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Neck flexor muscle fatigue in adolescents with headache – An electromyographic study

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Abstract

Background: Muscular disorders of the neck region may be of importance for the etiology of tension-type headache. However, in adolescents, there are no data on the association between neck muscle fatigue and headache.
Aim: To study differences in fatigue characteristics of the neck flexor muscles in adolescents with and without headache.
Methods: A population-based sample of 17-year-old adolescents with migraine-type headache ($N = 30$), tension-type headache ($N = 29$) and healthy controls without headache ($N = 30$) was examined. Surface EMG data were recorded from the sternocleidomastoid (SCM) muscles bilaterally during an isometric neck flexor endurance test. The spectral median frequency (MF) change during the total endurance time (TMF) and the initial time of 30 s (IMF) was calculated. The intensity of discomfort in the neck area was assessed with the visual analogue scale (VAS).
Results: The rate of decline in TMF of both SCM muscles was significantly increased in the tension-type headache group compared with controls (right SCM, $P = 0.030$, OR 2.0, 95% 1.2–3.7; left SCM, $P = 0.009$, OR 2.5, 95% 1.4–4.9), while no significant differences were found between controls and subjects with migraine. The rate of decline in IMF, the total endurance time ($P = 0.050$), and VAS did not differ significantly among the study groups.
Conclusions: This preliminary finding shows that increased neck flexor muscle fatigue in adolescents seems to be associated with tension-type headache.

Keywords: Adolescent; Headache; Sternocleidomastoid muscle; Muscle fatigue; Electromyography

1. Introduction

Headache may either cause or be a consequence of the dysfunction of the neck and pericranial muscles. In adults, an association between increased pericranial myofascial tenderness (Sandrini et al., 1994; Bendtsen et al., 1996; Jensen and Rasmussen, 1996; Lipchik et al., 1996; Ulrich et al., 1996; Jensen et al., 1998) and increased electromyographic (EMG) activity of neck and pericranial muscles and tension-type headache has been reported (Jensen et al., 1994, 1998; Clark et al., 1995; Barton and Hayes, 1996). Increased muscle activity of neck extensor and forehead muscles (Pritchard,

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1995) and increased pericranial muscle tenderness (Anttila et al., 2002b) have also been shown in children with migraine-type headache. In addition, clinical mechanical measures have identified reduced endurance capacity in the neck flexor muscles in neck pain patients (Watson and Trott, 1993; Treleaven et al., 1994; Placzek et al., 1999). In EMG analysis, there is evidence of increased fatigability of the neck muscles in patients with neck pain (Gogia and Sabbahi, 1994; Alricsson et al., 2001; Falla et al., 2003; Falla et al., 2004), and of back extensor muscles in patients with low back pain (Roy et al., 1989; Biedermann et al., 1991; Kankaanpää et al., 1998; Mannion et al., 1998). However, even in adults, there are few data on the association between neck muscle fatigue and headache.

During sustained, isometric exercise, an objective, motivation-independent assessment of fatigue of skeletal muscles can be monitored by the time-dependent changes in the EMG frequency properties such as mean (MEF) and median frequency (MF) (Mannion and Dolan, 1994; Roy et al., 1995; Mannion et al., 1998; Marletti et al., 2001). In a population study by Jensen et al. (1994), decreased EMG frequency values, indicating fatigue of temporal muscles during maximal voluntary contraction, have been indicated in subjects with chronic tension-type headache. On the other hand, in their clinical study, Jensen and Olesen (1996) showed no changes in EMG frequency levels in the temporal muscles during maximal voluntary contraction neither in chronic nor in episodic tension-type headache patients.

To our knowledge, no evidence has been shown of the fatigue characteristics of neck muscles in children and adolescents with headache. However, proneness to headache appears in childhood and some of the pathophysiological factors associated with headache might appear most clearly in childhood and adolescents. Thus, it is important to examine the possible role of neuromuscular changes in the etiology of different types of headache early in life. This information might contribute to the selection and improvement of suitable and specific rehabilitation methods for different types of headache and the prevention of chronic headache.

The purpose of this study was to further the knowledge of neck flexor muscle dysfunction in adolescents with headache by examining the fatigue characteristics of both sternocleidomastoid muscles (SCM) that are important for cervical postural control and force production. EMG manifestations of muscle fatigue were examined during an isometric clinical test of neck flexor endurance in adolescents with migraine- and tension-type headache and in healthy controls. Our hypothesis was that a greater rate of decline of the median frequency of the SCM muscle, indicative of greater muscle fatigue, is identified for the adolescents with headache compared to the subjects without headache, especially for those with tension-type headache.

2. Methods

2.1. Subjects

The present study is part of a population-based follow-up study of headache in schoolchildren. The first phase of the study was a questionnaire study for all 12-year-old schoolchildren in the city of Turku in south-western Finland. The second phase of the study consisted of a face-to-face interview at the age of 13 with a random sample of children with primary headaches (migraine or tension headache) or no headache. The third phase of the study consisted of a follow-up interview at the age of 16 for the same sample and a random sample of children with only secondary or non-classifiable headaches at the age of 12. Detailed information on the previous phases of the study have been presented earlier (Anttila et al., 2002a,b; Laimi et al., 2005). The total number of participants at the age of 16 was 304. In all phases of the study the different types of headache were confirmed by a pediatrician (PA) using the IHS criteria (Headache Classification Committee of the International Headache Society, 1988). As the second, present, edition of the International Classification of Headache Disorders was not published at the time of data collection, IHS criteria (1988) were used.

In the present, fourth phase of the study, a random sample of 30 of the subjects with frequent migraine-type headache (headache at least once a month), 30 of the subjects with frequent tension-type headache and 30 of the headache-free subjects who did not report any neck–shoulder pain were asked to participate in a neck flexor endurance test and EMG measurements. (The detailed diagnoses of the adolescents with headache were IHS 1.1–1.2 (migraine with and without aura) $N = 28$; IHS 1.7 (migraine not fulfilling criteria) = 2; IHS 2.1 (episodic tension-type headache) $N = 25$; IHS 2.2 (chronic tension-type headache) $N = 4$; IHS 2.3 (tension-type headache not fulfilling criteria) $N = 1$). If an adolescent was unable to participate (11 from the migraine group, nine from the tension-type headache group, and six adolescents from the headache-free group) another randomly selected child from the same group was invited. Because six adolescents from the headache-free group were unable to participate, six adolescents were randomly selected for the control group from the adolescents whose headache frequency (IHS 2.1) was maximally 0.5 times a month, and who had no neck–shoulder symptoms.

Finally, the present study included 30 adolescents with migraine-type headache (26 girls, 4 boys) 29 adolescents with tension-type headache (18 girls, 11 boys), and

Table 1
Subject characteristics

	Migraine-type headache ($N = 30$) Mean (SD)	Tension-type headache group ($N = 29$) Mean (SD)	Control group ($N = 30$) Mean (SD)	P-value
Age (years)	17 (0.5)	17 (0.5)	17 (0.6)	0.484
Height (cm)	169 (9.3)	170 (7.4)	172 (10.8)	0.376
Weight (kg)	62 (10.3)	69 (14.0)	67 (14.9)	0.099
Body mass index (kg/m^2)	23 (2.9)	24 (3.4)	22 (3.5)	0.074
Gender				
Girls	26	18	14	0.003
Boys	4	11	16	

30 control subjects (14 girls, 16 boys), all 17 years of age at the time of the study. The measurements were carried out in the Department of Physical and Rehabilitation Medicine, Turku University Central Hospital, and they were all done by one exercise physiologist (AO). Adolescents did not report headache or neck pain during the measurements, but eleven subjects with migraine-type headache and 12 with tension-type headache reported headache on the examination day (before or at midday). Fourteen adolescents with migraine-type headache and 12 with tension-type headache reported subjective neck–shoulder symptoms on the day of the examination, but none of the subjects reported symptoms during the measurements. The measurements were done between 5 and 8 p.m. All subjects were considered otherwise healthy and none of them had headache or clear neck and shoulder symptoms during the measurement sessions. The subjects had not specifically trained their neck and shoulder muscles, and none of them was a competing athlete. The study groups were similar in regards to anthropometric measures. The physical characteristics of the three subject groups are shown in Table 1.

The adolescents and their parents received prior written information on the examination and gave their informed consent. The study design was approved by the Joint Ethics Review Committee of the University of Turku Medical School and Turku University Central Hospital.

2.2. Study design

2.2.1. EMG measurement

The surface EMG data were recorded from the sternocleidomastoid (SCM) muscles bilaterally during an isometric neck flexor endurance test (Fig. 1). Muscle Tester ME8000P microprocessor-based device[1] was used for the EMG measurement. The measurements were performed online and the signal was transferred directly from the microprocessor to the computer through an optic cable. Oval shaped bipolar self-adhesive disposable surface electrodes[2] of width 2.0 cm and length 2.5 cm were placed on the muscle, while the subject was sitting erect. The interelectrode distance was 15 mm. The position of the electrodes was based on palpation of the muscle belly during manually resisted isometric muscle contractions. The electrodes of right and left SCM muscles were placed slightly posteriorly over the middle part of the muscles (Hamilton, 1996; Sommerich et al., 2000) in the direction of the muscle fibres as recommended by Basmajian (1978). The caudal electrode of the SCM muscle was placed so that the lowest edge of the electrode was above the midpoint of the muscle belly. For each pair of electrodes, the reference electrode was placed near the bony area over the medial part of the clavicular, about 8 cm from the measuring spot. The electrodes were attached to the skin in a standardized manner. To keep the interelectrode resistance low (<2 kΩ), the skin was shaved and lightly rubbed with a piece of sandpaper and cleaned with 60% alcohol. The resistance was determined before and after each measurement with a digital multimeter.[3] The position of the electrodes was marked on the skin with indelible ink.

2.2.2. Data processing

The measurement signals were preamplified 1000 times. The present measurement system used preamplifiers located in the cables to ensure high signal quality. The EMG data were analyzed with EMG software of MegaWin 2.0.[1] Filtering of the raw signal was performed with low and high pass filters, the cut-off frequencies being low 20 Hz and high 500 Hz. The raw signal was passed through a 12 bit AD converter with a sampling frequency of 1000 Hz. Background noise in the filtered signal was less than 1 μV. The fatigue index, MF (median frequency), was analyzed from the raw EMG data as a function of time using a moving window up to the end of the endurance test. The myoelectric power density spectrum was calculated with the aid of the fast Fourier transform (FFT) algorithm, using a 1024 data point window. The MF was calculated in a way described elsewhere (Hägg, 1992). In the EMG software, the marker function was used manually to mark

[1] Mega Electronics Ltd, P.O. Box 1199, 70211 Kuopio, Finland.
[2] Medicotest, Model N-00-S; Carmeda Oy, A/S Rugmarken 10, DK-3650, Ölstykke, Denmark.
[3] Mastech®, MAS830B, Suomen Huoltopalvelu Oy, Karvaamokuja 1, 00380 Helsinki, Finland.

Fig. 1. Neck flexion endurance test and bipolar surface electromyographic electrode arrangement over the sternocleidomastoid muscles.

the simultaneous starting and end point of the endurance test. The relative rate of change in MF (change in Hz/min) across the total contraction duration (TMF) and across the initial 30 s of contraction duration (IMF) of SCM muscles during the neck flexion endurance test was recorded.

2.2.3. Neck flexion endurance test

For the isometric endurance test, the subject reclined on a plinth in a sagittally symmetrical supine position. Both shoulders and thorax were against the plinth. The knees were at a 60° angle and supported with a roll pad under the knees, both upper extremities being straight at the sides. The test was forward flexion of the cervical spine (cervical flexion) jutting out the chin (Janda, 1983). First, the head was against the plinth and the face was in the horizontal position, directed vertically upwards toward the ceiling. After that, the subject was asked to flex the cervical spine, and the examiner guided the cervical spine to a flexion of 20° using a goniometer. In this neck flexion position, the subject was asked to jut out the chin as far as possible. This chin position was controlled by a small ball hanging from the ceiling. In addition, the head (cervical flexion of 20°) position was controlled using two rulers. Both rulers were attached vertically to the plinth, one at the side at the same level as the subject's ear and the other behind the head at the same level as the middle part of the subject's head (Fig. 1). When the test position was achieved, one of the red plastic markers attached around the ruler was located at the level of the upper edge of the ear and another at the level of the upper edge of the middle part of the head. The subject was asked to hold the static neck and head position in this marked position until exhaustion and the total endurance time (s) was measured. If the subject was not able to maintain the correct position the test was discontinued. The subject was warned once if only minor changes in the head position occurred during the test. If the subject was unable to correct the position immediately, the test was discontinued. No other encouragement was given. Immediately after the performance, the intensity of discomfort/pain in the neck–shoulder area was subjectively assessed with the visual analogue scale (VAS) (Joyce et al., 1975; Price et al., 1983). The scale used was a 10 cm long, horizontal line attached to a plastic stick with a width of 4 cm. The scale was anchored by 'No discomfort or pain, does not hurt at all' at one end, and 'Worst discomfort or pain imaginable' at the other. The intensity of discomfort was indicated by the movable indicator of the measure stick, by the subject. The subject was also asked to express verbally the target where the discomfort/pain was felt.

2.2.4. Repeatability of measures

Fourteen subjects (seven with tension-type headache and seven without headache) performed the test on two separate occasions (1 week apart) to examine the repeatability of measures of total endurance time and TMF changes in sternocleidomastoideus muscles of both sides. The EMG electrodes on the subject were repositioned each time. The same electrode positions for two measurement sessions were ensured with a tape measure and marked on the skin with indelible ink.

2.2.5. Statistical analysis

Chi-square and Fisher's exact test were used to find associations between two categorical variables. One-way analysis of variance was used to compare group means. Two-way ANOVA was used to check whether there was an interaction with group and gender. Then, analysis of covariance was used to compare group means, with gender and pain variables as covariates. Pairwise comparisons were adjusted using the Tukey–Kramer method. Spearman (r_s) and Pearson (r_s) correlations were used depending on the variable type and distribution. Log (Ln)- and square-root (Sqrt) -transformations were used when necessary to meet assumptions for parametric methods. The Wilcoxon rank sum test or the Kruskal–Wallis test was used when assumptions for parametric tests did not hold. Student's paired *t*-test or Wilcoxon signed rank test was used to test for any systematic differences between two measurement sessions. To determine absolute differences between trial variabilities in measurement values, coefficients of variation (CV) of method error were calculated (Portney and Watkins, 1993). The intraclass correlation coefficient, ICC (Shrout and Fleiss, 1979) with 95% confidence intervals was calculated to evaluate the test–retest reliability of the two measurement sessions. The following interpretation was used for ICC values: >0.90 = high reliability, 0.80–0.89 = good reliability, 0.70–0.79 = fair reliability, and <0.70 = poor reliability (Verstappen et al., 1997). Multinomial logistic regression with generalized logit link function was used to calculate odds ratios (OR) for belonging to different groups, for various explanatory variables by themselves, and adjusted for gender. *P*-value less than 0.05 was considered significant. Statistical analyses were carried out using SAS System software version 9.1.3.

3. Results

Among the characteristics of the study group subjects, age and anthropometric measures were similar in all groups. There was a significant difference in gender distribution between the study groups ($P < 0.05$): the majority of participants in the migraine group (87%) were girls (Table 1). A summary of the statistics covering the maximum neck flexion endurance time, relative MF changes with time, and subjective perception and target of neck muscle discomfort/pain (VAS) in adolescents with migraine-type and tension-type headache and the controls is shown in Table 2. Because interaction with gender and group was not significant in the responses it was removed from the model and only main effects were used.

3.1. Endurance time

In the gender-adjusted analysis, no significant difference ($P = 0.050$) emerged among the three study groups in the total endurance time (s) (Ln). In the pairwise comparisons, the tension-type headache group had

Table 2
Summary of statistics on total endurance time (s), relative MF changes with time (TMF, IMF), and subjective perception and target of neck muscle discomfort/pain (VAS) in adolescents with migraine-type headache, tension-type headache and in the control group

	Migraine-type headache (N = 30)		Tension-type headache group (N = 29)		Control group (N = 30)		Gender-adjusted group difference	Pairwise group difference
	Girls (N = 26) Mean (SD)	Boys (N = 4) Mean (SD)	Girls (N = 18) Mean (SD)	Boys (N = 11) Mean (SD)	Girls (N = 14) Mean (SD)	Boys (N = 16) Mean (SD)	*P*-value	*P* < .05
Maximum endurance time (s)	54.1 (25.0)	84.8 (13.9)	51.7 (38.5)	69.8 (28.8)	70.3 (36.3)	93.4 (43.7)	0.050	0.040 TC
TMF (Hz/min)								
Left SCM	−16.9 (10.8)	−16.2 (12.2)	−24.3 (13.7)	−19.8 (10.2)	−14.0 (9.6)	−11.4 (7.2)	0.004	0.003 TC
Right SCM	−14.8 (11.5)	−15.6 (13.5)	−27.7 (9.9)	−17.1 (9.5)	−13.8 (11.8)	−12.1 (7.3)	0.021	0.029 TC
IMF (Hz/min)								
Left SCM	−20.9 (14.8)	−9.3 (13.5)	−23.6 (11.6)	−25.6 (13.8)	−21.3 (12.2)	−13.7 (8.7)	0.065	
Right SCM	−19.2 (10.2)	−16.5 (11.7)	−19.5 (8.0)	−21.8 (13.4)	−20.6 (13.5)	−16.7 (10.2)	0.757	
VAS (0–10 cm)	4.6 (1.9)	5.5 (2.1)	4.6 (1.7)	5.1 (1.9)	3.8 (2.7)	4.3 (2.7)	0.298	
VAS target								
No target (%)	12 (3)	0 (0)	12 (2)	18 (2)	21 (3)	29 (5)		
Neck flexors (%)	36 (9)	25 (1)	47 (8)	27 (3)	58 (8)	29 (5)		
Neck extensors (%)	40 (10)	75 (3)	35 (6)	55 (6)	21 (3)	42 (7)		
Neck flexors/extensors (%)	12 (3)	0 (0)	6 (1)	0 (0)	0 (0)	0 (0)		

Abbreviations: SCM, sternocleidomastoideus muscle; VAS, visual analogue scale; VAS target, location of the neck discomfort/pain; MF, median frequency; TMF, change of median frequency across the total contraction duration; IMF, change of median frequency across the initial 30 s of the total contraction duration; TC, comparison between tension-type headache and control group.

Table 3
Gender-adjusted multivariate associations between variables of total endurance time (s) and relative MF change with time and types of headache

Variable	Migraine-type headache ($N = 30$)		Tension-type headache ($N = 29$)		P-value
	OR	95% CI	OR	95% CI	
Maximum endurance time (s)[a]	0.8	0.7–1.0	0.8	0.7–1.0	0.078
TMF (Hz/min)					
Left SCM[a]	1.5	0.8–2.9	2.5	1.4–4.9	0.009
Right SCM[a]	1.2	0.7–2.1	2.0	1.2–3.7	0.030
IMF (Hz/min)					
Left SCM[a]	1.0	0.6–1.7	1.5	0.9–2.4	0.133
Right SCM[a]	1.0	0.6–1.7	1.1	0.7–1.9	0.749

In the calculation of odds ratios (OR)[a] for migraine-type and tension-type headache, the control group was the reference.
Abbreviations: SCM, sternocleidomastoideus muscle; MF, median frequency; TMF, median frequency of total contraction duration; IMF, initial median frequency (first 30 s of the total contraction duration).
[a] Odds ratios represent a trend in association (10-unit decrease).

significantly lower endurance values than the healthy controls ($P = 0.04$).

3.2. Changes in MF

In gender-adjusted analyses, there was an overall difference in TMF of right SCM ($P = 0.02$) and in TMF of left SCM ($P = 0.005$). In pairwise comparisons, the TMF of right and left SCM decreased significantly faster in the tension-type group than in the control group (right SCM, $P = 0.03$, mean difference 7.3, CI95% 0.6–14.0; left SCM, $P = 0.005$, mean difference (Sqrt) 1.2, CI95% 0.3–2.1). Regarding the variables of IMF of SCM of both sides, no significant differences among the study groups were found. A gender-adjusted multinomial logistic regression analysis was performed on the studied variables (Table 3). In the analysis, the rate of decline in TMF of both sides remained significantly associated with headache (right SCM, $P = 0.030$; left SCM, $P = 0.009$). This raised the odds of belonging to the tension-type group compared with controls (right SCM, OR 2.0, 95% 1.2–3.7; left SCM, OR 2.5, 95% 1.4–4.9) when there was a 10-unit decrease in TMF values. The comparison between the migraine-type headache group and the control group was statistically non-significant (right SCM, OR 1.2, 95% CI 0.7–2.1; left SCM, OR 1.5, 95% CI 0.8–2.9) when the 10-unit decrease in the rate of TMF values of right and left SCM muscles was observed.

There was no interaction effect between the study groups and gender in any of the variables.

The relationship between the slope of TMF of the right SCM and the total endurance time (Ln) of the neck flexors in tension-type headache and the healthy control group is illustrated with a scatter-plot example shown in Fig. 2. There was a significant correlation between the total endurance time (Ln) and TMF of both right and left (Sqrt) SCM (right, $r_p = -0.59$, $P = 0.0016$; left,

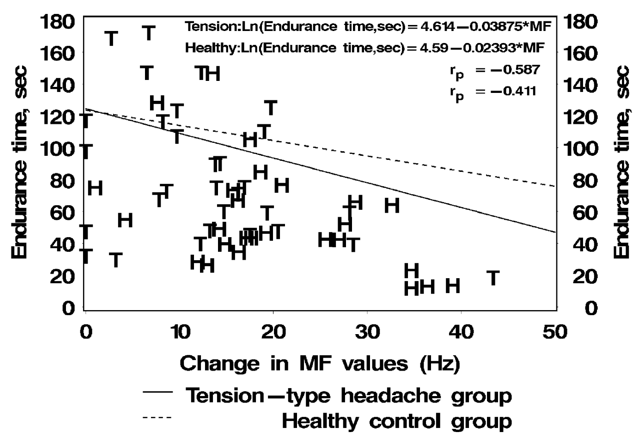

Fig. 2. Scatterplot of relative MF change (Hz) in right SCM with total endurance time (s) of the neck flexors in adolescents with tension-type headache (T) and healthy controls (H).

$r_p = -0.65$, $P = 0.0003$) in the tension-type headache group, and between the total endurance time (Ln) and TMF of right SCM in the healthy control group ($r = -0.41$, $P = 0.02$). There was no significant correlation between the total endurance time and TMF of right and left SCM in the migraine group (right, $r_p = 0.01$, $P = 0.97$; left, $r_p = -0.04$, $P = 0.86$) or between the total endurance time and TMF of left SCM ($r = -0.24$, $P = 0.40$).

No statistically significant differences were found in the TMF and IMF variables of both SCM muscles, nor in the total endurance time (s) and VAS between the adolescents with or without headache on the day of the examination in the migraine group. No significant differences in the corresponding variables were found between the adolescents with headache and those without headache on the day of the examination in the tension-headache group. No statistically significant differences were found in the variables between those with and those without neck–shoulder symptoms during the examination day in the migraine group, nor between

Table 4
The frequency of self-reported tenderness in the neck–shoulder region during daily activities in adolescents with migraine-type and tension-type headache

	Migraine-type headache *N* (%)	Tension-type headache *N* (%)
Never	5 (17)	11 (38)
Sometimes	15 (50)	12 (41)
Often	10 (33)	6 (21)

P-value for the difference between the group distributions = 0.012.

those with and those without neck–shoulder symptoms during the day of the examination in the tension-type headache group. Table 4 presents the frequency of self-reported tenderness in the neck–shoulder region during daily activities. There was an association between group and level of tenderness during daily activities ($P = 0.012$). Adolescents with migraine had subjective neck–shoulder symptoms more frequently than the other groups. The mean interval (days) from the most recent headache attack was 20 ± 26 days in the migraine-type headache group and 12 ± 19 days in the tension-type headache group ($P = 0.070$). The mean interval (days) from the most recent neck–shoulder symptoms was 14 ± 20 days in the migraine-type headache group and 32 ± 72 days in the tension-type headache group ($P = 0.528$). The difference between the groups was not statistically significant.

3.3. Repeatability of measures

The repeatability of the total endurance time and TMF values of right and left SCM was measured by comparing the trial-to-trial results. The CV for the total endurance time was 4.8%, and for the TMF of right and left SCM, 14.0% and 11.0%, respectively. The ICC (intraclass correlation coefficient) for the total endurance time was 0.99, for the TMF of right SCM 0.95, and of left SCM 0.97. Thus, the trial-to-trial repeatability of the total endurance time and the TMF of both SCM muscles in adolescents appeared to be acceptable.

4. Discussion

Our hypothesis that the adolescents with tension-type headache have an increased rate of decline in MF parameters of both SCM muscles was verified. The increased fatigue of SCM muscles appeared during the endurance test up to exhaustion (TMF). The adolescents with migraine did not show a difference in the rate of decline of TMF compared to controls. These results have not been reported earlier in adolescents with headache.

Our results in adolescents are in line with a previous population-based study by Jensen et al. (1994) where the rate of decline in frequency levels of frontal and temporal muscles, indicating muscle fatigue, was associated with chronic tension-type headache in adults. Previously, in adults, it has also been reported that a greater rate of decline in spectral indices of neck flexor muscles is associated with neck pain (Gogia and Sabbahi, 1994), that in and back extensor muscles with low back pain (Roy et al., 1989; Biedermann et al., 1991; Kankaanpää et al., 1998; Mannion et al., 1998). Paraspinal muscle fatigue, tested using a subjective isometric endurance test (s), has also been found to be increased in patients with low-back pain (Biering-Sorenesen, 1984; Nicolaisen and Jorgensen, 1985; Hultman et al., 1993). We found no significant differences in the total endurance time between the study groups, probably due to the rather small number of subjects in our study. In this case, the tension-type headache group had lower endurance values than the healthy controls only in the pairwise comparisons, but this difference was of no clinical importance (only a tendency). There was, however, a significant relationship between the rate of decline in MF of right and left SCM muscles and the total endurance time in the tension-type headache group, and between the rate of decline in MF of right SCM muscle and the total endurance time in the control group. Also in earlier studies close correlations between objective EMG spectral indices and the subjective endurance test (Roy et al., 1989; Mannion and Dolan, 1994; Roy et al., 1995) have been indicated, showing that the shorter the total endurance time, the greater the rate of decline in MF values.

The faster shift in the myoelectric power density spectrum towards lower frequencies is considered to indicate increased muscle fatigue (Edwards, 1981; Horita and Ishiko, 1987). The failure of neural drive, resulting in a reduction in the firing frequency of motor units (MU), has been taken to indicate central fatigue, whereas the failure of force generation of the whole muscle involving impaired neuromuscular transmission and failure of muscle action potentials, might indicate peripheral fatigue (Edwards, 1981). MF has the greatest sensitivity to alterations in the motor units' firing rate compare to other spectral variables (Hägg, 1992). According to Solomonov et al. (1990), MF is less sensitive to noise and more sensitive to muscle-fatigue-related changes during voluntary contractions than other spectral parameters. However, the EMG spectral changes may be influenced by a number of factors: slowing of action potential velocity, synchronization of motor units, slowing of firing frequency, increase in recruitment of motor units, and temperature-related increases in frequency parameters (Hägg, 1992).

There could be several possible explanations for our results. The increased rate of decline in MF values in the tension-type headache subjects may have occurred because they required a higher motor unit recruitment than healthy subjects in order to maintain a static neck flexion position. Reasons for this may be a changed activity strategy of neck flexion muscles or weakness of especially tonic SCM muscles in subjects with tension-type headache. It is possible that the high motor unit recruitment level led to an earlier accumulation of byproducts in the SCM muscles with an earlier recruitment of fast motor units. A diminution of MF values attributed to localized muscle fatigue has been correlated with increased accumulation of metabolites, reduced accumulation of calcium ions (Ca^{2+}), decreased concentration of intramuscular pH, and slowing of intramuscular conduction velocity (DeLuca, 1984; Brody et al., 1991). Previously, reduced metabolism and blood flow due to the increased contraction and weakness of neck muscles have been found to be related to tension-type headache (Harms-Ringdahl and Ekholm, 1986; Jensen et al., 1998). According to Booth (1982), neck flexor underuse might also change the properties of the typically slow-twitch muscle fibres toward those typical of fast-twitch fibres, which become rapidly fatigued. It is also possible that, due to genetic factors, the neck–shoulder muscles in subjects with tension-type headache are originally different from those in migraine or headache-free subjects. An important point is that adolescents in our study had suffered from headache for some years, but did not have chronic daily tension-type headache, indicating that our finding is not only associated with headache becoming chronic.

Adolescents with migraine had subjective neck–shoulder symptoms. In the present study, however, SCM muscle fatigue did not differ between migraine and controls. It might be that the mechanisms for disorders of the neck–shoulder area in migraine and tension-type headache are different. Subjects with migraine-type headache could modulate motor neuron activities in a different way compared to the tension-type headache group. It is also possible that subjects with migraine inhibit motor unit recruitment and compensate for the use of SCM tonic muscle with other phasic or deeper muscles. The dysfunction of the agonist muscle may be compensated for by simultaneous, increased antagonist muscle activity. Migraine headache itself may change and sensitize the person's ability to recruit the neck flexors and extensors by way of exception during the maximal effort of the neck muscles. A recent study by Valeriani et al. (2005) indicated that the primary somatosensory cortex is hyper-excitable in children with migraine.

The strength of the present study is that our data are population-based and consequently not weakened by the selection bias related to clinical patients. Further, the headache types were classified accurately according to the IHS criteria (1988) by the same trained pediatrician. The second, present edition of the International Classification of Headache Disorders (ICHD 2004) had not yet been published at the time of data collection. Cervicogenic headache according to the ICHD 2004 criteria could not be excluded in our patients. However, the clinical picture and careful investigation by a neurologist and a physiatrist in the third phase of the study did not indicate cervicogenic headache. In the study, the consistency of the repeated measurements was assessed, and showed high trial-to trial repeatability between the measurements. The study groups did not differ in subjective discomfort/pain in the neck–shoulder area during the measurement, nor in the interval from the most recent headache episode. As shown in a previous study (Anttila et al., 2002b), the migraine group had subjective neck–shoulder symptoms more frequently during daily activities than the tension-type group. Thus, the frequency of the neck–shoulder symptoms had no influence on the results of the tension-type group.

The design of the present study is cross-sectional. However, a longitudinal study would be valuable for a better understanding of the relation between the measured factors and the etiology of headache in adolescents. In this study, the individual anthropometric factors such as head weight, length of neck and cross-sectional area of the neck flexors were not measured, and these may have affected the degree of load applied to the neck flexors. However, because the IMF values were similar and did not differ significantly between the study groups, we may assume that the loading of the SCM muscles was similarly distributed in the initial phase of the endurance test; that is, the adolescents in all study groups performed the test in the same way. In this study, the possibility of the cross-talk phenomenon (activity from underlying or adjacent muscles) was considered, and we tried to decrease it by investigating the muscles with clear muscle mass, with a small electrode diameter and interelectrode distance, spacing and location of the electrodes relative to the muscle mass, as well as careful skin preparation. In addition, electrodes with preamplification were used to decrease artefacts.

In conclusion, this cross-sectional study in adolescents indicates a positive association between tension-type headache and increased fatigue of the neck flexors. However, it remains unknown whether the results are primary or secondary to the adolescent headache.

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