in MVC (%)	-11.9 ± 7.9	-6.5 ± 5.9	-5.6 ± 7.9	-1.0 ± 8.2
NDI (/50)	4.4 ± 2.4	7.4 ± 3.9	6.9 ± 3.3	10.6 ± 6.0
Headache frequency (n/ per month)	4.9 ± 6.7	5.8 ± 4.3	9.8 ± 9.1	12.5 ± 9.3
Max headache intensity (/10)	6.5 ± 2.3	6.5 ± 1.4	7.2 ± 1.1	8.6 ± 0.8

F= female; M= male; MVC= maximum voluntary contraction; NDI= neck disability index.

[Insert Figure 3. About here]

Figure 3. Clinical and physical outcomes by levels of headache-related disability as measured by the HIT-6 questionnaire. A) Maximum intensity of headache episodes; B) Frequency of headache episodes; C) Decrease in MVC after the endurance task; D) Neck-related incapacity.

DISCUSSION

The purpose of this study was to compare endurance and strength of neck extensor muscles under acute muscle fatigue in individuals with TTH and asymptomatic participants. The results showed that participants with TTH had similar endurance (length of task), rate of muscle fatigue (EMG RMS and MDF mean slopes), and isometric strength in extension compared to asymptomatic participants.

The current research protocol was based on the premise that TTH and neck pain are, from a physiological and clinical standpoint, intricately linked. The development of chronic neck pain (CNP) has been previously associated with changes in neck muscle endurance with recent evidence suggesting a decreased resistance to fatigue ranging from 21% to 76% in neck pain patients compared to controls [32-34]. Our results combined with previously published evidence do not support this observation in TTH participants.

However, Madsen et al. reported that concomitance of neck tenderness in patients with TTH has a negative influence on force production which could be explained by a modulation of muscle activity aimed at avoiding painful experiences characterized by an increased activity in antagonist muscles and a decreased activity in agonist muscles [35]. An imbalance in force production between the neck flexor and extensor muscles has also been considered a potential contributing factor of CTTH development. As such, Madsen et al. reported a 12% decrease in neck extension/flexion strength ratio in the TTH population [36] and a 26% difference in extension strength between TTH and healthy subjects [21]. In addition, TTH patients have been found to have significantly lower neck extension force steadiness compared to healthy controls [35]. Even though in our study, those with severe headache-related disability, showed a significantly reduced force production, the TTH group as a whole did not show a significant difference in neck extensor force compared to the control group. Indeed, the proportion of participants belonging to each headache-related disability subgroups may very well explain the conflicting results observed across studies with regard to neck muscle function in patients with TTH.

Interestingly, individuals with severe headache-related disability had the lowest decrease in MVC post-experiment. Although surprising, this observation could be explained by high levels of pericranial tenderness expected in those with greater headache frequency and intensity, which could have influenced their performance given the nature of the experimental setting. Although the strap on which participants exerted pressure while performing the extension task was padded to avoid discomfort, and that no participants reported such discomfort, it cannot be excluded that pain or discomfort during the task may have played a role in participants' performance.

In addition, muscular fiber type changes have been hypothesized as an adaptive response to conditions such as injuries, presence of pain, nerve pathology or inflammatory processes [37] and have been reported in TTH [38]. Fiber type conversion is characterized by an increase in the proportion of slow twitch fibers which in turn led to a reduction in MVC amplitude in headache sufferers [38]. Modification to muscular fibers distribution, characterized by an increased number of intermediate fibers (type IIC), occurs in subsequent stages (from either slow twitch or fast twitch fibers) and is believed to start within the first year of symptoms onset and terminate 1 to 2 years later [39]. The combination of data obtained from surface EMG for muscle fatigue (RMS and MDF mean slopes) and the endurance time which was similar in both our TTH and asymptomatic participants suggests that there is no morphologic difference in neck extensor muscle fiber types between the two groups. These results are in accordance with the findings from the study by Biyouki et al. which reported minimal differences in muscles activity between CTTH and controls at rest [40]. Results could however be different in the case of CTTH.

The absence of a clear cervical musculoskeletal impairment in the majority of subjects tested in this study revives the debate around the hypothesis that neck pain may be part of TTH pain pattern, rather than reflecting a local cause in the cervical spine. Although central sensitization pathways and the afferents from the trigeminocervical complex [10, 11] have both been identified as possible mechanisms underlying pain pattern presentation in headaches uncertainty persists around the nature of the role played by neck pain, if any, in TTH presentation [41]. Despite the lack of association between neck muscular dysfunction and clinical portrait found in the present study, future studies should aim to identify a core set of outcome measures, similar to the one developed in migraine patients [42], to help clarify the origin or cause of neck pain in TTH.

Performance of participants with headache

Another aim of this study was to compare the results of the TTH participants based on the four levels of headache-related disability (from the Headache Impact Test-6). Among headache sufferers, those with “high headache-related disability” produced less maximum neck extensor force and lost minimal strength during the fatigue task than those in the “little to no disability” to the “substantial headache-related disability” categories. In addition, participants scoring at high levels of headache-related disability had greater neck-related disability, reported greater pain severity and suffered from headache more frequently than their counterparts. Overall, participants in the lower three categories of headache-related disability did not behave differently than the control group. These findings suggest that patients with severe headache incapacity display physiological changes that may be mediated by associated psychological factors that were not captured in the present study or that may be triggered as the condition progresses to a more chronic stage.

Limitations

This study is not without limitations. Data related to severity and frequency of headache episodes were self-reported based on episodes from the previous month, which may be subject to recollection bias. A prospective data collection would have allowed for a more precise estimate of these clinical variables. In addition, the testing apparatus provided information regarding neck extensor muscle strength and endurance from a prone position, and considering that most waking hours are spent upright, the task may not be fully representative of the daily complex neck muscle interactions and postures. Similarly, the characterization of the chosen neck muscles as purely extensors may not exactly reflect the function of these muscles and does not take into consideration their stabilizing role which again may be different in bearing and non-weight bearing positions. Furthermore, an interim sample size calculation was conducted to ensure sufficient power to detect differences between the TTH and asymptomatic participants, but the uneven and small number of participants included in the ANOVAs for the four subcategories from the HIT-6 is likely to be underpowered and therefore the results of this analysis should be interpreted with caution.

CONCLUSION

The results from the present study indicate that a fatigue task consisting of isometric neck extension cannot efficiently differentiate participants with TTH from controls. In addition, parameters related to neck extensor muscles fatigability are not correlated with the severity of headache symptoms. Furthermore, force production may only be associated with symptomatology of patients that are categorized with high level of headache-related incapacity. Future studies should further investigate the relationship between levels of headache-related disability and physiological changes.

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Declaration of conflicting interests: The authors declare that there is no conflict of interest.

Author Contributions: Research area and study design: AAM and MD; data acquisition: AAM, MH, MPG, MEH; data analysis and interpretation: AAM, MH and MD; statistical analysis: AAM and MD, supervision and mentorship: MD. Manuscript writing: AAM, MH, MEH, MPG. MD takes responsibility that this study was been reported, transparently and honestly.

Competing interests: None to declare.

Ethics approval: This study has been approved by the ethic committee of human subjects of the Université du Québec à Trois-Rivières (CER-16-225-07.15).

Data sharing statement: No additional data are available.

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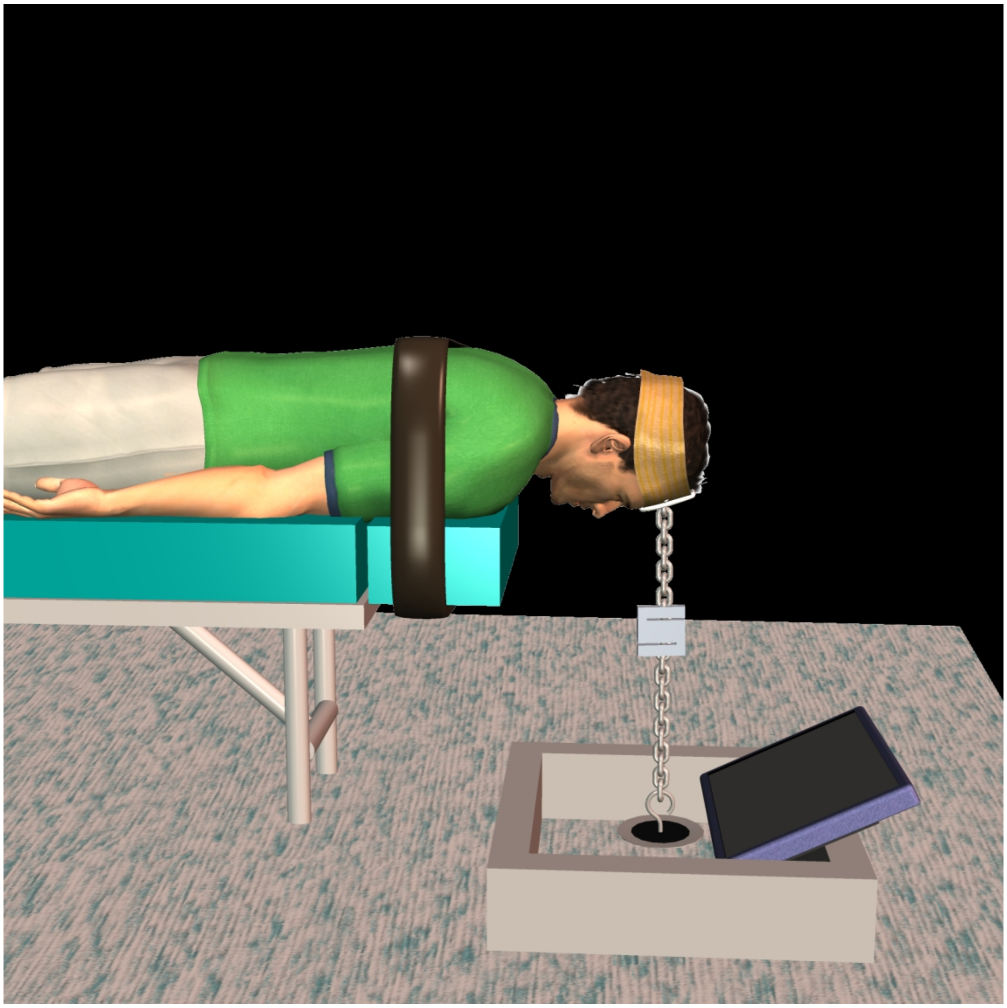

Figure 1. Isometric neck extensor muscles endurance test performed in the prone position with visual feedback.

152x152mm (300 x 300 DPI)

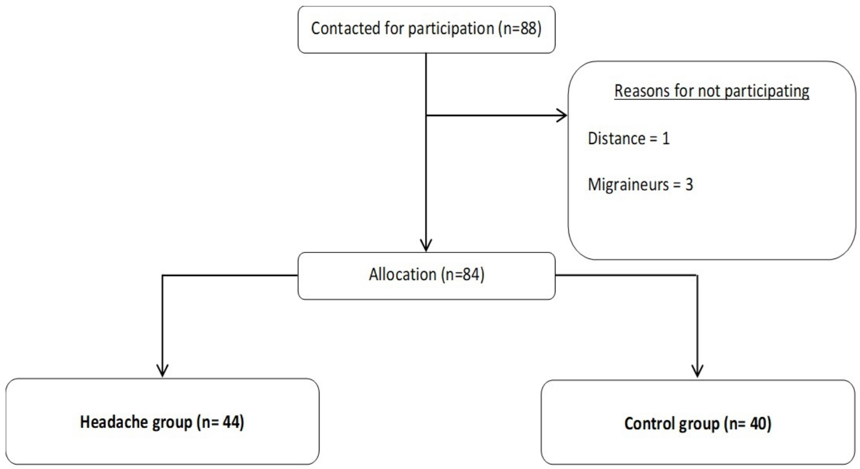

Figure 2. Flowchart of participants enrollment and reasons for exclusion.

108x60mm (300 x 300 DPI)

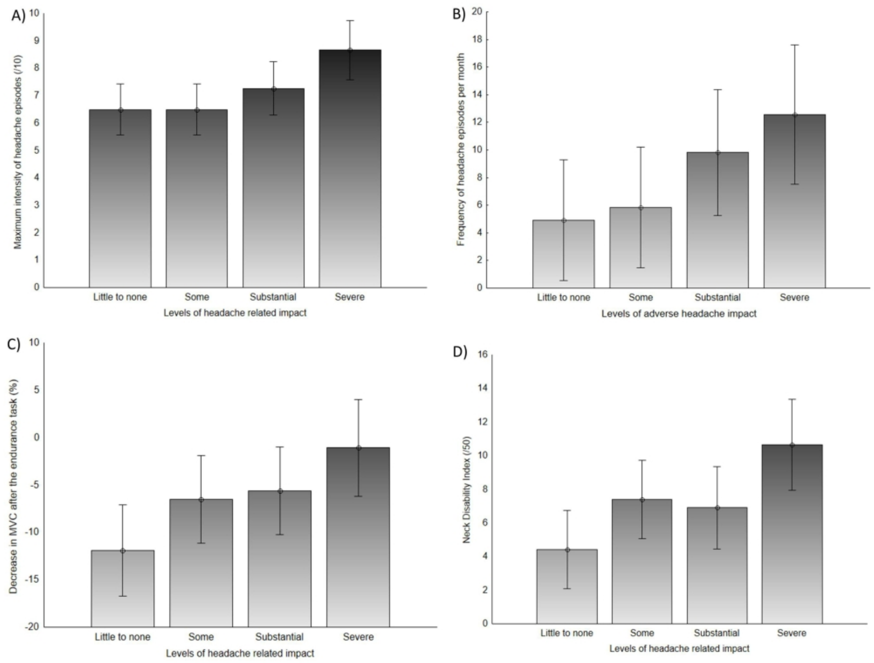

Figure 3. Clinical and physical parameters broke-down by levels of adverse headache-related impact as measured by the HIT-6 questionnaire. A) Maximum intensity of headache episodes; B) Frequency of headache episodes; C) Decrease in MVC after the endurance task; D) Neck-related incapacity.

254x190mm (300 x 300 DPI)

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	p 1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	p. 1-2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	pp. 3.4.5
Objectives	3	State specific objectives, including any prespecified hypotheses	p. 5
Methods			
Study design	4	Present key elements of study design early in the paper	p 6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	p 6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	pp. 6-7
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	pp 7-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	N/A.
Bias	9	Describe any efforts to address potential sources of bias	p 8
Study size	10	Explain how the study size was arrived at	N/A.
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	N/A
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	p. 11
		(*b*) Describe any methods used to examine subgroups and interactions	
		(*c*) Explain how missing data were addressed	
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	P.P. 11-12
		(b) Give reasons for non-participation at each stage	N/A
		(c) Consider use of a flow diagram	N/A
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	pp 11-12
		(b) Indicate number of participants with missing data for each variable of interest	
Outcome data	15*	Report numbers of outcome events or summary measures	
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	pp. 13-14
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	pp 13-14

1

Discussion			
Key results	18	Summarise key results with reference to study objectives	p.15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	p.19
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	p.p. 17–19
Generalisability	21	Discuss the generalisability (external validity) of the study results	
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	p. 20.

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Keys words: Headache; Electromyography; Muscle fatigue; Endurance; Strength.

ABSTRACT

Aim

To further the understanding of the pathophysiological mechanisms underlying tension-type headache (TTH) by comparing the endurance and strength of neck extensor muscles under acute muscle fatigue in participants with TTH and asymptomatic participants.

Methods

We conducted a cross sectional analysis of neck extensor muscle performance. Asymptomatic participants and participants with TTH were recruited via social media platforms and from the Université du Québec à Trois-Rivières community and employees. A total of forty-four participants with TTH and forty asymptomatic participants took part in an isometric neck extensor endurance task performed at 60% of their maximum voluntary contraction. Inclusion criteria for the headache group were to be older than 18 years old and to fulfill the International Headache Society classification's criteria for either frequent episodic or chronic tension-type headache. Clinical (self-efficacy, anxiety, neck disability and kinesiophobia) and physical parameters (neck extensors maximum voluntary contraction, endurance time, muscle fatigue) as well as characteristics of headache episodes (intensity, frequency, and associated disability) were collected for all participants. Surface electromyography was used to document, upper trapezius, splenius capitis, and sternocleidomastoids muscle activity and muscle fatigue.

Results

Both groups displayed similar neck extensor muscle endurance capacity with a mean difference of 6.2 seconds ($p>0.05$) in favor of the control group (control=68.1±32.3; TTH=61.9±20.1). Similarly, participants in the headache group showed comparable neck extensor muscle strength (95.9±30.4N) to the control group (111.3±38.7N). Among

participants with TTH, those scoring as severely incapacitated by headaches were the ones with higher neck-related disability (F[1,44]=10.77; p=0.002), the more frequent headache episodes (F[1,44]=6.70; p=0.01), and higher maximum headache intensity (F[1,44]=10.81; p=0.002).

Conclusion

A fatigue task consisting of isometric neck extension cannot efficiently differentiate participants with TTH from asymptomatic participants.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- Data related to severity and frequency of headache episodes were retrospectively self-reported based on episodes from the previous month.
- Surface electromyography was used to ensure and quantify muscle fatigue.
- Participants were mostly students and employees of the University community and the results may not be generalizable to different work environments.
- Eighty-four participants were included based on standardized diagnostic criteria.

BACKGROUND

Headache disorders are a common health issue, with more than 46 % of the adult population suffering from active headache [1]. Among all types, tension-type headache (TTH) is the most widespread type of headache worldwide with a global prevalence of 42%[2]. On average, TTH develops in individuals of 25-30 years of age, its prevalence peaks between 30 to 39 years and affects women slightly more than men, with a prevalence ratio of 5:4[3]. Risks factors to develop chronic tension type headache (CTTH) include analgesic medication overuse, depression, history of migraine and presence of other pain syndromes[4]. TTH is characterized by a pressing and tightening pain, of non-pulsating quality and bilateral location of symptoms of mild to moderate intensity with no or little aggravation of pain during physical activity[5]. According to the International Headache Society (IHS), TTH can be further divided into three subcategories based on the frequency of episodes. Infrequent episodic headaches are characterized as occurring one day or less per month, the frequent episodic form corresponds to headaches occurring between 1 to 14 days per month for at least 3 consecutive months (> 12 and < 180 days per year) and the chronic form consists of fifteen days or more with headache per month (> 180 days per year)[2, 3, 5].

Previous studies have shown that myofascial tissues are more sensitive in TTH patients than in healthy patients and that such tenderness is correlated with TTH episode intensity and frequency [6-8]. Similarly, nociceptive hypersensitivity has been reported at both cephalic and extracephalic locations in patients with CTTH [9]. The clinical phenomenon of spread and pain referral for which pain is perceived as originating from a distant receptive field rather than the affected tissue, is common in primary headaches [10]. A mechanism that could explain this finding is the combination of convergence of trigeminal and cervical afferents on to neurons in the trigeminocervical complex of the brain stem, sensitization of supraspinal neurons and decreased antinociceptive activity from supraspinal structures [11, 10]. In line with this concept, a study reported that of patients with TTH 88% had concomitant neck pain and that there was a significant correlation between the number of days with TTH and the number of days with neck pain in a year[12].

Current evidence regarding musculoskeletal physical outcomes in TTH such as neck mobility and muscle strength is mixed. As such, Fernández-de-las-Peñas showed that patients with episodic tension-type headache (ETTH) or CTTH have less neck mobility than controls [13-15] while other authors reported no difference in global cervical ranges of motion between these two groups [16, 17, 14]. Similarly, TTH have been associated with shortening in muscle length [18, 19] and declined strength of the extensor muscles when progressing to the chronic form [20, 21] while no difference between TTH and healthy participants has also been found [16]. On the other hand, evidence both in favor [20] and against [16, 21] a decrease in flexion strength has been reported. Lastly, limited evidence is available regarding neck muscle endurance with one study reporting less neck flexor endurance in TTH compared to controls [22].

Current evidence suggests that increased neck flexor isometric strength helps increase pressure pain threshold tolerance in CTTH [23]. Furthermore, interventions aimed at the cervical region including massage, cervical strengthening, postural techniques, cervical mobilization, progressive stretching or cervical relaxation exercises, have shown to help reduce pain frequency, intensity and duration of headaches[24]. On the other hand, the role cervical extensor muscles play in the pathophysiological mechanism of TTH remains unclear, and the hypothesis that there is a relation between endurance and strength of these muscles and intensity and frequency of the TTH has not been explored thoroughly. To the best of our knowledge, this study is the first to investigate neck extensor muscle endurance in patients with TTH using electromyography fatigue parameters, but also the first to explore such parameters in TTH participants according to levels of headache-related disability.

Aim

This study aimed to compare endurance and strength of neck extensor muscles under acute muscle fatigue in participants with TTH and asymptomatic participants. It was hypothesized that overall, participants with TTH would have similar neck extensor strength and significantly lower neck extensor muscle endurance compared to controls. It was also hypothesized that subgroups of patients with higher levels of headache-related disability would present lower muscle strength and endurance.

Finally, potential correlations between physical variables related to the endurance task (muscle strength, endurance and muscular activity) and the clinical variables (anxiety, kinesiophobia, self-efficacy, neck and headache-related disability, neck pain and headache pain intensity) were explored.

METHODS

Design

The study was conducted at the Laboratory of Neuromechanics at the Université du Québec à Trois-Rivières (Canada). Recruitment and testing of participants went from August 2016 to July 2017.

Patient and Public Involvement

No patients or public members were involved in the research development process or the conduct of this study.

Participants' selection

A cross-sectional study was conducted for which eighty-four participants were conveniently recruited via social media platforms and from the university community and employees. Inclusion criteria for the headache group was to fulfill the International Headache Society (IHS) classification's criteria [5] for either frequent episodic or chronic TTH based on an estimated number of days with headaches each participant had over the last year (see table 1 for detailed classification criteria). Concomitance of neck pain and other types of headaches was allowed in the headache group as long as pain unrelated to TTH was not the dominant one. If participants fulfilled the IHS classification criteria for TTH but experienced only 12 episodes a year or less (classified as infrequent episodic TTH), they were allocated to the control group. Similarly, people not suffering from headache but still interested in participating in the research project were allocated to the control group if in addition they had no neck pain or had had less than 3 consecutive days of incapacitating neck pain over the last year.

Exclusion criteria included being under a course of treatment for headache or neck pain, having been diagnosed with fibromyalgia, having a recent history of cervical spine severe trauma, fracture, whiplash, medication overuse, infection, surgery or malignant lesion, and the presence of upper limb pain, neurological deficits or spasmodic torticollis. Pregnant women were excluded because of the prone position adopted during the experiment. This study was approved by the ethic committee of human subjects of the

Université du Québec à Trois-Rivières (CER-16-225-07.15). All participants provided informed written consent prior to their entry in the study.

Table 1. International Headache Association Classification criteria for frequent episodic and chronic tension-type headache [5].

Frequent episodic tension-type headache	Chronic tension-type headache
A. At least 10 episodes of headache occurring on 1-14 days per month on average for >3 months (≥12 and <180 days per year) and fulfilling criteria B-D	**A**. Headache occurring on ≥15 days per month on average for >3 months (≥180 days per year) and fulfilling criteria B-D
B. Lasting from 30 min to 7 days	**B**. Lasting hours to days, or unremitting
C. At least two of the following four characteristics: 1. bilateral location 2. pressing or tightening quality (non-pulsating) 3. mild or moderate intensity 4. not aggravated by routine physical activity such as walking or climbing stairs	**C**. At least two of the following four characteristics: 1. bilateral location 2. pressing or tightening quality (non-pulsating) 3. mild or moderate intensity 4. not aggravated by routine physical activity such as walking or climbing stairs
D. Both of the following: 1. no nausea or vomiting 2. no more than one of photophobia or phonophobia	**D**. Both of the following: 1. no more than one of photophobia, phonophobia or mild nausea 2. neither moderate or severe nausea nor vomiting

Data collection

Clinical outcome measures

The experimental session began with a history taking to obtain demographic data, information regarding typical episodes of headache and neck pain as well as the completion of validated questionnaires. Mean and maximum pain intensity over the last month for headache and neck pain was assessed using a visual analog scale (VAS).

Disability was assessed using the 6-item Headache impact test (HIT-6) questionnaire for headaches[25] and the Neck Disability Index (NDI) for neck pain[26]. Kinesiophobia (Tampa Scale of Kinesiophobia), anxiety (state-trait anxiety inventory (STAI-Y))[27] and self-efficacy[28] were documented as potential factors that could explain the differences found between groups if any.

Physical outcome measures

Surface electromyography (muscle activity)

Surface electromyography (EMG) data were collected bilaterally using bipolar surface electrodes applied over the midsection of the upper trapezius and splenius capitis muscles (at the vertebral level of C4) and parallel to the fibers orientation, as described by Criswell and Cram[29]. Unwanted levels of co-contraction from the neck flexor muscles were monitored via the sternocleidomastoids muscle activity. A ground electrode was placed over the left acromion. To avoid inter-rater variability, anatomical structures palpation and placement of electrodes were assessed by the same investigator for all participants. Skin impedance was reduced by shaving body hair, gently abrading the skin with fine-grade sandpaper (Red Dot Trace Prep, 3M, St. Paul, MN, USA), and wiping the skin with alcohol swabs.

EMG activity was recorded using a single differential Delsys Surface EMG sensor with a common mode rejection ratio of 92 dB at 60 Hz, a noise level of 1.2 µV, a gain of 10 V/V ± 1%, an input impedance of 10^{15} Ω, a bandwidth of 20–450 ± 10% (Model DE2.1, Delsys Inc., Boston, MA, USA) and sampled at 2048 Hz with a 12-bit A/D converter (PCI 6024E, National Instruments, Austin, TX, USA). The EMG data were filtered digitally by a 10- to 450-Hz bandpass, zero-lag, and fifth-order Butterworth filter. Data were collected using the OT Bioelettronica custom software (OT Bioelettronica; Torino, Italy) and processed using Matlab (R2007b MathWorks, Natick, MA, USA).

Neck extensor muscle maximum voluntary contraction

Following skin preparation and electrodes placement participants were asked to lay prone with the head and neck past the edge of the table. The cervico-thoracic junction was stabilized to ensure minimal recruitment of scapular and thoracic muscles throughout the task. The strap length was then adjusted over the protuberantia occipitalis with the participant's head in a neutral horizontal position as depicted in figure 1. One maximum voluntary contraction (MVC) trial was performed to allow participants to get familiar with the isometric extension contraction required during the endurance task and a further two trials were conducted afterwards. Participants were asked to slowly build up the force to maximal strength within two seconds, and then exert maximal pressure for about three seconds and thereafter slowly relax. Participants were verbally encouraged to perform maximally. From the greater of the 2 contractions, the target force (and visual feedback) for the endurance task was set at 60 per cent of the MVC deployed.

Neck extensor muscle endurance task

The feedback was displayed on a computer screen placed on the floor and for ease of identification the 1 bar graph became green when the target was reached or stayed red if under the target and became blue if over the 60 per cent mark. Participants were instructed to maintain the neck extension for as long as possible and were verbally encouraged throughout the task. The test was stopped when participants mentioned that they were no longer able to maintain the position because of fatigue or when they were unable to maintain the head in a neutral horizontal position or if they failed to maintain within ±5% from the 60% feedback mark on 3 occasions. Within seconds of the end of the endurance task participants were asked to score their perceived level of effort using a Borg's scale[30] and to perform one last maximum voluntary contraction. The development of any post-experimental headache was documented, and its intensity recorded using a numerical rating scale.

[Insert figure 1. about here]

Figure 1. Isometric neck extensor muscles endurance test performed in the prone position with visual feedback.

Data and statistical analyses

Muscle fatigue was assessed using the pre- and post-experiment (fatigue task) assessment differences in maximum voluntary contraction. In addition, the root mean square (RMS) mean slope and the median frequency (MDF) mean slope were calculated from adjacent non-overlapping EMG signal epochs of 0.5s for each muscle throughout the task.

Differences between groups were assessed using T-tests for independent samples. One-way ANCOVAs were conducted to assess the difference between TTH and asymptomatic individuals on neck muscle extensor strength and endurance while controlling for sex. Physical and clinical outcomes of participants with TTH were compared based on their level of headache-related disability using one-way ANOVAs. Correlations between physical (endurance time and MVC before the task) and clinical parameters (kinesiophobia, anxiety, self-efficacy, neck and headache-related disability, and pain frequency and intensity) were evaluated using Pearson's correlation coefficient. Analyses were performed using STATISTICA statistical package version 10 (Statsoft, Tulsa, OK), and the level of significance was set at $\alpha = .05$.

RESULTS

Baseline demographics

T-tests for independent samples confirmed that both groups were similar for age, height, weight and scores for the fear of movement, and self-efficacy questionnaires. However, the TTH group had a greater proportion of female participants (72.9%) compared to the control group (47.5%). In addition, the anxiety level differed between the groups with the participants with TTH ranking at low and the control group at minimal anxiety (p=0.03). The headache group included 44 participants and the control group 40. Reasons for participant exclusion are presented in figure 2.

[Insert figure 2. about here]

Figure 2. Flowchart of participants' enrollment and reasons for exclusion.

Variables related to headache and neck pain differed between the two groups. Participants in the headache group had higher disability related to the presence of both headaches and neck pain, with the headache impact test questionnaire (mean±SD= 54.6±8.5 for the TTH group; 42.6±5.6 for the control group) scoring at some disability on daily life functioning and the Neck Disability Index (mean±SD= 7.1±4.4 for the TTH group; 2.0±2.7 for the control group) at mild disability. Similarly, headache intensity and frequency were higher in the headache group with a mean intensity of 4.6 on the VAS, which is considered moderate (1.9 for the control group), and a mean frequency of 8 episodes per month (<1 per month for the control group). Neck pain was also reported more frequently and of greater intensity in the headache group and although neck pain episodes were reported almost as frequently as headaches the intensity was rated lower than headache episodes with a mean score of 3.1 out of 10, which is considered mild [31].

Endurance task

One-way ANCOVA showed a significant effect of TTH on neck extension strength at the post-fatigue measurement after controlling for sex ($F_{1,84}$= 134.7, p< 0.001) but not at baseline ($F_{1,84}$=0.14, p=0.71). In addition, the difference in sex ratios between groups did not impact the time to fatigue in the endurance task ($F_{1,84}$= 0.17, p=0.68). Fatigue occurred in all muscles with EMG data analysis showing a positive RMS slope, confirming the recruitment of additional motor units as the task went on (values ranging from 1109.8 up to 6245.9 Hz/s, p>0.05). Fatigue was also confirmed in both groups by a mean negative median frequency slope found for all muscles (values ranging from -0.11 up to -0.30

Hz/sec, p>0.05). As it was expected, SCM muscles showed the least contribution during the endurance task as shown by their low levels of muscle fatigue (lowest amongst all measured muscles). The mean scores for the perceived amount of effort put into the task were slightly above 15 in both groups (p>0.05). Finally, a 7% decrease in MVC was observed after the endurance task in the control group compared to 9% in the TTH group (t_{82}=0.5, p=0.06) whereas the mean time for the endurance task was similar in both groups (mean difference= 6.2 seconds, p>0.05). Greater headache (r= -0.29; p=0.006) or neck-related disability (r=-0.24; p=0.03), anxiety (r= -0.28; p=0.01) and higher maximum headache pain intensity (r=-0.27; p=0.01) were negatively correlated to the baseline maximum voluntary contraction. Results for all clinical and physical variables are presented in table 2.

Table 2. Participants' results for clinical and physical variables.

	Variables	Control group (n=40) Mean±SD	Headache group (n=44) Mean±SD	*p*
Demographics	Age (years)	29.8±10.9	27.6±10.3	0.34
	F : M	19 : 21	32 : 12	0.01*
	Years w/ headache	0.8±3.9	10.7±8.7	<0.001*
	Weight (kg)	72.3±15.5	67.4±11.5	0.10
	Height (m)	1.7±0.1	1.6±0.1	0.08
	IMC (kg/m^2)	24.5±4.0	24.1±3.9	0.64
	Kinesiophobia (17-68)	26.8±6.1	28.5±6.2	0.20
	Self-efficacy (10-40)	35.8±.3.9	34.7±3.6	0.18
	Anxiety (20-80)	33.1±10.6	38.0±10.2	0.03*
Headache	Frequency (per month)	0.5±1.0	8.0±7.8	<0.001*
	Mean intensity (/10)	1.9±1.8	4.6±1.2	<0.001*
	Maximum intensity (/10)	3.3±2.6	7.1±1.7	<0.001*
	HIT-6 (36-78)	42.6±5.6	54.6±8.5	<0.001*
Neck	Frequency (per month)	2.7±6.3	7.2±9.2	0.01*
	Mean intensity (/10)	1.6±1.4	3.1±1.7	<0.001*

pai	Maximum intensity (/10)	2.6±2.3	4.6±2.3	<0.001*
	NDI (/50) (%)	2.0±2.7 (4.0)	7.1±4.4 (14.2)	<0.001*
	NDI (/45)† (%)	1.5±2.6 (3.3)	5.0±4.4 (11.1)	<0.001*
Endurance task	MVC before (N)	111.3±38.7	95.9±30.4	0.04*
	MVC after (N)	104.0±33.9	87.7±24.8	0.01*
	Endurance time (sec)	68.1±32.3	61.9±20.1	0.30
	Perceived effort (6-20)	15.0±1.7	15.2±1.7	0.68

F= female; M= male; IMC= body mass index; HIT-6= headache impact test; NDI= neck disability index; MVC= maximum voluntary contraction; *= statistically significant difference; †= NDI score calculated without the headache question (item 5).

Performance of headache participants

Participants with TTH were divided into levels of headache-related disability based on their score obtained on the HIT-6 questionnaire (minimum possible score is 36 and maximum possible score is 78). Categories are as followed; level 1) little to no disability with score= ≤49; level 2) some disability with score= 50-55; level 3) substantial disability with score= 56-59; and level 4) severe disability with score= ≥60.

Comparing results of physical outcomes across levels of headache-related disability showed that individuals categorized into levels 1 to 3 behaved differently than those into the level 4. Results of clinical and physical parameters that differed based on levels of headache-related disability are presented in Table 3. Participants with severe headache-related disability produced a mean MVC 20.0% lower (mean±SD=80.1N±19.4) than the individuals in the other 3 categories (mean±SD= 100.1N±32.3). Similarly, participants scoring as severely incapacitated on the HIT-6 questionnaire were the ones with the smallest decrease in MVC after the endurance task (F[1,44]=9.40; p=0.004), the higher neck-related disability (F[1,44]=10.77; p=0.002), the more frequent headache episodes (F[1,44]=6.70; p=0.01), and the higher maximum headache intensity (F[1,44]=10.81; p=0.002). Among the physical and clinical outcomes, lower baseline MVC (r=0.43, p=0.05), neck pain-related disability (r=0.47, p=0.02), frequency of headache episodes (r=0.42, p=0.05), and maximum intensity of headache episodes (r=0.45, p=0.03) were moderately but significantly correlated with HIT-6 scores.

Figure 3 shows the main results based on headache-related disability categories.

Table 3. Results of physical and clinical parameters that differ between levels of headache-related disability as measured by the HIT-6 questionnaire.

Variables	Little to no disability N=12	Some disability N=12	Substantial disability N=11	Severe disability N=9
F:M	9:3	9:3	7:4	7:2
Prior MVC (N)	101.3 ± 29.6	94.5 ± 30.4	104.6 ± 36.9	80.1 ± 19.4
Decrease in MVC (%)	-11.9 ± 7.9	-6.5 ± 5.9	-5.6 ± 7.9	-1.0 ± 8.2
NDI (/50)	4.4 ± 2.4	7.4 ± 3.9	6.9 ± 3.3	10.6 ± 6.0
Headache frequency (n/ per month)	4.9 ± 6.7	5.8 ± 4.3	9.8 ± 9.1	12.5 ± 9.3
Max headache intensity (/10)	6.5 ± 2.3	6.5 ± 1.4	7.2 ± 1.1	8.6 ± 0.8

F= female; M= male; MVC= maximum voluntary contraction; NDI= neck disability index.

[Insert Figure 3. About here]

Figure 3. Clinical and physical outcomes by levels of headache-related disability as measured by the HIT-6 questionnaire. A) Maximum intensity of headache episodes; B) Frequency of headache episodes; C) Decrease in MVC after the endurance task; D) Neck-related incapacity.

DISCUSSION

The purpose of this study was to compare endurance and strength of neck extensor muscles under acute muscle fatigue in individuals with TTH and asymptomatic participants. The results showed that participants with TTH had similar endurance (length of task), rate of muscle fatigue (EMG RMS and MDF mean slopes), and isometric strength in extension compared to asymptomatic participants.

The current research protocol was based on the premise that TTH and neck pain are, from a physiological and clinical standpoint, intricately linked. The development of chronic neck pain (CNP) has been previously associated with changes in neck muscle endurance with recent evidence suggesting a decreased resistance to fatigue ranging from 21% to 76% in neck pain patients compared to controls [32-34]. Our results combined with previously published evidence do not support this observation in TTH participants.

However, Madsen et al. reported that concomitance of neck tenderness in patients with TTH has a negative influence on force production which could be explained by a modulation of muscle activity aimed at avoiding painful experiences characterized by an increased activity in antagonist muscles and a decreased activity in agonist muscles [35]. An imbalance in force production between the neck flexor and extensor muscles has also been considered a potential contributing factor of CTTH development. As such, Madsen et al. reported a 12% decrease in neck extension/flexion strength ratio in the TTH population [36] and a 26% difference in extension strength between TTH and healthy subjects [21]. In addition, TTH patients have been found to have significantly lower neck extension force steadiness compared to healthy controls [35]. Even though in our study, those with severe headache-related disability, showed a significantly reduced force production, the TTH group as a whole did not show a significant difference in neck extensor force compared to the control group. Indeed, the proportion of participants belonging to each headache-related disability subgroups may very well explain the conflicting results observed across studies with regard to neck muscle function in patients with TTH.

Interestingly, individuals with severe headache-related disability had the lowest decrease in MVC post-experiment. Although surprising, this observation could be explained by high levels of pericranial tenderness expected in those with greater headache frequency and intensity, which could have influenced their performance given the nature of the experimental setting. Although the strap on which participants exerted pressure while performing the extension task was padded to avoid discomfort, and that no participants reported such discomfort, it cannot be excluded that pain or discomfort during the task may have played a role in participants' performance.

In addition, muscular fiber type changes have been hypothesized as an adaptive response to conditions such as injuries, presence of pain, nerve pathology or inflammatory processes [37] and have been reported in TTH [38]. Fiber type conversion is characterized by an increase in the proportion of slow twitch fibers which in turn led to a reduction in MVC amplitude in headache sufferers [38]. Modification to muscular fibers distribution, characterized by an increased number of intermediate fibers (type IIC), occurs in subsequent stages (from either slow twitch or fast twitch fibers) and is believed to start within the first year of symptoms onset and terminate 1 to 2 years later [39]. The combination of data obtained from surface EMG for muscle fatigue (RMS and MDF mean slopes) and the endurance time which was similar in both our TTH and asymptomatic participants suggests that there is no morphologic difference in neck extensor muscle fiber types between the two groups. These results are in accordance with the findings from the study by Biyouki et al. which reported minimal differences in muscle activity between CTTH and controls at rest [40].

The absence of a clear cervical musculoskeletal impairment in the majority of subjects tested in this study revives the debate around the hypothesis that neck pain may be part of TTH pain pattern, rather than reflecting a local cause in the cervical spine. Although central sensitization pathways and the afferents from the trigeminocervical complex [10, 11] have both been identified as possible mechanisms underlying pain pattern presentation in headaches uncertainty persists around the nature of the role played by neck pain, if any, in TTH presentation [41]. Despite the lack of association between neck muscular dysfunction and clinical portrait found in the present study, future studies should aim to identify a core set of outcome measures, similar to the one developed in migraine patients [42], to help clarify the origin or cause of neck pain in TTH.

Performance of participants with headache

Another aim of this study was to compare the results of the TTH participants based on the four levels of headache-related disability (from the Headache Impact Test-6). Among headache sufferers, those with “high headache-related disability” produced less maximum neck extensor force and lost minimal strength during the fatigue task than those in the “little to no disability” to the “substantial headache-related disability” categories. In addition, participants scoring at high levels of headache-related disability had greater neck-related disability, reported greater pain severity and suffered from headache more frequently than their counterparts. Overall, participants in the lower three categories of headache-related disability did not behave differently than the control group. These findings suggest that patients with severe headache incapacity display physiological changes that may be influenced by other biological or associated psychological factors that were not captured in the present study or that may be triggered as the condition progresses to a more chronic stage.

Limitations

This study is not without limitations. Data related to severity and frequency of headache episodes were self-reported based on episodes from the previous month, which may be subject to recollection bias. A prospective data collection would have allowed for a more precise estimate of these clinical variables. In addition, the testing apparatus provided information regarding neck extensor muscle strength and endurance from a prone position, and considering that most waking hours are spent upright, the task may not be fully representative of the daily complex neck muscle interactions and postures. Similarly, the characterization of the chosen neck muscles as purely extensors may not exactly reflect the function of these muscles and does not take into consideration their stabilizing role which again may be different in bearing and non-weight bearing positions.

Furthermore, an interim sample size calculation was conducted to ensure sufficient power to detect differences between the TTH and asymptomatic participants, but the uneven and small number of participants included in the ANOVAs for the four subcategories from the HIT-6 is likely to be underpowered and therefore the results of this analysis should be interpreted with caution.

CONCLUSION

The results from the present study indicate that a fatigue task consisting of isometric neck extension cannot efficiently differentiate participants with TTH from controls. In addition, parameters related to neck extensor muscles fatigability are not correlated with the severity of headache symptoms. Furthermore, force production may only be associated with symptomatology of patients that are categorized with high level of headache-related incapacity. Future studies should further investigate the relationship between levels of headache-related disability and physiological changes.

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Author Contributions: Research area and study design: AAM and MD; data acquisition: AAM, MH, MPG, MEH; data analysis and interpretation: AAM, MH and MD; statistical analysis: AAM and MD, supervision and mentorship: MD. Manuscript writing: AAM, MH, MEH, MPG. MD takes responsibility that this study was been reported, transparently and honestly.

Competing interests: None to declare.

Ethics approval: This study has been approved by the ethic committee of human subjects of the Université du Québec à Trois-Rivières (CER-16-225-07.15).

Data sharing statement: No additional data are available.

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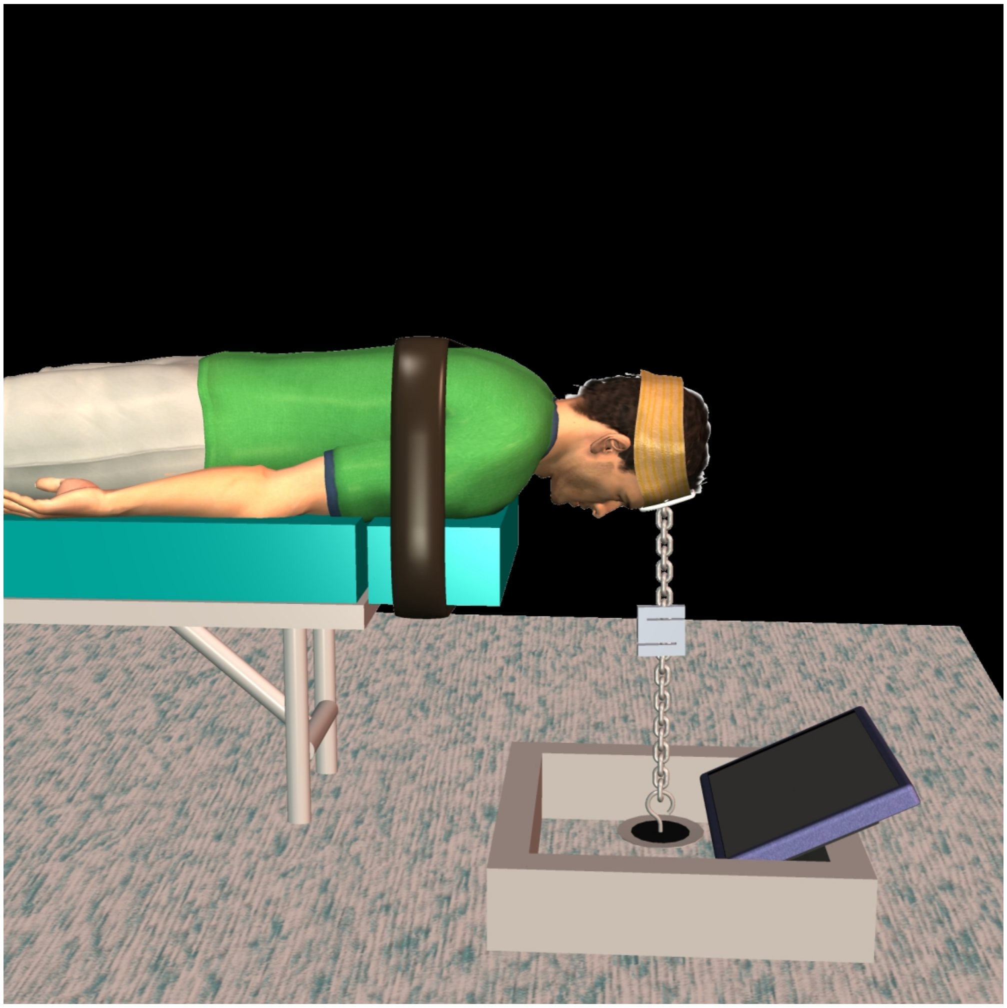

Figure 1. Isometric neck extensor muscles endurance test performed in the prone position with visual feedback.

152x152mm (300 x 300 DPI)

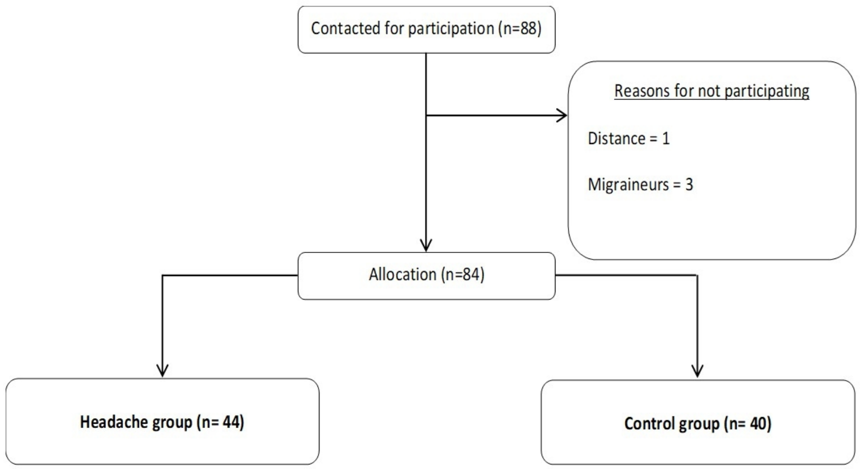

Figure 2. Flowchart of participants enrollment and reasons for exclusion.

108x60mm (300 x 300 DPI)

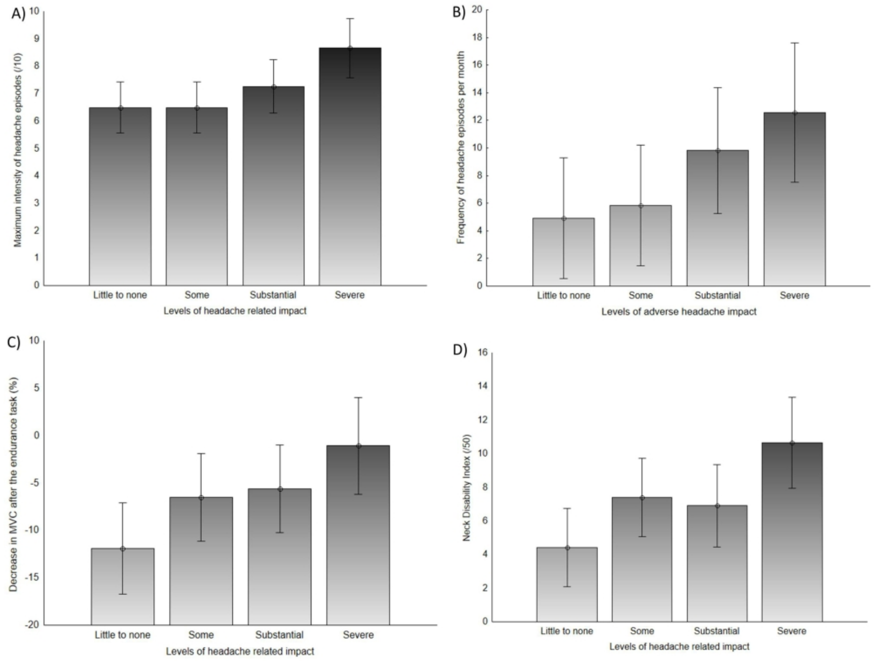

Figure 3. Clinical and physical parameters broke-down by levels of adverse headache-related impact as measured by the HIT-6 questionnaire. A) Maximum intensity of headache episodes; B) Frequency of headache episodes; C) Decrease in MVC after the endurance task; D) Neck-related incapacity.

254x190mm (300 x 300 DPI)

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	p. 1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	p. 1-2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	pp. 3,4,5
Objectives	3	State specific objectives, including any prespecified hypotheses	p. 5
Methods			
Study design	4	Present key elements of study design early in the paper	p 6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	p6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	pp. 6-7
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	pp 7-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group N/A	
Bias	9	Describe any efforts to address potential sources of bias	p8
Study size	10	Explain how the study size was arrived at N/A	
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why N/A	
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	p.11
		(*b*) Describe any methods used to examine subgroups and interactions	
		(*c*) Explain how missing data were addressed	
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	pp. 11-12
		(b) Give reasons for non-participation at each stage N/A	
		(c) Consider use of a flow diagram N/A	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	pp 11-12
		(b) Indicate number of participants with missing data for each variable of interest	
Outcome data	15*	Report numbers of outcome events or summary measures	
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	pp. 13-14
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	pp 13-14

Discussion			
Key results	18	Summarise key results with reference to study objectives	p.15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	p.19
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	p.p. 17–19
Generalisability	21	Discuss the generalisability (external validity) of the study results	
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	p. 20.

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.