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Neck muscle function and adolescent headache

by

Airi Oksanen

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From the Departments of Physical and Rehabilitation Medicine, Public Health, and Child Neurology, University of Turku, Turku, Finland

Supervised by

Docent Jouko J Salminen, MD, PhD
Department of Physical and Rehabilitation Medicine,
University of Turku, Turku, Finland

and

Docent Liisa Metsähonkala, MD, PhD
Department of Child Neurology,
Helsinki University Central Hospital, Helsinki, Finland

Reviewed by

Docent Esa-Pekka Takala, MD, PhD
Centre of Expertise for Health and Work Ability,
Finnish Institute of Occupational Health, Helsinki, Finland

and

Professor Ari Heinonen, PT, PhD
Department of Health Sciences,
University of Jyväskylä, Jyväskylä, Finland

Dissertation opponent

Professor Arja Häkkinen, PT, PhD
Department of Physical and Rehabilitation Medicine,
Jyväskylä Central Hospital, and
Department of Health Sciences,
University of Jyväskylä, Jyväskylä, Finland

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To Adolescents

ABSTRACT

Airi Oksanen

Neck muscle function and adolescent headache

Departments of Physical and Rehabilitation Medicine, Child Neurology, and Public Health, University of Turku, Finland.

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Muscular function of the neck region may be of importance for the etiology of headache, especially of tension-type headache. However, very few data exist on the association of neck muscle function with different types of headache in adolescents. The main aim of the study was to examine the association of neck muscle function with adolescent headache. The associations between leisure time activities, endurance strength of the upper extremities (UE endurance) and mobility of the neck-shoulder region and adolescent headache were studied. In addition, the associations of force production, EMG/force ratio, co-activation and fatigue characteristics, and cross-sectional area (CSA) of neck muscles with adolescent headache were studied.

The study is part of a population-based cohort study of 12-year-old children with and without headache. The study had five phases (years 1998-2003). At the age of 13 years, a sample of 183 adolescents (183/311) participated in muscle endurance strength and mobility measurements of the neck-shoulder region. In addition, the type and level of physical and other leisure activity were elicited with open and structured questions. At the age of 17 years, a random sample of 89 adolescents (89/202) participated in force and EMG measurements of the neck-shoulder muscles. In addition, at the age of 17 years, a sample of 65 adolescents (65/89) participated in CSA measurements of the neck muscles.

At the age of 13 years, intensive participation in overall sports activity was associated with migraine. Frequent computer use was associated both with migraine and tension-type headache. The type of sports or other leisure activity classified them on the basis of body loading was not associated with headache type. In girls, low UE endurance of both sides, and low cervical rotation of the dominant side, were associated with tension-type headache, and low UE endurance of non-dominant side with migraine. In boys, no associations occurred between UE endurance and mobility variables and headache types. *At the age of 17 years*, in girls, high EMG/force ratios between the EMG of the left agonist sternocleidomastoid muscle (SCM) and maximal neck flexion and neck rotation force to the right side as well as high co-activation of right antagonist cervical erector spinae (CES) muscles during maximal neck flexion force were associated with migraine-type headache. In girls, neck force production was not associated with headache types but low left shoulder flexion force was associated with tension-type headache. In boys, no associations were found between EMG and force variables and headache. Increased SCM muscles fatigue of both sides was associated with tension-type headache. In boys, the small CSA of the right SCM muscle and, in girls, of combined right SCM and scalenus muscles was associated with tension-type headache. Similarly, in boys, the large CSA of the right SCM muscle, of the combined right SCM and scalenus muscles, of the left semispinalis capitis muscle, of the combined left semispinalis and splenius muscles was associated with migraine. No other differences in the CSA of neck flexion or extension muscles were found.

Differences in the neuromucular function of the neck-shoulder muscles were associated with adolescent headache, especially in girls. Differences in the cross-sectional area of unilateral neck muscles were associated with headache, especially in boys. Differences in the neuromuscular function and in the cross-sectional area of the neck muscles also occurred between different types of headache. It remains to be established whether the findings are primary or secondary to adolescent migraine and tension headache.

Keywords: adolescent, cross-sectional area, electromyography, endurance strength, fatigue, force, headache, leisure time activity, migraine, mobility, neck muscles, tension-type headache

TIIVISTELMÄ

Airi Oksanen

Niskalihasten toiminta nuorten päänsäryssä

Fysiatrian ja Lastenneurologian yksikkö, Kansanterveystieteen osasto, Turun Yliopisto, Suomi.

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Niskalihasten toimintahäiriöillä voi olla merkitystä päänsäryn aiheuttajana, erityisesti tensiotyyppisessä päänsäryssä. Tutkittua tietoa niskalihasten toiminnan ja päänsäryn yhteydestä lapsilla ja nuorilla on olemassa erittäin vähän.

Tutkimuksen päätarkoituksena oli selvittää niskalihasten toimintahäiriöiden yhteyttä nuoren päänsärkyyn. Tutkimuksessa tutkittiin vapaa-ajan harrastusten, niskahartiaseudun kestävyysvoiman ja liikkuvuuden sekä niskalihasten voiman, EMG/voimasuhteen, yhtäaikaisen aktivoitumisen, väsyvyyden ja poikkipinta-alan yhteyttä nuoren päänsärkyyn.

Tämä tutkimus on osa väestöpohjaista 12-vuotiaiden päänsärkyisten ja päänsäryttömien lasten kohortti-tutkimusta. Tutkimus koostuu viidestä eri vaiheesta (vuodet 1998-2003). 13-vuotiaina 183 nuorta (183/311) osallistui niskahartiasedun lihasten kestävyyden ja liikkuvuuden mittauksiin. Lisäksi selvitettiin liikunnan ja muun vapaa-ajan harrastuksen sisältöä ja määrä avoimilla ja suljetuilla kysymyksillä. 17-vuotiaina 89 nuorta (89/202) osallistui niskalihasten voima- ja EMG-mittauksiin. Lisäksi 17-vuotiaina 65 nuorta (65/89) osallistui niskalihasten poikkipinta-alamittauksiin.

Nuorten ollessa 13-vuotiaita, liikunnan harrastamisen intensiivisyys oli yhteydessä migreeniin ja tietokoneen runsas käyttö sekä migreeniin että tensiotyyppiseen päänsärkyyn. Liikunnan tai muulla vapaa-ajan harrastuksella, luokiteltaessa harrastukset kehon eri osien kuormittavuden suhteen, ei ollut yhteyttä päänsärkyyn. Tytöillä alhainen sekä hallitsevan että ei-hallitsevan puolen hartiaseudun lihaskestävyys ja alentunut niskan kiertoliike hallitsevalle puolelle olivat yhteydessä tensiotyyppiseen päänsärkyyn ja ei-hallitsevan puolen alhainen hartiaseudun lihaskestävyys migreeniin. Pojilla ei esiintynyt eroja lihaskestävyyden ja liikkuvuuden suhteen eri päänsärkyryhmissä. Nuorten ollessa 17-vuotiaita, tytöillä korkea EMG/voimasuhde vasemman puolen sternocleidomastoideus lihaksen (SCM, agonisti) EMG aktiivisuuden ja vastaavan niskalihasten maksimaalisen fleksiovoiman ja oikealle suunnatun maksimaalisen kiertovoiman välillä oli yhteydessä migreeniin. Lisäksi korkea oikean puolen niskan ojentajalihasten (CES, antagonisti) yhtäaikainen aktivoituminen maksimaalisen fleksiovoimantuoton aikana olivat yhteydessä migreeniin. Tytöillä niskalihasten voima ei ollut yhtey-dessä päänsärkytyyppiin, mutta alhainen olkanivelen fleksiovoima oli yhteydessä tensiotyyppiseen päänsärkyyn. Pojilla ei esiintynyt eroja niskalihasten voiman ja EMG-aktiivisuuden suhteen eri päänsärkyryhmissä. Sekä oikean että vasemman puolen SCM lihasten lisääntynyt väsyvyys oli yhteydessä tensiotyyppiseen päänsärkyyn. Pojilla oikean SCM lihaksen pieni poikkipinta-ala ja tytöillä oikean puolen yhdistetyn SCM ja scalenus lihaksen pieni poikkipinta-ala olivat yhteydessä tensiotyyppiseen päänsärkyyn. Vastaavasti pojilla suuret oikean puolen SCM lihaksen, oikean puolen yhdistetyn SCM ja scalenus lihaksen, vasemman puolen semispinalis capitis lihaksen, yhdistetyn semispinalis capitis ja splenius lihaksen poikkipinta-alat olivat yhteydessä migreeniin. Muissa niskalihasten poikkipinta-aloissa ei esiintynyt eroja ryhmien välillä tytöillä ja pojilla.

Niska- ja hartialihasten toiminnan poikkeavuudet olivat yhteydessä päänsärkyyn, erityisesti tytöillä. Toispuoliset poikkeavuudet niskalihasten poikkipinta-alassa olivat yhteydessä päänsärkyyn, erityisesti pojilla. Niskalihasten toiminnassa ja poikkipinta-alassa esiintyi myös eroja päänsärkyryhmien välillä. Se, ovatko löydökset nuorilla päänsärkyä aiheuttavia tekijöitä vai seurausta päänsärystä jää selvitettäväksi.

Avainsanat: elektromyografia, kestävyysvoima, liikkuvuus, migreeni, niskalihakset, nuori, poikkipinta-ala, päänsärky, tensiotyyppinen päänsärky, vapaa-ajan harrastus, voima, väsymys

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ABBREVIATIONS

C1/C2	intervertebral disc level between C1 and C2
C4/C5	intervertebral disc level between C4 and C5
CI	confidence interval
CNS	central nervous system
CROM	cervical range of motion
CSA	cross-sectional area
CV	coefficient of variation
EMG	electromyography
Hz	herz
ICC	intraclass correlation coefficient
ICD 10	International Classification of Diseases
ICHD 1	Headache Classification Committee of the International Headache Society. Classification and diagnostic criteria for headache disorders, cranial neuralgias and facial pain. 1st edition at 1988
ICHD 2	Headache Classification Subcommittee of the International Headache Society. The International Classification of Headache Disorders, 2nd edition at 2004
IHS	International Headache Society
kΩ	kilo-ohm
GΩ	giga-ohm
MF	median frequency
MRI	magnetic resonance imaging
μV	microvolt
MVC	maximal voluntary contraction
ms	millisecond
N	newton
Nm	Newton meter
OR	odds ratio
p	significance level, p-value
ROM	range of motion
SD	standard deviation
VAS	visual analogue scale
WHO	World Health Organization

LIST OF ORIGINAL ARTICLES

This work is based on the following original articles, which are referred to in the text by Roman numerals I-V:

I Oksanen A, Metsähonkala L, Anttila P, Aromaa M, Jäppilä E, Viander S, Salminen J, Helenius H, Sillanpää M. Leisure activities in adolescents with headache. Acta Pædiatrica 2005;94:609-615.

II Oksanen A, Metsähonkala L, Viander S, Jäppilä E, Aromaa M, Anttila P, Salminen J, Sillanpää M. Strength and mobility of the neck-shoulder region in adolescent headache. Physiotherapy Theory and Practice 2006;22:163-174.

III Oksanen A, Pöyhönen T, Ylinen JJ, Metsähonkala L, Anttila P, Laimi K, Hiekkanen H, Aromaa M, Salminen JJ, Sillanpää M. Force production and EMG activity of neck muscles in adolescent headache. Disability and Rehabilitation 2008;30:231-239.

IV Oksanen A, Pöyhönen T, Metsähonkala L, Anttila P, Hiekkanen H, Laimi K, Salminen JJ. Neck flexor muscle fatigue in adolescents with headache – An electromyographic study. European Journal of Pain 2007;11:764-772.

V Oksanen A, Erkintalo M, Metsähonkala L, Anttila P, Laimi K, Hiekkanen H, Salminen JJ, Aromaa M, Sillanpää M. Neck muscles cross sectional area in adolescents with and without headache – MRI study. Accepted for publication in European Journal of Pain.

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1. INTRODUCTION

Headache is a major and common disorder already in children and adolescents (Perquin et al. 2000 Petersen et al. 2003, Roth-Isigkeit et al. 2004), and it represents the most common pain in children after musculoskeletal and abdominal pain (Kristjandottir 1997, Perquin et al. 2000, Roth-Isigkeit et al. 2004). Headache contributes a large burden of disability, loss of schooldays, diminished quality of life and causes a substantial cost to parents and the healthcare system. Over the recent decades, the prevalence of childhood and adolescent headache seems to have increased (Bandell-Hoekstra et al. 2001, Laurell et al. 2004, Anttila et al. 2006).

Previous studies have demonstrated that there is an association between headache and neck and shoulder muscle disorders both in adults (Jensen et al. 1994, Jensen 1996, Bendtsen et al. 1996, Ulrich et al. 1996, Jensen et al. 1998, Bansevicius et al. 1999) and in children (Pritchard 1995, Anttila et al. 2002b). In addition, in adults, it has been suggested that increased muscle strength may also prevent headache with neck-shoulder symptoms (Levoska and Keinänen-Kiukaanniemi 1993). The knowledge concerning the role of muscular function of the neck and shoulder region in headache symptoms in children and adolescents is scarce. Thus, there is a need for further detailed and comprehensive population-based studies on the association between different types of headache and neuromuscular function of the neck-shoulder region in adolescent headache. Proneness to headache appears in childhood and some of the possible pathophysiological factors might appear most clearly in childhood and among young people. Neuromuscular factors of the neck region may have an essential role in the etiology of some types of headache already early in life. On the other hand, neuromuscular differences in the neck region may be a consequence of headache. A better understanding of muscular function in headache might have implications for the development of non-pharmagolocial treatment programmes designed to target specific problems, and for the prevention of chronic headache. In addition, the identification of typical musculoskeletal abnormalities in subjects with headache should aid in developing examination methods for headache subjects to identify those abnormalities. There are no population-based studies on the association between primary headaches and physical activity and neuromuscular function of neck-shoulder muscles in adolescents. The main emphasis of this population-based study was to investigate the possible associations between primary headaches (migraine and tension-type headache) and neuromuscular function of the neck-shoulder muscles in adolescents.

2. REVIEW OF THE LITERATURE

Headache can be a symptom of several somatic or psychiatric disorders also in children and adolescents. Migraine and tension-type headache represent the primary headache types and are very frequent already in children and adolescents. The definition of primary headache relies exclusively on the symptoms. The definitions are distinctive but the borderlines between different headache types are not always clear in practice (Olesen 2000).

2.1. Definition and prevalence of headache

In 1988 the International Headache Society (IHS) committee published the first international headache classification that included operational diagnostic criteria for all headache disorders (ICHD-1 1988) (Headache Classification Committee of the International Headache Society 1988). The Word Health Organization (WHO) accepted the major principles of the classification, which have been used in the International Classification of Diseases 10 (ICD 10) (World Health Organization 1992-1994). The second edition of the International Classification of Headache Disorders was published in 2004 (ICHD-2 2004) (Headache Classification Subcommittee of the International Headache Society 2004). This classification consisted of 14 major groups for headache, divided into subgroups, which are further divided into subgroups **(Table 1).** The diagnostic criteria of tension-type headache and migraine are virtually the same from 1988 to 2004.

Table 1. Headache classification of the International Headache Society (ICHD-2 2004).

1.	Migraine
2.	Tension-type
3.	Cluster headache and other trigeminal autonomic cephalalgias
4.	Other primary headaches
5.	Headache attributed to head and/or neck trauma
6.	Headache attributed to cranial or cervical vascular disorder
7.	Headache attributed to non-vascular intracranial disorder
8.	Headache attributed to a substance or its withdrawal
9.	Headache attributed to infection
10.	Headache attributed to disorder of homeostasis
11.	Headache or facial pain attributed to disorder of cranium, neck, eyes, ears, nose, sinuses, teeth, mouth, or other facial or cranial structures
12.	Headache attributed to psychiatric disorder
13.	Cranial neuralgias and central causes of facial pain
14.	Other headache, cranial neuralgia, central or primary facial pain

Previously tension-type headache has been an ill-defined syndrome. The terms muscle contraction headache, tension headache, psychogenic headache, psychomyogenic headache, stress headache, essential headache, and non-migrainous headache have been used interchangeably without operational definitions (ICHD-2 2004). Generally, in tension-type headache (episodic form), the pain is typically bilateral, pressing or tightening in quality, and of mild to moderate intensity. The pain does not worsen with routine physical activity and there is no nausea, but photophobia or phonophobia may be present (ICHD-1 1988; ICHD-2 2004). The detailed diagnostic criteria of the ICHD-2 (2004) major group of tension-type headache are presented in Appendix 1 in Table 2.

Migraine is a recurrent headache disorder that may present with a variety of neurological and non-neurological manifestations. It has been classified into two major subtypes: migraine without aura (common migraine) and migraine with aura (ICHD-2 2004). The typical features of migraine without aura are unilateral location, pulsating quality, moderate or severe intensity, aggravation by routine physical activity, and association with nausea and/or phonophobia and photophobia. Migraine with aura (classic migraine) is a syndrome characterized by recurrent attacks of reversible focal neurological symptoms that usually develop gradually over 5 to 20 minutes, and last for less than 60 minutes, followed by headache that fulfils the same criteria as migraine without aura (ICHD-2 2004). The detailed diagnostic criteria of the ICHD-2 (2004) of the major group of migraine are presented in Appendix 2 in Table 3. The IHS classification of migraine is similar for adults and children. However, the duration of a minimum headache attack in children with migraine without aura is two hours, and in adults with migraine four hours.

Prevalence rates of migraine and tension-type headache vary between different studies. The discrepancy is most likely due to differences in the headache diagnostic criteria, the sampling methods used, the age and sex of the study population, the country of origin, and the presentation and analysis of data (McGrath 2001, Stovner et al. 2006).

The prevalence rate of headache increases with age in children, with female predominance, after the age of 13 years (Bille 1997, Aromaa et al. 2000, Bandell-Hoekstra et al. 2001, Boardman et al. 2003, Russell et al. 2006). The headache prevalence increases slightly from adolescence to adulthood, and it declines from middle age with advancing age (Hagen et al. 2000, Stovner et al. 2006).

In different populations, the prevalence of adolescent migraine varies from 3% to 22% (Pothmann et al. 1994, Raieli et al. 1995, Lu et al. 2000, Anttila et al. 2002a, Zwart et al. 2004, Wang et al. 2005, Russell et al. 2006, Laurell et al. 2006). Migraine has been found in 4-10% among boys, and 8-18% among girls (Abu-Arafeh et al. 1994, Barea et al. 1996, Lu et al. 2000, Zwart et al. 2004). Migraine is more common in girls than in boys after the age of 10 years, and the peak prevalence rates occur during middle age (Stovner et al. 2006, Russell et al. 2006).

In tension-type headache, the prevalence rates in adolescents have varied from 10% to 25%, being higher in girls than in boys (Anttila et al. 2002a, Özge et al. 2003, Zwart et al. 2004, Laurell et al. 2004). In a twin study by Russell et al. (2006), the prevalence of adolescent tension-type headache has been shown to be as high as 81-91% among girls, and 79% among boys. In this study, the twins showed no significant difference in tension-type headache analyzed separately by gender. The frequent and chronic tension-type headache has been shown to increase in both genders from 12 to 39 years of age (Russell et al. 2006). The chronic tension-type headache has been suggested to be rare in 12-14 year-old adolescents (Russell et al. 2006), the prevalence rate being 4-5% (Perquin et al. 2000).

2.2. Pathophysiological aspects of headache

The basic mechanisms of the different headache types are unclear, and overlapping symptoms are frequent, and differentiation between tension-type headache and migraine may be difficult, especially in children (Anttila 2006). Whether primary headache disorders represent heterogeneous entities, each with its unique pathophysiology, or are different clinical expressions of the same pathophysiological process is not certain (Cady et al. 2002).

2.2.1. Tension-type headache

Scientific interest in tension-type headache has been sparse (Bendtsen 2000, ICHD-2 2004, Anttila 2006). One simple pathophysiological mechanism cannot be expected in tension-type headache and, therefore, the mechanism is most likely multifactorial (Russell et al. 1998, Jensen 1999). Environmental factors may have an effect on the development of episodic tension-type headache (Ulrich et al. 2004), while genetic factors may be important in chronic tension-type headache (Östergaard et al. 1997, Russell et al. 1998).

In adults, peripheral pain mechanisms might be pivotal in episodic tension-type headache, while central pain mechanisms might play an important role in chronic tension-type headache (Russell et al. 1998, Jensen 1999). The interaction between peripheral nociceptive and mechanoceptive second-order brainstem neurons and their descending control systems in tension-type headache is shown in Figure 1.

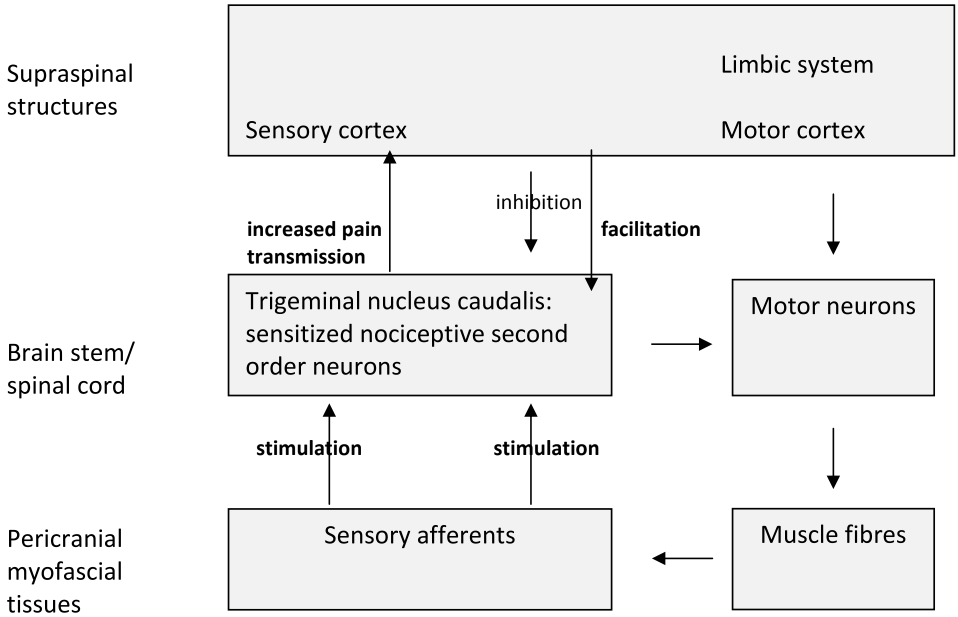


Figure 1. The interaction between peripheral nociceptive and mechanoceptive second-order brainstem neurons and their descending control systems in tension-type headache.

However, it is increasingly evident that the central mechanisms are also involved in the pathophysiology of episodic tension-type headache (Bendtsen 2000), and that the central sensitization and/or an impaired supraspinal modulation of prolonged incoming nociceptive stimuli from myofascial tissue may be of importance in chronic tension-type headache (Jensen 1999, Bendtsen 2000). In children and adolescents, knowledge about the pain mechanisms of tension-type headache is still lacking (Anttila 2006).

Pain thresholds are lower in the area of the cranium than in the extremities (Petersen et al. 1992). A general lowering of pain thresholds and thus increased sensitivity could result in head pain. There is increasing evidence that pain perception is not a simple reflection of simultaneous afferent noxious input, but a dynamic process that is highly influenced by the effects of past experience (Olesen and Schoenen 2000). Peripheral and central sensitization of nociceptors plays a pivotal role in these processes, involving striking biochemical and physiological changes in primary and second-order nociceptive neurons (Woolf 1996, Bendtsen 2000).

An acute episode of tension-type headache may be viewed as a deflection of the normal mechanisms of nociception and central modulation of nociception from myofascial tissues, or increased afferent nociceptive input from the myofascial tissues (Olesen and Schoenen 2000, Bendtsen 2000) **(Figure 1).**

Long-term immobilisation, physical stress, nonphysiological static working position and lack of rest or sleep may increase nociception from strained muscles and may cause them to hurt. In this case, increased nociception from strained muscles may also be the primary cause of the headache attack. Myofascial tissues need exercise because they are constructed to move. In addition, recurrent changes of positions are necessary for joints and fascia. During normal functioning, there is a constant cross-talk between myofascial tissues and the central nervous system elicting the necessary changes in position and the necessary rest and, thus, the person is protected from increased nociceptive input from myofascial tissue and muscle pain (Olesen and Schoenen 2000). In addition, various noxious and innocuous events, such as ischemia, mechanical stimuli and chemical mediators, may excite and sensitize myofascial tissue (Mense 1993, Mense et al. 2001, Bendtsen 2000), and may therefore result in headache (Bendtsen 2000).

Increased input in myelinated Aδ fibres (pain impulses) and unmyelinated C fibres may cause an increased sensitivity of neurons of the trigeminal tract, and pain may then propagate itself to some extent (Olesen and Schoenen 2000, Bendtsen 2000). Under normal circumstances, increased nociceptive activation is counteracted by descending anti-nociceptive systems (Bendtsen 2000). The tension-type headache is favoured by an inadequate activation of pain-controlling pathways, possible because of stress, anxiety, and emotional disturbances. The latter may increase muscle tension through the limbic system of muscle control and through input from nociceptive muscle afferents (Olesen and Schoenen 2000, Merskey and Boduk 2004).

Chronic tension-type headache usually develops from the episodic tension-type headache. Prolonged painful input from the periphery may cause central sensitization in the trigeminal system (**Figure 1**). Such mechanisms have been demonstrated in animal models where irritative stimuli from myofascial deep tissues have been found to be much more effective for induction of central sensitization than cutaneous stimuli (Burstein et al. 1998). Myofascial factors are thus likely to contribute to the chronification of pain. When the central sensitization becomes sufficiently strong and widespread, the pain becomes chronic as a result of self-perpetuating disturbances in pain perception. A vicious circle may be initiated, and incoming peripheral stimuli may produce an increased sensitization reaction and probably maintain it long after the primary causative stimulus or stressor has stopped. Initiating and chronifying mechanisms are less clear in tension-type headache unassociated with muscular disorder. In these patients, there may be differences only in the central processing mechanisms (Jensen 1999, Bendtsen 2000, Olesen and Schoenen 2000).

2.2.2. Migraine

The neural mechanisms underlying the development of migraine attacks are not completely clear. However, the mechanisms are better known than those in tension-type headache. According to recent studies, increased neuronal excitability of the central nervous system is a pivotal factor in the pathophysiology of migraine headache (Burstein 2001, Valeriani et al. 2005, Welch 2005, Moskowitz 2007).

Migraine attack can be precipitated by a wide variety of internal and external factors, such as psychosocial stress, hormonal changes, certain foods, and lack of sleep, as well as visual and auditory stimulation (Burstein 2001). The factors triggering a migraine attack appear to vary through complex interactions with physiological, environmental and genetic factors (Ulrich et al. 1999, Burstein 2001, de Tommaso 2005). Several hypotheses have emerged regarding the initiation of migraine pain: 1) activation of peripheral sensory fibres that innervate intracranial blood vessels and the dura mater, 2) activation of descending pathways that facilitate processing of pain signals by spinal cord neurons, and 3) suppression of descending pathways that inhibit such processing of pain signals in the spinal cord (Burstein 2001, Moskowitz 2007). The clinical characteristics of migraine with aura (visual disturbances, hemisensory symptoms, hemipareses, or dysphasia, or combinations thereof) demonstrate that migraine originates from the cerebral cortex. This view is based on the finding of many similar characteristics of migraine with aura and without aura, the frequent co-occurrence of the two conditions, a number of pathophysiological similarities, and the identical response of both forms to prophylactic and acute treatment (Lance and Goadsby 1998).

Positron emission tomography scans during the acute migraine attack have shown that migraine is an episodic dysfunction of brainstem or diencephalic sensory modulation systems (Weiller et al. 1995). These systems control input from pain-producing trigeminal nerves that innervate the large intracranial vessels and dura mater, and whose cell bodies are found in the trigeminal ganglion (Weiller et al. 1995, Burstein 2001, Goadsby 2001). Referral of pain to the back of the neck results from projections from the high cervical nerves (C1/C2) onto neurons of the trigeminal nucleus, which is known to descend to the C2 level of the cervical spinal cord (trigeminocercival complex) (Goadsby 2001). It is likely that acute attack treatments, such as triptans, target this trigominovascular system which is responsible for pain expression, whereas preventive medications affect the central control systems involved in the genesis of the attacks (Lance and Goadsby 1998).

Olesen (1991) has shown a model of migraine pain perception (vascular-supraspinal-myogenic integration model) that includes the source of pain and also its central modulation. Neurons in the nucleus caudalis are known to integrate nociceptive input from intracranial and extracranial tissues and to receive supraspinal facilitatory and inhibitory inputs **(Figure 2).**

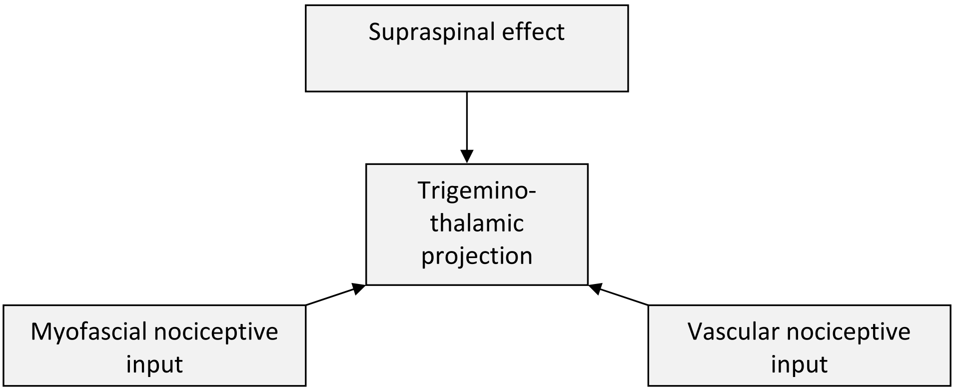


Figure 2. The interaction between vascular, supraspinal, and myogenic factors in migraine.

On the basis of the model, a marked modulation in the central nervous system (CNS), and neurons in the nucleus caudalis of the tract of the trigeminal nerve are the key importance in migraine pain perception. The neurons in the nucleus caudalis receive input not only from the vasculature but also from other structures of the head (Olesen and Goadsby 2000). Myofascial input interacts with vascular input. This marked myofascial input may trigger migraine attacks and aggravate migraine. The supraspinal control of these neurons is important, some pathways increasing the sensitivity of these neurons, others decreasing the sensitivity via the endogenous antinociceptive system (Olesen 1991, Burstein 2001). Emotional factors play a primary role in the supraspinal control system. Even if the migraine pain is primarily vascular or dural, additional nociceptive input from muscles may also contribute to migraine pain. The strong vascular input of the migraine attack is usually enough to fire the neurons in the nucleus caudalis. A modest additional input from pericranial muscles, then, is sufficient to fire the neurons and cause pain. This explains the increased tenderness of pericranial tissues during migraine attacks, and the effect of trigger point injections (Olesen and Goadsby 2000). Supraspinal control may enhance or diminish the pain caused by a certain nociceptive input. The aggravating effect of psychosocial or physical stress, and the ameliorating effect of relaxation, are most likely affected via supraspinal control of neurons of the trigeminal nucleus caudalis. The vascular-supraspinal-myogenic model of migraine pain perception provides a rationale for the different, generally accepted treatment modalities in migraine. Pharmacological treatment reduces vascular neuronal input. Psychological and behavioural techniques reduce supraspinal inhibition, while methods of physiotherapy, biofeedback, and trigger point injections reduce myofascial input (Olesen and Goadsby 2000).

2.3. Function of neck muscles

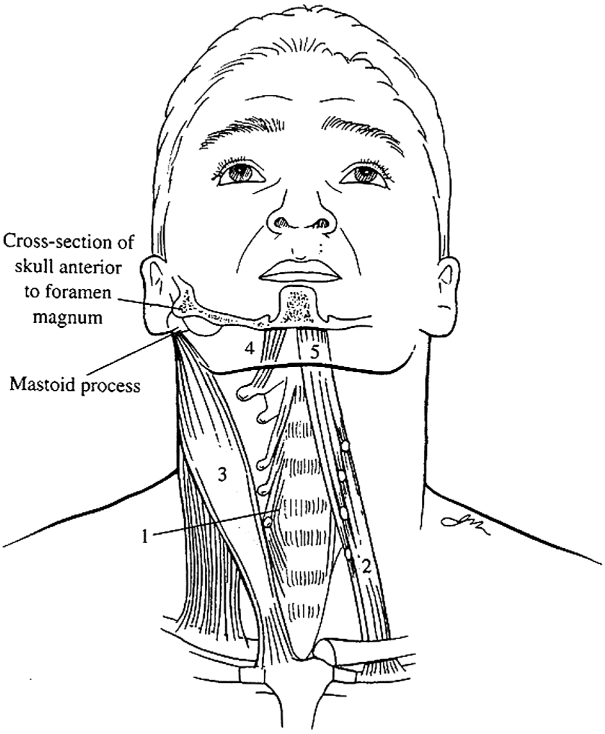
Neck muscle function is multifaced. The muscle system of the flexible cervical column must permit three-dimensional head movements in space, and maintain mechanical stability of the head and neck in all orientations, as well as distribute loads within local neck tissue from the weight of the head and the functional upper limbs (Nordin and Frankel 2001). The muscle system of the neck is closely connected with eye function, vestibular function and proprioceptive systems that serve local needs, and also the needs of postural orientation and stability of the whole body (Keshner 1990).

Normal function of the cervical spine depends on strength, recruitment capacity, coordination, and proper flexibility of neck muscles, which also have a close relationship with each other (Hertling and Kessler 1996, O'Leary et al. 2003, Nordin and Frankel 2001). In the cervical spine, muscle strength also has a role in reducing stresses on bones (Nordin and Frankel 2001). The head is held in a balanced, erect, anatomical position partly by its own weight pressing down on the atlanto-occipital joint and by the isometric and coordinated action of the neck muscles. The function of antagonists is important in head and neck movements because the movement is largely completed by gravity. The antagonists then have the role of regulating the gravity movement and checking it at the appropriate point. For instance, when the head and the neck are bent forward in flexion, the antagonist muscles extend and control the forward fall of the head produced by gravity (Edvinsson and Dahl 2000).

All muscles of the neck have a role in motion and in postural control of the cervical region. The varying locations, attachments, lever arms, and fibre composition of individual muscles define their primary function (Nordin and Frankel 2001).

Flexors of the head and neck

The flexion muscles exert their action anterior to the axis of motion of the atlanto-occipital and the intervertebral joints. Some of the muscles lie close to the anterior surface of the bodies of the cervical vertebrae (Lehmkuhl and Smith 1983). The primary anterior head and neck flexion muscles are presented in Figure 3.



1. Longus colli
2. Scalenus anterior
3. Sternomastoid
4. Rectus capitus anterior
5. Longus capitis

Figure 3. Head and neck flexion muscles (Clarkson 2000, reproduced with permission of the copyright holder, Lippincott, Williams & Wilkins).

The deepest of these muscles are the short rectus capitis anterior muscles, acting on the atlanto-occipital joint only. Of the deep anterior neck muscles, the longus capitis act both on the head and the cervical spine, while the longus colli acts on the neck only. They are small muscles with origins in and insertions on the bodies of the cervical vertebrae. In spite of their size, they are very strong and have very good leverage. The main action of these muscles is flexion of the head and neck, and they may also have an effect on lateral bending and on rotation. In general, they aid in balancing the head and the cervical spine. The longus muscles cover portions of the anterior convexity of the cervical curve of the vertebral column and may prevent an undue increase in this curve because of the vertical pressure of the head on the spinal column. These muscles are important postural muscles that aid in the maintenance of proper alignment of the cervical spine (Lehmkuhl and Smith 1983, Hertling and Kessler 1996).

The other major flexors are the scalenus muscles, which have their origins in the first and second ribs and their insertions on the lateral tubercles of C2 to C7. Acting bilaterally, the scalenus muscles flex the neck on the thorax or elevate the upper ribs. Because of their antero-lateral location, when acting on one side, they bend the neck laterally. In the erect position, they contribute to the balance of the neck both anteriorly and laterally. With the cervical spine stabilized, they aid in elevation of the upper ribs (in breathing) (Lehmkuhl and Smith 1983). The sternocleidomastoid muscle is the strongest and the most superficial of the anterior neck muscles. From its dual origins in the sternum and clavicle, it inserts on the mastoid process, posterior to the centre of gravity of the head. When both heads of the sternocleisomastoid are contracted together, they act as flexors of the neck but extensors of the head. When only one side is contracted, the head and neck are laterally flexed and are rotated to the opposite side. Flexion of the head is accomplished by stabilization of the mandible by the muscles of mastication and a downward pull on the mandible by the strap (suprahyoid and infrahyoid) muscles (Hertling and Kessler 1996, Clarkson 2000).

Extensors of the head and neck

The posterior extensor muscles as a group have considerably more bulk than the anterior ones, indicating that greater strength is needed in extension than in flexion (Lehmkuhl and Smith 1983). The primary head and neck extension muscles are presented in Figure 4.

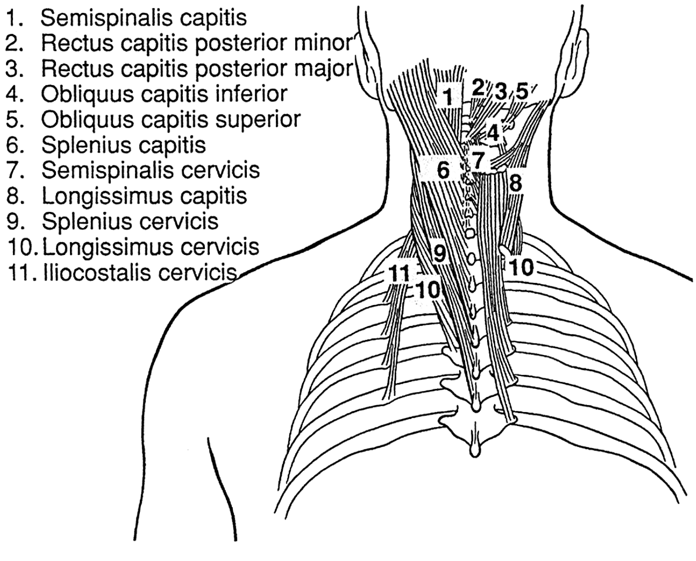


Figure 4. Head and neck extension muscles (Clarkson 2000, reproduced with permission of the copyright holder, Lippincott, Williams & Wilkins).

Among the deepest extensor muscles, there is a group of short suboccipital muscles which connect the upper two cervical vertebrae with the occipital bone and with each other. Some of these muscles are concerned mainly with extension and others with rotation.

Of the deep extensor muscles, the multifidi have their origins in the trasverse processes and insertions on the spinous process of the vertebra one to two segments above. When contracted together they extend the cervical spine, and when contracted unilaterally they rotate the cervical spine to the opposite side and sidebend to the same side (Hertling and Kessler 1996, Clarkson 2000). The longissimus capitis, the semispinalis capitis and the semispinalis cervicis are also deep muscles of the neck, acting on the head and neck. These muscles are covered by the splenius muscle, which in turn is covered, in part, by the trapezius and by the upper portion of the sternocleidomastoid muscle (Lehmkuhl and Smith 1983, Clarkson 2000).

The trapezius muscle is the largest, strongest, and most prominent of the posterior neck muscles. It inserts into the nuchal ligament and occipital ridge and extends the head and neck. In its function of maintaining the head in an erect position against the pull of gravity, the trapezius works most efficiently when the head and neck are in their optimal position. Superior fibres of one trapezius muscle turn the head to the opposite side and both trapezius muscles extend the head (Clarkson 2000). The levator scapulae, splenius capitis, and splenius cervicis are other large superficial muscle groups that assist in extending the head and neck and holding the head up against gravity (Hertling and Kessler 1996, Clarkson 2000).

The functional roles of muscle with respect to movements

The muscle has a functional role with respect to a certain movement. *The agonist muscle* (prime movers) plays the greatest part in the movement. *Assisting muscles (synergists)* do not carry out the movement but help the prime mover and may partly compensate if it is inhibited. *The antagonist muscle* performs motion in the opposite direction. These muscles are passively stretched during the agonist muscle function and, in normal circumstance, this does not influence the movement's range. *Stabilizers* do not perform the movement but fix the relevant part of the body in a constant position so that motion can take place in the right direction. Poor fixation can result in a decrease in the final strength. *Neutralizers* abolish or eliminate the muscle function (second component of the normal direction of movement due to the prime mover) that is not suitable for the particular movement, and thus for the collaboration of the muscles. Each muscle functions in at least two directions corresponding to its anatomical position. The same muscle can act both as a synergist and as a neutralizer (Kendall et al. 1993). The muscles have also been classified functionally as one joint stabilizer muscles (mono-articular, segmental attachments, often deep muscles) and two joint mobilizer muscles (bi-articular, superficial) (Janda 1983, Janda 1985).

Substitution and incoordination of the muscles

The muscles can compensate the function of the other muscles due to the pain or other pathological disorders (substitution phenomenon), which may cause incoordination between muscles and undesirable movement patterns. Incoordination is regarded principally as a disturbance of motor regulation, either in the altered patterns of muscle recruitment or in the altered timing (delay) of individual muscle groups. It appears within a certain movement pattern and may lead, for example, to an overstressed joint, decreased performance and premature exhaustion of the muscle (Kendall et al. 1993, Comerford and Mottram 2001).

In an efficient movement function, the muscles must be precisely coordinated to occur at the correct time, for the correct duration, and in the correct combination of forces. The coordinated action occurs within groups of synergistically acting muscles and extends to agonist and antagonist muscle interaction. It requires sensory, biomechanical and motor-processing strategies, along with learned responses from previous experience and anticipation of change (Gandevia et al. 1992, Gandevia 1994). The proprioceptors' activation from the muscles, joints and ligaments is a primary sensory mechanism for motor control. The proprioceptive impulses from the periphery relate to its sensation of position and movement of the joints, sensation of force, effort and heaviness of workload, and sensation of the perceived timing of muscle contraction (Gandevia et al. 1992).

2.4. Neck pain and adolescent headache

In adults, self-reported neck pain has been associated with headache (Jensen 1999, Aprill et al. 2002, Sjaastad et al. 2006), and pericranial tenderness and neck pain have usually been associated with adult headache (Jensen et al. 1998). However, neck pain in adults has been shown more clearly to be associated with headache frequency than with headache type (Hagen et al. 2002). In adolescents, neck pain and headache have also been shown to be concomitant (Anttila et al. 2001, Ståhl et al. 2004, Laurell et al. 2005). Of the 9-11-year-old Finnish schoolchildren with weekly neck pain, 62% also reported weekly headache (Mikkelsson et al. 1997). Co-occurring neck pain has been found in adolescents with migraine as often as in adolescents with tension-type headache (Anttila et al. 2002a, Laurell et al. 2005, Laimi et al. 2007a). In adolescents, intensive, frequent neck pain have been shown to be associated with disturbing headache (Laimi et al. 2007a). No studies have been carried out on the possible causal association of neck pain and headache in adolescence. It is not known if neck pain and headache contribute to each other. Neck pain can initiate or maintain headache, or neck pain could be a consequence of headache (Jensen et al. 1998, Davidoff 1998, ICHD-2 2004) **(Figure 5)**.

There are some hypotheses on the association between neck pain and headache. Neck pain has been regarded as a peripheral cause of adult headache (Jensen 1999, Bogduk

2004). Prolonged nociceptive stimuli from the neck muscles could be important for the conversion of episodic headache into chronic headache by producing continious afferent input of the trigeminal nerve nucleus and trigemonivascular system (Jensen 1999, Bendtsen 2000). Headache can also precide neck pain. Neck pain could be a consequence of pain extending from the head to other parts of the body. Central neuroplastic changes in headache could affect the regulation of peripheral mechanisms and lead to changed pericranial muscle activity (Bendtsen 2000). Neck pain could be a manifestation of central mechanisms. Recurrent headache may also predispose to experiencing neck pain through changes of postures, or the headache may later change to neck pain by sensitization of pain (Grimmer et al. 2006). Neck pain and headache may also be a part of a widespread pain syndrome (Mikkelsson et al. 1999, El-Metwally et al. 2004) and they may have other causal factors or a common risk factor (e.g. psychosocial, genetic, physical) which may predispose to pain sensitivity (Scher et al. 2006).

In adolescents, sitting in a static, ergonomically unfavourable position while using information technology such as computers repeatedly and for many hours a day could be a determinant of both neck pain and headache. In adolescents, the rapid growth of spinal structures may increase the exposure to increased neck flexion postures (Straker et al. 2007). Computer use can induce excessive inbalanced loading of the neck structures and muscles, and can cause difficulties in coordinating and relaxing neck muscles (Grimmer et al. 2006). The extreme flexion position of the cervical spine and sustained pericranial muscle contraction have been shown to induce headache (Harms-Ringdahl and Ekholm 1986, Jensen and Olesen 1996, Dalenbring et al. 1999). A forward head posture has been associated with adult tension-type headache (Fernández-de-las-Peñas et al. 2006a, 2007a) and also with migraine headache (Fernández-de-las-Peñas et al. 2006b). In Figure 5, the author proposes a conceptual model describing the inter-relationship between the neuromuscular system and headache, neck pain or headache with concomitant neck pain. The model shows how the ergonomically unfavourable working postures and movement habits associated with abnormal neural sensitivity may disturb control of the neck muscles, and increase the mechanical stress of neck tissues which may finally result in only headache (especially tension-type headache) or neck pain symptoms, or neck pain with concomitant headache. On the contrary, the pain symptoms (headache, neck pain or both together) may increase neural sensitivity of the tissues and disturb muscle function. Non-mechanical pain factors such as depression or anxiety may increase or contribute to the development of various pain symptoms (Anttila et al. 2002a, Virtanen et al. 2004, Scher et al. 2006).

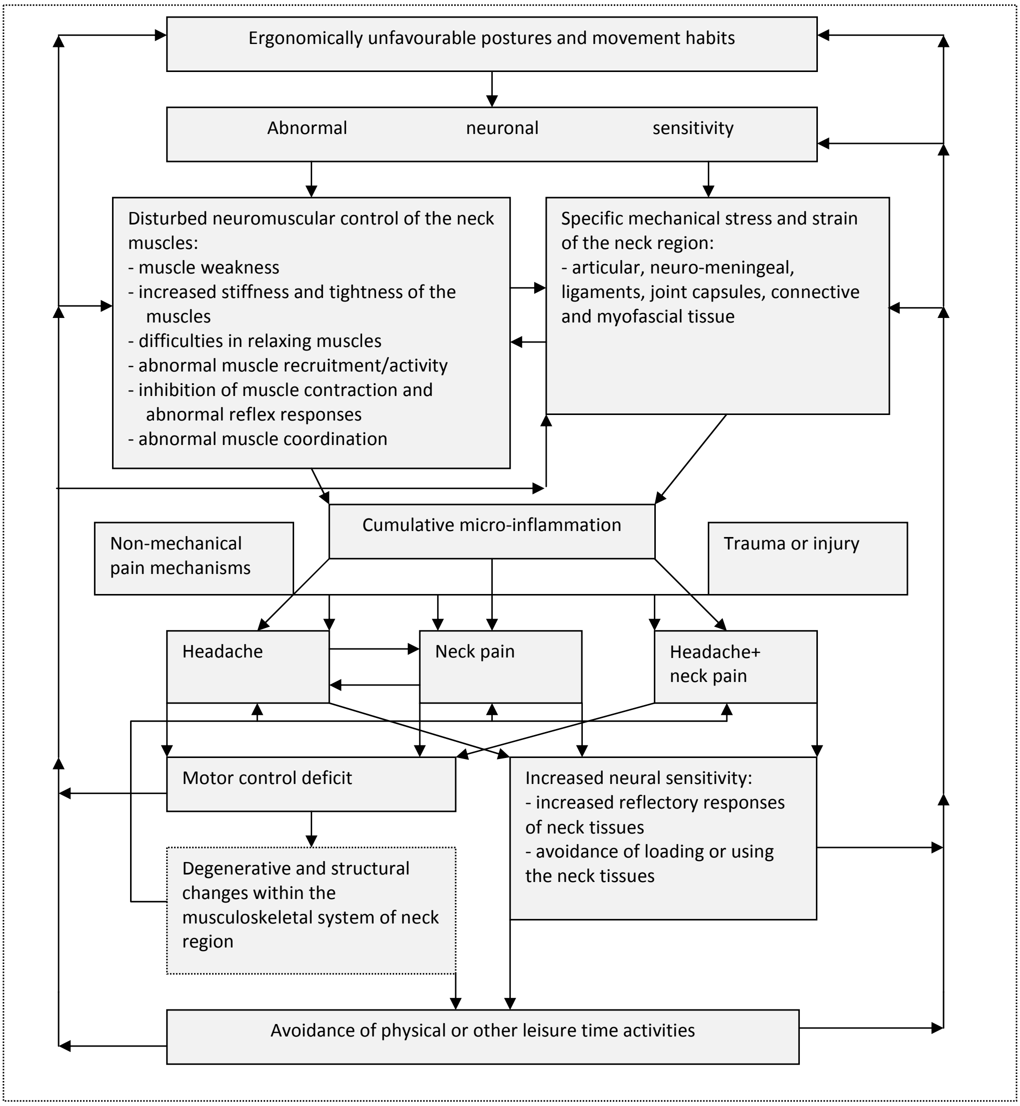


Figure 5. Conceptual model of the inter-relationship between disturbed neuromuscular function and specific mechanical stress of the neck region and headache, neck pain, or headache with concomitant neck pain. Unfavourable postural and movement habits (e.g. while using computers) may contribute to imbalance between the different neck muscles (stabiliziers and mobiliziers) and other tissues which may develop pain symptoms (e.g. tension-type headache). Pain can further disturb the control of the motor system and increase neural sensitivity of the tissues (both in tension-type headache and in migraine). These factors may further result in a predisposition to unfavourable postures, recurrence of disturbed neuromuscular function or increased mechanical stress. Pain may also cause progression of degenerative changes and avoidance of tissue loading of the neck region, which may contribute to the avoidance of activities. Avoidance of physical activities itself may predispose to unfavourable postures, abnormal neural sensitivity, disturbed neuromuscular control or increased mechanical stress, and may thus contribute to headache and neck pain symptoms.

2.5. Muscular function and musculoskeletal pain

Pain can disturb the neuromuscular system which itself can cause a further increase in pain. On the other hand, the perception of pain may be increased by deconditioning, which may further cause chronic pain (Mense et al. 2001). Pain can be associated with injury, degeneration, inflammation, overstrain, sustained contraction or psychiatric disorders, and may thus cause a biochemical imbalance and activation of the symphathetic nervous system (Mense et al. 2001). Pain can also disturb control of the motor nervous system by disturbing muscle coordination and inhibiting muscle contraction, or it can cause neural hypersensitivity which may lead to increased reflectory responses and avoidance of loading the tissues (Simons and Mense 1998, Mense et al. 2001).

Many studies have reported that there is the link between abnormal patterns of muscle recruitment, an imbalance between agonist and antagonist muscles, and different types of pain symptoms (Janda 1996, Kankaanpää et al. 1998, Lee et al. 1999, Jull et al. 1999, Ludewig and Cook 2000). Some of the above factors may further lead to avoidance of physical activity (Mense et al. 2001). Acute musculoskeletal pain has been shown to induce changes in motor system function, such as alteration of spinal motor reflexes, effect on the gamma motor system, altered motor recruitment patterns, and effects on supraspinal neurones (Madeleine et al. 1999, Thunberg et al. 2001, Mense et al. 2001).

2.5.1. Muscular function in neck pain

Most studies reporting an association between muscular dysfunction and the pain disorders of the musculoskeletal system have been performed in adult subjects. In neck pain patients, decreased neck flexor or extensor muscle strength (Barton and Hayes 1996, Jordan et al. 1997, Chiu and Lo 2002, Ylinen et al. 2004), decreased isometric extension and abduction strength of the shoulder muscles have been reported to be linked with nontraumatic neck pain (Kvarnstöm 1983). In addition, increased fatigability of both anterior and posterior neck muscles (Gogia and Sabbahi 1994) and increased neck flexion muscle fatigue in chronic neck pain patients (Falla et al. 2003, 2004) have been reported. The shoulder lifting forces have been found to be lower in sewing machine users with neck-shoulder symptoms than sewers without symptoms (Sjøgaard et al. 1987). Increased muscle strength and neck pain reduction as an effect of training have been reported in some uncontrolled studies (Berg et al 1994, Ylinen and Ruuska 1994) and in controlled studies (Revel et al. 1994, Taimela et al. 2000, Ylinen et al. 2003). In addition, limited neck rotation and neck retraction (Olson et al. 2000) and small size of suboccipital muscles (Hallgren et al. 1994, Partland et al. 1997) have been associated with chronic neck pain.

A reduction in the muscle activity of the deep cervical flexors, coupled with an increase in activity of the superficial flexor, has been demonstrated during the performance of a graded, low-load test of craniocervical flexion in chronic neck pain and whiplash patients

(Falla et al. 2003, Jull 2000). In chronic whiplash disorders, an increased EMG activity of upper trapezius muscles has also been shown (Nederhand et al. 2002).

Many studies have reported decreases in cervical kinaesthetic sense and repositioning ability in subjects with neck pain (Revel et al. 1994, Loudon et al. 1997, Heikkilä and Wennegren 1998), as well as decrease in repositioning ability also in patients with low back pain (Brumagne et al. 1998, Taimela 1999). In the above-mentioned studies, the researchers concluded that precise muscle spindle input is essential for accurate positioning of the pelvis and lumbo-sacral spine. The proprioception from muscles may serve as a pain gate that blocks or inhibits nociceptor transmission into the spinal cord and higher centres of the central nervous system (Woolf and Decosterd 1999, Mense et al. 2001).

2.6. Muscular function and headache

In the population-based study by Jensen and Rasmussen (1996), 66% of adults with episodic tension-type headache and 87% of those with chronic tension-type headache had mucular disorders defined as increased tenderness of the pericranial muscles. Muscular disorders may be of importance for the development of increased pain sensitivity, especially in subjects with chronic tension-type headache (Bendtsen et al. 1996), and they may be of major importance for the conversion of episodic into chronic tension-type headache (Jensen et al. 1998). Most of the studies concerning the association between muscular disorders of the neck-shoulder region and different headache types have been implemented in adults, while such studies on child and adolescent headache are sparse.

2.6.1. Myofascial tenderness

In adults, it has been demonstrated that increased tenderness to palpation of myofascial tissues of the pericranial and neck-shoulder region is the most obvious abnormality in adults with tension-type headache (Jensen et al. 1993, Lipchik et al. 1997, Bendtsen et al. 1996, Jensen et al. 1996, Jensen et al. 1998, Ashina et al. 1999, Jensen 1999). The tenderness has been shown to be uniformly increased throughout the pericranial region and both muscles and tendon insertions have been found to be excessively tender (Langemark and Olesen 1987, Jensen et al. 1993). The pericranial tenderness has been demonstrated to be positively associated with both the intensity and the frequency of tension-type headache (Jensen et al. 1993). Nociceptive impulses from the pericranial tissue have been assumed to reflect to the head, and have been perceived as headache (Jensen 1999, Mense et al. 2001). In a Danish population-based study, pericranial and neck-shoulder muscle tenderness has been found to be highest in adults with chronic tension-type headache. In the study, tenderness of splenius muscles in males and tenderness of temporal, massetter, sternocleidomastoid, frontal, trapezius muscles and posterior neck muscles insertions in females were associated with frequent tension-type headache (Jensen 1999).

However, it is not known for certain whether the increased myofascial tenderness in tension-type headache is primary or secondary to headache (Russell et al. 1998, Bendtsen 2000). The muscle tenderness in tension-type headache is increased not only on days with headache but also on days without headache, indicating that the tenderness in tension-type headache is not solely the consequence of an actual headache episode (Lipchik et al. 1997, Jensen et al. 1998, Ashina et al. 1999). Conversely, in migraineurs, increased pericranial tenderness has been found to occur during migraine attacks, indicating that the tenderness may be induced by the headache (Jensen et al. 1988).

In a study by Leistad et al. (2006), increased pain responses (visual analogue scale) have been shown in temporalis and frontalis muscles in subjects with tension-type headache, and in splenius and temporalis muscles in subjects with migraine headache during a sixty-minutes cognitive stress test. On the same task, migraine subjects had more regional muscle pain responses than tension-type headache subjects. Migraineurs had more pain in the neck and trapezius muscles than in the temporalis and frontalis muscles.

Myofascial pain is characterized by the presence of myofascial trigger points, with the most clinical characteristics including circumscribed spot tenderness in a nodule or a palpable taut band (increased hardness) of muscles. Typical findings are the pain that is evoked by pressure on the tender spot, pain referred in the pattern characteristic of trigger points in that muscle, a local twitch response, painful limitation of the stretch range of motion, and weakness of that muscle (Mense et al. 2001). An increased degree of hardness of trapezius muscles has been found in subjects with chronic tension-type headache (Sakai et al. 1995, Ashina et al. 1999), and the hardness has been associated with the tenderness of the trapezius muscle (Ashina et al. 1999). Active trigger points in the neck muscles have been shown in both migraine and tension-type headache (Marcus et al. 1999), especially in the upper trapezius, sternocleidomastoid, and temporalis muscles in episodic tension-type headache (Fernándes-de-las-Peñas et al. 2007a), and in the upper trapezius in chronic tension-type headache (Couppe et al. 2007). It has been shown that stimulation of myofascial trigger points can induce headache (Fernándes-de-las-Peñas et al. 2006b), and that inactivation of the trigger points can eliminate the headache (Hou et al. 2002).

In children, increased pericranial and neck-shoulder muscle tenderness has been reported to be associated with severe pain in migraine, but not in tension-type headache (Anttila et al. 2002b). However, in a study by Metsähonkala et al. (2006), neither children with migraine nor children with episodic tension-type headache showed increased extracephalic muscular sensitivity to palpation.

2.6.2. Range of motion

In adults, the joints of the upper cervical spine have been shown to be a common origin of occipital headaches (Aprill et al. 2002) although the role of the mobility of the neck-shoulder region in primary headache types is not clear. In previous studies, headache patients have showed reduced cervical movements (Kidd and Nelson 1993, Zwart 1997) and increased forward head posture (Watson and Trott 1993).

In an earlier study by Marcus et al. (1998), no mechanical abnormalities in passive intervertebral mobility or in active or passive cervical mobility in adults with migraine and tension-type headache have been shown. However, according to the current studies, there is evidence of abnormalities in the cervical posture and movements of the classified primary headache types. Patients with both chronic (Fernándes-de-las-Peñas et al. 2006a) and episodic tension-type headache (Fernándes-de-las-Peñas et al. 2007a) have shown a large forward head posture (restricted craniovertebral angle) and restricted neck mobility in nearly all cervical movements. Decreased neck mobility has not been shown to correlate with headache parameters such as headache intensity, duration or frequency in patients suffering from chronic or episodic tension-type headache (Fernándes-de-las-Peñas et al. 2006a, Fernándes-de-las-Peñas et al. 2007a). In an experimental study on healthy subjects, it was observed that extreme flexion positions of the lower-cervical–upper-thoracic spine alone provoked cervical pain and headache (Harms-Ringdahl and Ekholm 1986). These positions are thought to exert a load on passive tissues, and the sources of pain are most likely the ligaments and joint capsules that are under continuous tension (Harms-Ringdahl et al. 1986, Mense et al. 2001).

2.6.3. Muscle strength and endurance

In adults, some studies on the association between neck-shoulder muscle strength and headache have reported lower neck-shoulder muscle strength in headache subjects compared to healthy controls. In a study by Watson and Trott (1993), adults with headache have been shown to have decreased isometric strength and endurance of the upper cervical flexor muscles compared to non-headache subjects. Barton and Hayes (1996) have found sternocleidomastoid muscle weakness in adults with unilateral neck pain with headache. Decreased deep neck flexor muscle contraction has been reported not only in cervical headache subjects (Jull et al. 1999) but also, currently, in chronic tension-type headache subjects (Fernándes-de-las-Peñas et al. 2007b).

It is known that the capacity to develop neck force is related to the cross-sectional area of the neck muscles (Maughan et al. 1983, Mayoux-Benhamou et al. 1989). There is evidence of increased atrophy in the suboccipital muscles in adults with chronic neck pain with headache (Hallgren et al. 1994), as well as increased atrophy in both rectus capitis muscles in adults with chronic tension-type headache (Fernándes-de-las-Peñas et al. 2007c).

The clinical-based studies in adults show that there is a connection between muscle weakness and primary headaches, for which there are tentative results in adults (Levoska and Keinänen-Kiukaanniemi, 1993) showing that active dynamic muscular training of the neck-shoulder muscles creates a protective effect against headache. However, there are no studies concerning the association between neck-shoulder muscle strength and primary headache in children and adolescents.

2.6.4. Electromyographical findings (EMG)

Electromyography (EMG) is a measurement technique, recording electrical activity (myoelectric activity) produced by muscle (Basmajian and De Luca 1985). Activation of muscle fibres results in a temporo-spatial spread of electric potentials within and across the surface of the muscle. The electric potentials are recorded in a bipolar electrode configuration by two electrodes (the electrical potential difference is measured), using either surface or fine-wire electrodes. EMG is used to study neuromuscular function, including identification of which muscles develop tension throughout a movement, and which movements elicit more or less tension from a particular muscle or muscle group. The rate of EMG activity is in almost direct relation to the produced force of the muscle. The EMG measurements are highly dependent on the normalising technique used to reduce variability between subjects or different trials (De Luca 1997). The repeatability of surface EMG has been shown to be good (Giroux and Lamontagne 1990, Krivickas et al. 1996, Ollivier et al. 2005), also in the measurements of pericranial (Jensen et al. 1993) and neck-shoulder muscle activity (Sommerich et al. 2000).

The relation between EMG activity level and pain is not simple. In previous studies, some of the authors have regarded increased muscle tension/activation in pericranial muscles or a central limbic dysfunction as aetiological factors in tension-type headache (Olesen and Jensen 1991, Sakai et al. 1995, Jensen 1999). It is also suggested that motor changes are reflex responses that serve to minimize further damage to injured tissues, and should therefore be considered a normal protective factor rather than a pathogenic factor (Ashton-Miller et al. 1990, Lund et al. 1991, Mense et al. 2001). Changed muscle activity may be a physiological response to cognitive stress, occurring as a direct consequence of stress (Westgaard 1999), or it may be linked to a change in pain modulation such as central sensitization (Holstege 1992, Leistad et al. 2006).

Numerous electomyographic (EMG) studies have been performed in adults, and most of them have been clinical-based studies. EMG studies in which the headache subjectes have been classified with IHS criteria are presented in Table 6. In adults, most of the studies have reported significant changes, especially increased muscle activity of both pericranial and neck muscles, in chronic tension-type headache. One population-based study (Jensen et al. 1994) has shown, besides the increased activity, also increased fatigue of pericranial muscles in chronic tension-type headache. In one clinical-based study

(Sandrini et al. 1994), pericranial muscle activity was reported to be decreased and neck muscle activity increased in migraine headache. The earlier EMG studies have focused on studying mainly muscle activation levels of cephalic muscles such as temporalis and frontalis muscles, but also the muscle activity of extracephalalgic trapezius muscle has been examined.

Table 6. Quantitative surface EMG studies on primary headaches (fulfil IHS criteria)

Study/type	Task/objective	Muscles	Episodic tension-type headache	Chronic tension-type headache	Migraine	Control	Results
Schoenen et al. (1991) **Clinical-based**	At rest in supine and standing position, mental arithmetic task	Left frontalis Left temporalis Left trapezius		Mean age 35 years N = 32 F = 32		Mean age 35 years N = 20 F = 20	In all muscles activity at rest and during arithmetic task higher in C-TTH than in controls
Hatch et al. (1992) **Clinical-based**	To sit and focus on video monitor	Frontalis Temporalis Posterior neck (at the level C6)	Mean age 33.2 years N = 27 F = 22, M =5			Mean age 32.1 years N = 32 F = 19, M = 13	Temporalis muscle activity higher in E-TTH than in controls; no difference between groups in activity of other muscles
Sandrini et al. (1994) **Clinical-based**	At rest in sitting position, maximal voluntrary contraction, mental arithmetic task	Frontalis Trapezius	Mean age 27.3 years N = 15 F = 6, M = 9	Mean age 37.4 years N = 29 F = 19, M = 10	Mean age 36 years N = 22 (no aura) F = 12, M =10	Mean age 30 years N = 37 F = 20, M = 17	Frontalis muscle activity at rest and during arithmetic task higher in C-TTH than in controls; frontalis muscle activity during maximal contraction lower in migraine than in controls; frontalis muscle activity at rest and during arithmetic task higher in C-TTH with increased tenderness of pericranial muscles than in controls, and lower in C-TTH without increased muscle tenderness; trapezius muscle activity at rest higher in migraine with or without increased muscle tenderness than in controls; trapezius muscle activity during arithmetic task higher in migraine with muscle tenderness than in controls; no difference between migraine and other groups during maximal contraction; trapezius muscle activity during arithmetic task higher in C-TTH with or without muscle tenderness than in controls
Jensen et al. (1994) **Population-based (547/735/1000 adults**)	At rest in supine position, maximal voluntary contraction	Right frontalis Temporalis	Aged 25-64 years N = 144 F = ?, M = ?	Aged 25-64 years N = 15 F = ?, M = ?	Aged 25-64 years N = 70 F = ?, M = ?	Aged 25-64 years N = 20 F = ?, M = ?	Temporalis muscle activity at rest higher in C-TTH than in other groups; temporalis and frontalis muscle frequency values during maximal contraction lower (fatigue) in C-TTH than in other groups; frontalis muscle activity at rest higher in subjects with current TTH than in other groups; frontalis and temporalis muscle activity during maximal contraction lower in current TTH than in other groups
Clark et al. (1995) **Clinical-based**	Muscle activity was measured for 3 consecutive days and nights by the subjects themselves	Temporalis	Mean age 24 years N = 36 F = 30, M = 6			Mean age 23 years N = 36 F = 30, M = 6	No difference between the groups in temporalis muscle activity; muscle activity level in TTH and control group not related to subjects pain or stress level
Jensen (1996) **Clinical-based**	Muscle activity during and outside episode of TTH: at rest in supine position and maximal voluntary contraction	Temoralis Trapezius	Mean age ? years N = 9 F = ?, M = ?	Mean age 45 years N = 19 F =17, M = 11 (some in E-TTH group)		Mean age 42 years N = 30 F = 18, M =12	Temporalis and trapezius muscle activity outside headache episode higher in TTH than in controls; the difference between the groups the same during current TTH

Study/type	Task/objective	Muscles	Episodic tension-type headache	Chronic tension-type headache	Migraine	Control	Results
Jensen and Olesen (1996) **Clinical-based**	Muscle activity was recorded before and after sustained tooth clenching: at rest in supine position and maximal voluntary contraction	Temporalis Trapezius		Mean age 45 years N = 58 (both frequent episodic and chronic) F = 36, M = 22		Mean age 42 years N = 30 F = 18, M = 12	Trapezius muscle activity higher at rest before and after tooth clenching in the C-TTH than in controls; no difference between the groups in EMG frequency values of both muscles neither in activity of temporalis muscles before and after tooth clenching
Jensen and Rasmussen (1996) **Population-based (547/735/1000 adults**)	At rest in supine position: to examine correlation between EMG, muscle tenderness and pain threshold	Temporalis	Aged 25-64 years N = 144 F = ?, M = ?	Aged 25-64 years N = 15 F = ?, M = ?	Aged 25-64 years N = 70 F = ?, M = ?	Aged 25-64 years N = 20 F = ?, M = ?	Temporalis muscle activity positively related to muscle tenderness and inversely related to pain threshold in C-TTH; no association between muscle activity and muscle tenderness or pain threshold in other groups
Jensen et al. (1998) **Clinical-based**	At rest in supine position, maximal voluntary contraction	Temporalis Trapezius	Mean age 41.2 years N = 28 F = 22, M = 6	Mean age 48.7 years N = 28 F = 14, M = 14		Mean age 42 years N = 30 F = 18, M = 12	Trapezius muscle activity higher at rest in C-TTH with increased muscular tenderness than in C-TTH without muscular tenderness; no other differences between groups.
Bansevicius et al. (1999) **Clinical-based**	1-hour reaction-time test	Frontalis Temporalis Splenius Trapezius	Mean age ? years N = 6 F = ?, M = ?	Mean age 41.2 years N = 14 F = 13, M = 7 (some in E-TTH group)		Mean age 39.5 years N = 20 F = 13, M = 7	Splenius muscle activity during whole test period and trapezius muscle activity during first 10 minutes of test period higher in TTH than in controls; no other differences between groups
Leistad et al. (2006) **Clinical-based**	Sixty min cognitive stress followed by 30 min relaxation	Trapezius Splenius Temporalis Frontalis	Mean age 34.7 years N = 6 F = 9, M = 9 (some in C-TTH group)	Mean age 34.7 years N = 12	Mean age 40.2 years N = 22: without aura N = 9 with aura N = 13 F = 20, M = 2	Mean age 39.0 years N = 44 F = 35, M = 9	No differences in muscle activity responses among groups; activity responses did not correlate with pain responses in study groups; the recovery of trapezius muscle activity was more delayed in E-TTH than in controls and migraine group

E-TTH = episodic tension-type headache, C-TTH = chronic tension-type headache, TTH = tension-type headache, HA = headache group, EMG = electromyography, N = number of all subjects, F = number of females, M = number of males

In a population-based study with adults, increased EMG activity of the temporal and frontal muscles during rest, and decreased levels of muscle activity of these muscles during maximal voluntary contraction, was associated with chronic tension-type headache, but not with the episodic form (Jensen et al. 1994, Jensen 1999). This may indicate insufficient relaxation of these muscles at rest and impaired recruitment at maximal activity (Jensen 1999). In the clinical studies by the same author (Jensen 1996, Jensen and Olesen 1996), the EMG activities were also increased during rest in the temporal and trapezius muscles only in the population with frequent headache. Increased EMG activity levels of neck and shoulder muscles have been reported in chronic tension-type headache, especially with neck-shoulder muscle tenderness (Jensen and Rasmussen 1996, Jensen et al. 1998), but not in the episodic tension-type headache with neck-shoulder muscle tenderness (Jensen and Rasmussen 1996). Increased EMG activity levels of frontalis, temporalis and trapezius muscles have not shown to be associated with headache severity, anxiety, or response to biofeedback treatment in chronic headache (Schoenen et al. 1991, Clark et al. 1995). EMG responses of neck-shoulder muscles in tension-type headache increased during a reaction time test (Bansevicius et al. 1999), but not during cognitive stress (Leistad et al. 2006). However, after cognitive stress, the episodic tension-type headache patients had delayed EMG recovery in the trapezius muscle.

Only a few clinical-based studies are available describing EMG findings in childhood headache. Gallai et al. (1989) have reported increased rest values of the frontal muscle and muscles of the nuchal region in children with tension-type headache. Increased activation of neck extensor and forehead muscles has been reported in ten-year-old children with severe headache during an arithmetic task (Pritchard 1995). In the study the headache was not classified with IHS criteria.

In some previous studies, spontaneous EMG activity (measured with needle electrode) has been reported to be increased at myofascial trigger points (Hubbart and Berkoff 1993, Hubbard 1996, Simons 1996). According to these studies, theoretically, continuous activity in a few motor units over a long period may be sufficient for the development of myofascial pain and even headache. Therefore, the slightly increased EMG activity (Jensen et al. 1994) may be explained by either continuous activity in a few motor units or by slight general activity in several motor units. However, in the current study with adults, high spontaneous EMG activity of trigger points could not be demonstrated in the chronic headache subjects (Couppe et al. 2007). Psychological stress has been reported to aggravate tension-type headache (Jensen 1999), and it has also been shown to both intensify trigger point pain and increase EMG activity at trigger points (McNulty et al. 1994).

2.7. Leisure activities and headache

Both physical and sedentary activities may play a role in aggravating and provoking headache both in adults and in children and adolescents.

2.7.1. Physical activity and inactivity

Migraine headache may be provoked by excessive effort or exertion during sports and exercise activities (Bener et al. 2000, McCrory 2000, Turner 2003). There is also evidence that headache occurs especially in relation to sports such as aerobic exercise, running, jogging and contact sports (Nassar et al. 1999, McCrory 2000, Sallis 2000). Physical activity has been shown to be a common precipitating factor especially for migraine headache (Bener et al. 2000, Spierings et al. 2001, Rossi et al. 2001, Zivadinov et al. 2003). However, Kujala et al. (1999) found no difference in the occurrence of non-classified headache between adolescents with abundant leisure physical activities and adolescents with fewer physical activities (Kujala et al. 1999). Although the level of physical activity has not been associated with migraine headache in a population-based study in adults, men with tension-type headache were physically less active than headache-free subjects (Rasmussen 1993). Reduced aerobic endurance and muscle flexibility, measured with an objective physical test, have been reported in adults with headache (Neususs et al. 1997).

Neck and shoulder symptoms have been shown to be associated with unfavourable static sitting and working postures, especially when arms are raised and/or neck and back are in the flexion position (Harms-Ringdahl and Ekholm 1986, Kilbom and Persson 1987). Recently, especially the increased use of computers could be a determinant of both neck pain and headache. Excessive computer use in unfavourable spinal postures may lead to increased, continious muscle contraction and weakness of the neck-shoulder muscles with reduced muscle metabolism, blood flow and cervical mobility. These factors have been reported to be related to tension-type headache (Jensen et al. 1994, Barton and Hayes 1996, Jensen et al. 1998). Changes in cervical postures have also been found in adults with headache (Vernon et al. 1992). Passive tissue loading, such as joint capsules and ligaments, during excessive and extreme cervical positions may cause neck pain and also headache in adults (Harms-Ringdahl and Ekholm 1986, Dalenbring et al. 1999). Also in children, the laxity of the transverse ligament in the forward head position has been reported to be one cause of headache (Ormos 2003).

In addition, computer or TV viewing may aggravate especially migraine headache (Vanagaite et al. 1997, Bener et al. 2000, Spierings et al. 2001). The flashing lights are precipitating factors for migraine. The eyestrain and excessive fatigue of the eyes caused by staring at a computer or TV monitor may also cause headache (Spierings et al. 2001). The relation between computer use (games) and headache may partly lie in psychosocial factors. Lack of social relationships, social phobia and depression can be displayed as increased use of the computer. Moreover, previous studies suggest that psychosocial factors and depressive symptoms are associated with headache in children and adolescents (Karwautz et al. 1999, Anttila et al. 2002a).

These studies have been performed mainly in adults, and they have shown an association between sedentary or physical activities and headache, especially migraine. More detailed evidence on the associations between leisure activities, including the content and level of the activities, and primary headaches in children and adolescents is needed.

In summary, most of the studies have demonstrated an association with disturbed neuromuscular function of neck and shoulder muscles especially in adult neck pain subjects. However, neuromuscular factors of the neck-shoulder region especially with classified primary headaches have received less attention even though the muscular factors may play an important role in the genesis of headache, especially in tension-type headache. Primary headache types have also been reported to be concomitant with neck pain in adults and also in adolescents. However, the possible causal association between neck pain and headache is not known in adolescence. According to previous studies in adults, there is some evidence of decreased neck mobility and strength, and increased atrophy of neck extensor muscles in tension-type headache. In addition, most of the studies have reported increased muscle activity of both pericranial and neck muscles, especially in chronic tension-type headache. The earlier EMG studies have been focused mainly on muscle activation levels of cephalic muscles and much less information is available on muscle activity capacity of extracephalalgic muscles. There is one study in adults where reduced aerobic endurance and less physical activity have been reported to be associated with tension-type headache.

The importance of the above-mentioned factors in primary headache is not yet clear, and more reliable and better standardized population-based studies are needed. Very little is known about the association between leisure activities and adolescent headache, and hardly anything on the association between neuromuscular function and structural factors of the neck muscles and headache in children and adolescents. However, neuromuscular factors of the neck region may have an essential role in the etiology of some types of headache, especially in tension-type headache, already early in life. On the other hand, neuromuscular differences in the neck region may be a consequence of headache, and they themselves may further maintain or increase headache.

It can be supposed that there are more neuromuscular differences in adolescents with tension-type headache than in those with migraine due to the heterogeneity of the study population in the tension-type headache group. On the other hand, it could also be possible that neuromuscular differences appear clearly in migraine due to the severe pain in this headache group. However, there is no actual information on the association between neuromuscular factors and primary headache in population-based adolescents.

3. AIMS AND HYPOTHESES

The objective of the present thesis was to examine differences in neck-shoulder muscle function and the cross-sectional area between adolescents with migraine, tension-type headache and healthy controls.

More specially, the aims were:

1. To study associations between the occurrence of different types of headache and leisure activities in 13-year-old schoolchildren (Paper I).

   Hypothesis 1.1. Children with tension-type headache practice more non-sports activities, involving a mainly static use of the upper extremities, than children with migraine or with no headache.
   Hypothesis 1.2. Children with tension-type headache practise sports activities less than children with migraine or with no headache.
   Hypothesis 1.3. Children with both migraine and tension-type headache use computers more often than children with no headache.

2. To study associations between the occurrence of different types of headache and strength and mobility of the neck-shoulder region in 13-year-old schoolchildren (Paper II).

   Hypothesis 2.1. Children with tension-type headache have lower endurance strength of the upper extremities than children with migraine or with no headache.
   Hypothesis 2.2. Children with tension-type headache have less mobility of the neck and shoulder region than children with migraine or with no headache.

3. To study associations between the occurrence of different types of headache and maximal voluntary force, the EMG/force ratio and co-activation capacity of the neck and shoulder muscles during isometric actions in 17-year-old adolescents (Paper III).

   Hypothesis 3.1. Adolescents with tension-type headache have lower maximal neck and shoulder force production, a higher EMG/force ratio of the agonist neck flexion and extension muscles, and higher co-activation of the neck muscles than adolescents with migraine or with no headache.

4. To study associations between the occurrence of different types of headache and fatigue of neck flexion muscles in sustained, static action in 17-year-old adolescents (Paper IV).

Hypothesis 4.1. Adolescents with tension-type headache have more fatigue of left and right sternocleidomastoid muscles than adolescents with migraine or with no headache.

5. To study associations between the occurrence of different types of headache and the cross-sectional area of neck flexion and extension muscles in 17-year-old adolescents (Paper V).

Hypothesis 5.1. Adolescents with tension-type headache have a smaller cross-sectional area of both neck flexion and extension muscles than adolescents with migraine or with no headache.

4. STUDY DESIGN

	Study I	**Study II**	**Study III**	**Study IV**	**Study V**
Study population	N = 183	N = 183	N = 89	N = 89	N = 65
Age of subjects	12 and 13 years of age	12 and 13 years of age	17 years of age	17 years of age	17 years of age
Study setting	Cross-sectional comparative study	Cross-sectional comparative study	Cross-sectional comparative study	Cross-sectional comparative study	Cross-sectional comparative study
Examination methods	Questionnaire	1. Dynamic repetition test of upper extremities 2. Mobility test of upper extremities: fingertips together behind back 3. Keno –cervical measurement device	1. Neck strength measurement device 2. Shoulder strength measurement device 3. Surface EMG recordings with ME8000P device	1. Isometric neck flexor endurance test 2. Visual Analogue Scale 3. Surface EMG recordings with ME8000P device	1. Magnetic resonance imaging (MRI) with 1.5 T scanner
Outcome variables	1. Type of leisure activity 2. Number of non-sports activities (0-3) 3. Number of sports activities (0-3) 4. Frequency of sports activity (times/week) 5. Time spent in sports activity (hours/week) 6. Frequency of computer use (days/week)	1. Dynamic UE endurance strength: number of repetitions 2. Distance of fingertips from each other (cm) 3. Cervical range of motion (◦): - flexion - lateral flexion - rotation	1. Isometric neck muscle forces: - neck flexion and extension (N) - right/left neck rotation (Nm) 2. Isometric shoulder muscle forces: - right/left shoulder flexion (N) 3. EMG/agonist neck and shoulder muscle force ratio 4. Co-activation rate of antagonist neck muscles (%) 5. Co-activation rate of non-antagonist neck muscles (%)	1. Neck flexion muscles endurance time (sek) 2. Pain/discomfort after endurance test (0-10 cm) 3. Both SCM muscles' fatigue (MF) during endurance test	1. Neck flexion muscles CSA (mm^2): - right SCM - left SCM - right scalenus - left scalenus 2. Neck extension muscles CSA (mm^2): - right/left rotator, multifidus, semispinalis cervicis - right/left semispinalis capitis - right/left levator scapulae - right/left splenius capitis and cervicis -right/left trapezius

Abbreviations: UE, upper extremities; EMG, electromyography; (µV), microvolt; N, newton; Nm, Newton meter; VAS, visual analogue scale; SCM, sternocleidomastoid muscle; CES, cervical erector spinae muscles; MF, median frequency; CSA, cross-sectional area.

The study design and the informed consent procedures were approved by the Joint Ethics Review Committee of the Turku University Medical Faculty and the Turku University Central Hospital. Informed consent was signed by both the parents and participant in all phases of the study.

5. STUDY POPULATION AND METHODS

The present study is part of a population-based follow-up study of headache in school-aged children, to evaluate the prevalence and outcome of headache, stomatognathic factors and association of neck pain with headache. The participants in all the phases of the study came from the same original study population but were selected according to specific selection criteria in the different phases of the study. A flow chart of the study population is presented in Figure 6.

5.1. Study population

The study had five phases **(Figure 6)**. In the first phase, in the spring of 1998, the original study population was collected by sending a structured questionnaire on headache and its predisposing factors to all 1409 children in the sixth grade of the 35 primary schools in the city of Turku (Anttila et al. 2002a, Anttila et al. 2002b). Of these children, altogether 1135 (81%) completed the questionnaire. The mean age of the children at the time of the questionnaire study was 12.6 years. Different types of headache were classified using the IHS criteria (IHS 1988). No child met the IHS criteria for chronic tension-type headache. The second phase was to establish a random sample of children from each questionnaire-based headache group and the control group. The groups were randomly selected by computer for face-to-face interviews and clinical examinations (N = 327). Altogether 311 13-year-old children participated. The face-to-face interviews and clinical examinations were performed by a trained pediatrician at a paediatric outpatient clinic in the city of Turku from November 1998 to February 1999. The confirmation of the headache types was performed using IHS criteria (IHS 1988). Detailed information is presented in the study by Anttila et al. (2002a, 2002b).

Studies I-II are based on data from phase 2. To restrict the analysis to the purest and clearest headache cases, only children whose headache type fulfilled the IHS criteria of either migraine or episodic tension-type headache, and whose headache type was the same in both the original questionnaire (February-March 1998) and the face-to-face interview (November 1998-February 1999), were selected for the analysis. The study group comprised 59 children (32 girls and 27 boys) with migraine, 65 children (21 girls and 44 boys) with episodic tension-type headache, and 59 children (37 girls and 22 boys) without headache. The mean age of the children was 13.4 years.

In the third phase, in 2002, at the age of 16 years, all the 311 adolescents examined at the age of 13 years were invited to a face-to-face interview and clinical re-examination. In addition, adolescents reporting at the age of 12 years headache associated with head or neck trauma, or a reflective disorder of the eyes, and adolescents with non-classifiable headache (IHS 13) were invited (Laimi et al. 2006 and 2007a-c). Of the 311 adolescents, altogether 228 participated in the interview and clinical re-examinations (73%; 82% of girls and 65% of boys). In addition, 33 of the 43 adolescents with headache secondary to trauma or refractive error at 12 years, and 43 of the 69 adolescents with headache not classifiable at 12 years, were examined. Altogether 304 adolescents were examined at the age of 16. The classification of the headache types (IHS 1988) was based on a structured interview and neurological examination performed by a paediatrician. There appeared to be some changes in the headache types from 13 to 16 years of age. The headache type changed in 65% of participants. In migrainous (IHS 1) children, headache remained as migraine, evolved to tension-type headache, or disappeared in 43%, 50% and 7% of the girls, and in 37%, 37% and 26% of the boys, respectively. In children with tension-type headache (IHS 2), headache remained as tension-type headache, evolved to migraine, or disappeared in 54%, 33% and 13% of the girls, and in 70.5%, 8% and 21.5% of the boys, respectively (Laimi et al. 2007c).

Studies III-IV are based on the data from phase 4. The subjects were randomly selected from among the patients in phase 3. A random sample of 30 of the subjects with frequent migraine-type headache (headache at least once a month, N=62), 30 of the subjects with frequent tension-type headache (headache at least once a month, N=102), and 30 of the headache-free subjects who did not report any pain in the neck-shoulder region (N=38) were asked to participate in the repeated and current measurements of neck and shoulder muscle force and in the simultaneous EMG activity measurements. The detailed diagnoses of the adolescents with headache were IHS 1.1-1.2 (migraine without and with aura) N=28, IHS 1.7 (migrainous disorder not fulfilling IHS criteria) N=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 IHS criteria) N=1. If an adolescent was unable to participate (11 from the migraine group, 9 from the tension-type headache group, and 13 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 among the adolescents whose headache frequency (IHS 2.1) was maximally 0.5 times a month and who had no neck-shoulder symptoms. Finally, the study group comprised 30 adolescents with migraine-type headache (26 girls, 4 boys), 29 adolescents with tension-type headache (18 girls, 11 boys), and 30 control subjects (14 girls, 16 boys), all 17 years of age at the time of the study. The mean headache frequency in the migraine-type headache group was 3.9 times a month (SD 3.0), and in the tension-type headache group 3.4 times a month (SD 2.9). The measurements were carried out in the Department of Physical and Rehabilitation Medicine, Turku University Central Hospital. All subjects were considered otherwise healthy. None of the subject had specifically trained their neck and shoulder muscles and none of them was a competing athlete.

Study V is based on the data from phase 5. All adolescents with headache at least three times a month and a sample of the headache-free subjects were selected from each of the study groups taking part in studies III and IV. The adolescents were invited to undergo magnetic resonance imaging (MRI) of the cervical spine, and all of them participated in the measurements. The study group comprised 19 adolescents with migraine headache (13 girls, 6 boys; IHS 1.1-1.2, migraine without and with aura), 24 adolescents with episodic tension-type headache (14 girls, 10 boys; IHS 2.1, episodic tension-type headache), and 22 adolescents without headache (8 girls, 14 boys), all 17 years of age at the time of the study. The study group included also took part in a study where the association between degenerative changes of the cervical spine and headache was examined (Laimi et al. 2007b). The MRI measurements were carried out in the Department of Diagnostic Radiology, Turku University Central Hospital, and they were all done by the same experienced neuroradiologist.

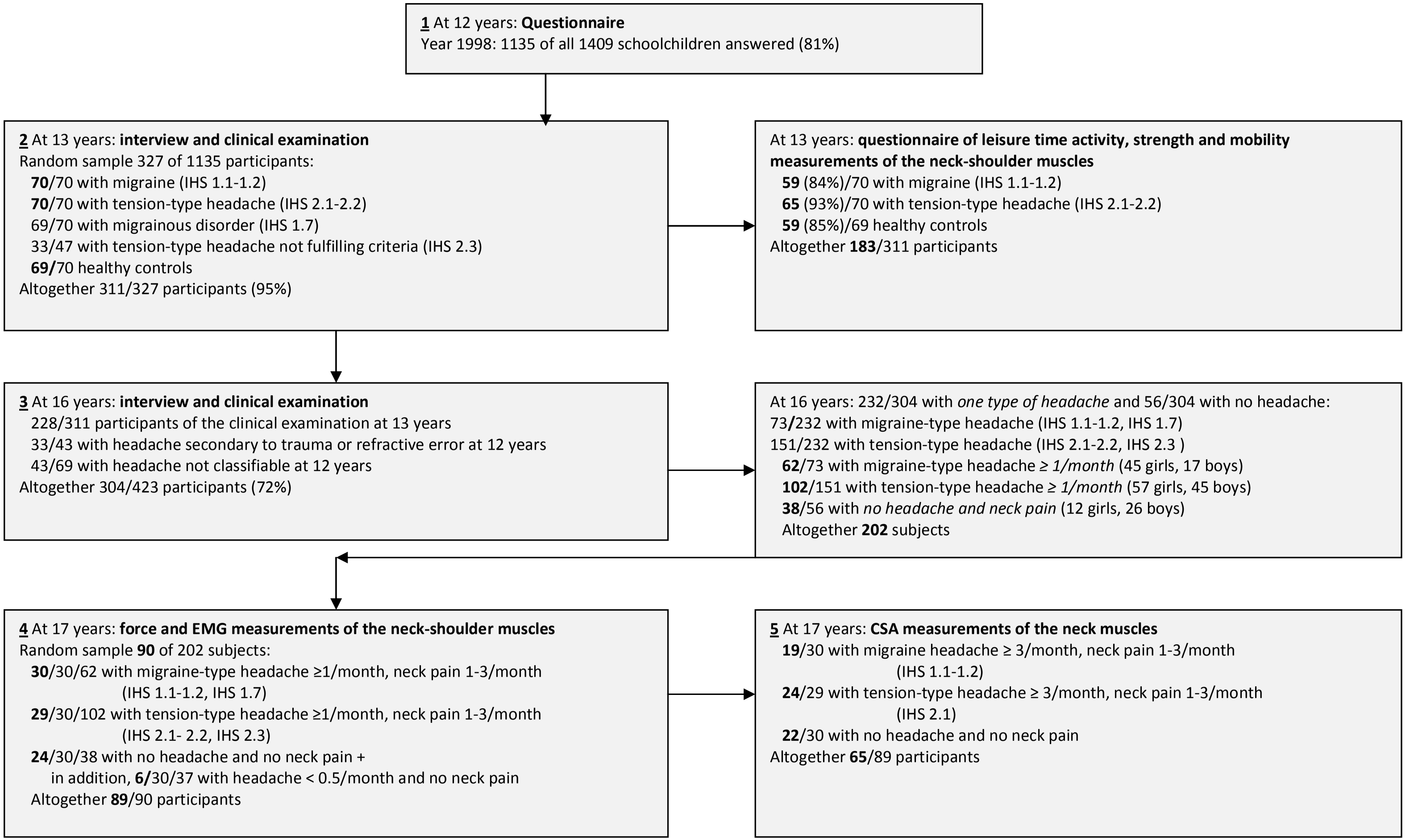


Figure 6. Flow chart of the study population. EMG, electromyography; CSA, cross-sectional area; 1-5, different phases of the study _

5.2. Methods

In the clinical interview at the ages of 13 and 16 (Papers I-V) the headache diagnosis using the IHS criteria (IHS 1988) and the headache frequency were confirmed (**Appendix 3**) by the same paediatrician.

5.2.1. Leisure activity (Study I)

In the interview, performed by a paediatrician, the children were asked with open and structured questions about their leisure activities: the type, number, (options: 0,1,2, at most three main activities in order of importance), and frequency (options: daily, 4-6 times/week, 2-3 times/week, once a week, once a month, less than once a month, not at all), as well as the number of hours spent weekly in sports activities outside school hours so intensively as to be out of breath or sweating (options: not at all, half an hour, one hour, 2-3 hours, 4-6 hours, ≥7 hours). These questions on physical activity have been used in a cross national health survey of schoolchildren coordinated by the World Health Organisation (WHO), and they have proved accurate in surveying the state of physical activity (Aarø et al. 1986). In addition, the children were asked about the number of days in a week when they used the Internet or played computer games. All the children had the opportunity to use a computer, either at home or at school (**Appendix 5**).

The three most important leisure activities were classified as sports activities involving loading of 1) upper extremities (basketball, volleyball, handball, racket sport etc.), 2) lower extremities (icehockey, football, skating, downhill skiing etc.), 3) all muscle groups of the whole body (cross-country skiing, gymnastics, aerobics, dancing etc.). The fourth (4) classification covered other, non-sports hobbies, mostly indicating a static use of upper extremities (reading, working/gaming on computer, fishing, writing, etc.). Previously, Niemi et al. (1996) have used this classification of various types of leisure activity in their study with adolescent neck and shoulder symptoms.

5.2.2. Dynamic endurance strength (Study II)

The endurance strength of upper extremities was measured with a dynamic progressive repetition test where the subject was in sitting position. The test was modified from the dynamic repetition test of upper extremities by Alaranta et al. (1990), first used in the University of Jyväskylä, Finland, as a part of a fitness testing battery in 2125 Finnish schoolchildren (Nupponen et al. 1999). Holding weights in both hands, raised above the shoulders and with elbows pointing downwards, the subject started to extend the upper extremities upwards, alternating dominant and non-dominant upper extremity (right and left sides). After the maximum of 20 repetitions (with both upper extremities), the subject was given heavier weights and the test was continued immediately without a rest. If again 20 repetitions were completed, a pair of even heavier weights was given. Weights were 3, 4 and 5 kilograms for girls and 4, 6 and 8 kilograms for boys (Nupponen et al. 1999).

The total number of repetitions of both sides was used for analysis. Altogether, the test performance with all three different weights included for a maximum of 60 repetitions of both sides. The examiner terminated the test, if the subject told that he/she was not able to continue and/or, if it was not possible to continue with the pure performance.

5.2.3. Range of motion (Study II)

The simultaneous mobility of both shoulders with the thoracic spine (mobility of the upper extremities) was measured using a functional test where the subject in standing position tried to bring the middle fingertips of both hands together behind the back (Janda 1983, Cailliet 1991, Clarkson 2000). One hand, with flexed arm, moved downwards over the shoulder close to the ear, while the other hand, with flexed arm, moved upwards from behind, over the back. The test was performed so that dominant and non-dominant hand was alternatively on top over the shoulder and, respectively, behind the back. In both cases the distance between the middle fingertips was measured with both to the nearest 0.5 centimeter. If the fingertips reached or overlapped each other, the test result was positive, otherwise it was negative.

Cervical range of motion (CROM) was measured with a Keno®–cervical measurement instrument (Kuntoväline Oy & David Fitness & Medical Ltd, Helsinki, Finland). The instrument was aligned on the nosebridge and ears, and fastened on the head by a velcro strap the subject being in sitting. The Keno® included sagittal plane and lateral flexion meters, activated by force of gravity as the position of the head changed. The motion of cervical flexion and lateral flexion and the rotation of dominant and non-dominant sides were measured. To measure flexion, the subject was instructed to tilt the head towards the chest as far down as possible without trunk or shoulder movements. To measure lateral flexion, the subject was instructed to tilt the head sideways without trunk or shoulder movements. To measure cervical rotation, the subject turned the head to the side as far as possible while keeping the neck in the straight line and eyes fixed forwards. The reliability of the measurement device has been shown to be relatively good and the ICC has been varied from 0.62 to 0.91 (Capuano-Pucci et al. 1991, Alaranta et al. 1994, Peolsson et al. 2000).

5.2.4. Isometric strength (Study III)

The maximal isometric force of the neck muscles in rotation (Nm), flexion (N), and in extension (N) was measured by a neck strength measurement system (NSMS, Kuntoväline Ltd, Helsinki, Finland) (Ylinen and Ruuska 1994). Two strain gauges of the device were calibrated with standard weights three times before strength tests. Maximal rotation torque was measured first, with the head in the standardized neutral position. The participant then turned the head against the pads to produce the desired torque. To measure flexion force, the participant pushed against a load cell placed at the forehead;

and to measure extension force, the participant pushed against a load cell placed at the occiput. The procedure was repeated in the other direction after a rest of 5 minutes (Oksanen et al. 2007).

The maximal isometric force of the shoulder forward flexion (N) of both sides was tested using a computer-based force-dynamometer device (Kin-Com, 125 AP, Chattex Corp. Chattanooga, TN, USA). The subject was tested in a sitting position that allowed shoulder movements. The glenohumeral joint was carefully aligned with the rotational axis of the dynamometer and shoulder at 90 degrees of flexion. The arm was held with the elbow extended and the forearm semi-pronated, and with a fixation pad around the wrist. The length of the lever arm was individually adjusted to achieve an optimal position in relation to the extended elbow.

In each test trial of neck or shoulder flexion force measurements, the subjects were instructed to produce maximal efforts lasting 5 seconds each at 45-second intervals. If the last result showed an improvement of more than 5%, additional efforts were performed until no further improvement was observed. The largest strength value was chosen for the final analysis. The time point where the strength was largest varied from 2.5 seconds to 3.5 seconds (Oksanen et al. 2007).

Repeatability of force measurements

In our laboratory, intratester repeatability of all the neck forces and the shoulder flexion forces of both sides were assessed in subjects with headache and without headache (30 with tension-type headache, 29 with tension-type headache and 30 without headache). The force measurements were taken twice being retesting after one hour.

For all groups, ICC and CV showed good repeatability of all neck force measurements. In the migraine group, ICC varied from 0.98 to 0.99, and CV from 2.5% to 3.7%; in the tension-type headache group, ICC was 0.99 in all force measurements, and CV varied from 1.6% to 3.3%; in the healthy control group, ICC varied from 0.98 to 0.99, and CV from 0.7 to 3.5% (Oksanen et al. 2007).

The differences in almost all mean values for each neck force measurement in the three study groups were small across the two measurement sessions. In all study groups, differences in the forces of neck flexion/extension and left neck rotation, and between the first and the second measurement were plotted against their means. No marked variation was observed between the consecutive test results on the individual level. Means of differences in all measurements were small between the test-retest results, and the 95% limit of agreement indicated good repeatability in all study groups. There was no systematic difference between the measurements (Oksanen et al. 2007).

In all study groups, intratester repeatability of the shoulder flexion force measurement of both sides was slightly weaker than that in the neck force measurement. However, the repeatability was good. In the migraine group, ICC and CV of right shoulder flexion were 0.94 and 8.4% and of left shoulder flexion 0.91 and 10.9%, respectively; in the tension-type headache group, ICC and CV of right shoulder flexion were 0.98 and 5.3%, and of left shoulder flexion 0.96 and 9.0%, respectively; in the control group, ICC and CV of right shoulder flexion were 0.98 and 6.4%, and of left shoulder flexion 0.95 and 9.3%, respectively (pilot study).

5.2.5. Isometric endurance strength (Study IV)

For the test of the isometric endurance strength of the neck flexion muscles, the subject reclined on a plinth in a sagitally symmetrical supine position. The knees were at a 60° angle and supported with a roll pad under the knees. The test carried out with 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. Then 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. 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.

In our laboratory, intratester repeatability of the total endurance time test was assessed in fourteen subjects (seven with tension-type headache and seven without headache). The endurance time test was repeated two times retesting it after one week interval. The trial-to-trial repeatability appeared to be good. The ICC and the CV for the total endurance time were 0.99 and 4.8%, respectively.

5.2.6. Pain (Study IV)

Immediately after the performance of the neck flexion endurance test, the intensity of discomfort/pain in the pericranial or neck-shoulder area was subjectively assessed with the Visual Analogue Scale (VAS) (Joyce et al. 1975, Price et al. 1983). The occurrence of pain including headache was asked during the whole test by the examiner. The scale used was a 10 cm long, horizontal line attached to a plastic stick with a width of four centimeters. The scale was anchored by ‘No discomfort or pain, does not hurt at all’ at one end (0 cm) and ‘Worst discomfort or pain imaginable’ at the other (10 cm). The intensity of pain or discomfort was indicated by the movable indicator of the measure stick by the subject. The subject was also asked to express verbally the area where the pain/discomfort was felt.

5.2.7. Surface EMG measurements (Studies III-IV)

The surface EMG recordings were conducted online, the signal being transferred directly from the microprocessor to the computer via an optic cable. Oval shaped bipolar self-adhesive disposable surface electrodes (Ag-AgC, N-00-S, Medicotest, Ölstykke, Denmark), 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. Surface EMG activity was measured simultaneously with the maximal force measurements bilaterally from the cervical erector spinae muscles during neck extension, from the sternocleidomastoid muscles during neck flexion and rotations, from the upper trapezius during shoulder flexion (Study III), and simultaneously with the endurance isometric test bilaterally from the sternocleidomastoid muscles (Study IV) **(Figure 7a-c)**. Bipolar EMG recordings were made by using an 8-channel Muscle Tester ME8000P microprocessor-based device (Mega Electronics Ltd, Kuopio, Finland).

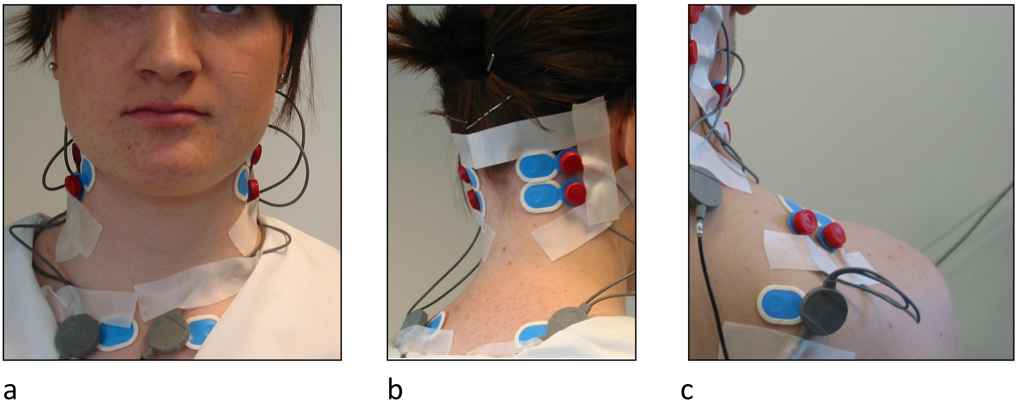


Figure 7. Bipolar surface elecromyographic electrode arrangement over (a) the both sternocleidomastoid muscles, (b) both cervical erector spinae muscles, and over (c) the right trapezius muscle.

The electrode were placed as follows: The cranial electrodes of both cervical erector spinaes muscles were attached lateral to the spinosus processes of the upper cervical vertebrae on the muscular prominence of the semispinalis and splenius capitis and the caudal electrodes of cervical erector spinaes muscles were placed over the muscle belly between the sternocleidomastoid muscle and the trapezius. The electrodes of cervical erector spinaes muscles were placed over muscle belly that was palpated between the sternoclaidomastoid muscle and trapezius when resistive extension and lateral rotation were performed in the same direction as muscles (Study III). The electrodes of right and left sternocleidomastoid muscles were placed slightly posterior over the middle part of muscles (sternal part). The caudal electrode of sternocleidomastoid muscle was placed so that the lowest edge of the electrode was above the midpoint of the muscle belly (Study III-IV). The electrodes of the upper section of both trapezius muscles were placed at the midpoint between the acromion and the spinosus process of the 7th cervical vertebra (Study III).

In study III the trial with the highest isometric force production and simultaneous EMG signal were selected for further analysis**.** The EMG signals were preamplified 1000 times. The measurement system used preamplifiers located in the cables to ensure high signal quality. EMG data were analyzed with the EMG software of MegaWin 2.0 (Mega Electronics Ltd, Kuopio, Finland). The raw signal was filtered through low and high pass filters, the cut-off frequencies being 20 Hz for low and 500 Hz for high, and passed through a 12-bit AD converter with a sampling frequency of 1000 Hz. The signals were carried out via a differential amplifier with an input impedance of 10 GΩ, a common mode rejection ratio >100 dB, and a signal-to-noise ratio of 72 dB. The background noise in the filtered signal remained below 1μV. The recorded raw EMG signal was full-wave rectified and averaged by using a 10-ms time constant. The maximal averaged EMG value (aEMG) was determined in the range between 50 ms before and 50 ms after the highest peak force. In the EMG software, the marker function was used manually to determine the simultaneous starting and end points of the force and EMG measurements. The unit of EMG signal was microvolt (μV) (Study III).

In study III, the ratios (EMG/force) between the maximal EMG values of agonist neck muscles and corresponding maximal neck-shoulder muscle force values (MVC), and the co-activation percentages of antagonist muscles, such as both sternocleidomastoid muscles during neck extension force measurement, both cervical erector spinae muscles during neck flexion force, and right trapezius muscle during neck flexion force measurement, were analyzed. In addition, the co-activation percentages of non-antagonist muscles, such as left cervical erector spinae and left sternocleidomastoid muscles during right shoulder maximal flexion force measurement, and right trapezius muscles during neck maximal extension force measurement, were analyzed. The co-activation percentages of the muscles were assessed by normalizing the maximal EMG value of the muscles during different actions to the maximal EMG of the muscles (% MVC).

In study IV, after the neck flexion endurance test, the fatigue index MF (median frequency) of both sternocleidomastoid muscles, 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 Fast Fourier transform (FFT) algorithm, where a 1024 data point window was used. The MF was calculated in a way described elsewhere (Lindström et al. 1970, Hägg 1992). In the EMG software, the marker function was used manually to mark the simultaneous starting and end point of the endurance test. The relative rate of change of MF (change in Hz/min) 1) across the total sustained contraction duration (was performed until exhaustion, maximal performance time was 200 seconds) and 2) across the initial 30 seconds of the total sustained contraction were reported.

Repeatability of EMG measurements

In our laboratory, intratester repeatability of EMG activity (μV) of both cervical erector spinae, sternocleidomastoid and trapezius muscles during simultaneous maximal isometric force measurements of neck and shoulder flexion muscles was assessed in subjects with headache and without headache (30 with tension-type headache, 29 with tension-type headache and 30 without headache). The EMG activity measurements with corresponding force measurements were retested after one hour. In the repeatability measurements, the position of the electrodes was carefully marked on the skin with indelible ink to ensure the same electrode position for both measurement sessions. After the first measurement session the electrodes were removed and correctly repositioned at the same place before the second measurement session.

For all groups, ICC and CV showed good repeatability of all EMG activity measurements of neck muscles. In migraine group, ICC varied from 0.95 to 0.99 and CV from 4.9% to 10.1% and in tension-type headache group, from 0.98 to 0.99 and from 5.1% to 8.0%, and in healthy control group, from 0.97 to 0.98 and from 5.5 to 8.7%, respectively (Oksanen et al. 2007).

The differences in almost all mean values for each EMG measurement in the three study groups were small across the two measurement sessions. In the second measurement session, EMG values of the cervical erector spinae muscles in tension-type headache and in control groups were significantly higher ($p < 0.05$ and $p< 0.05$, respectively) on the left side. There was no significant difference between the two measurements in other EMG parameters. In study groups, differences in the EMG values of left and right sternocleidomastoid and right cervical erector spinae muscles, and between the first and the second measurements were plotted against their means. No marked variation was observed between the consecutive test results on the individual level. Means of differences in EMG measurements were small between the test-retest results, and the 95% limit of agreement indicated a good repeatability in all study groups. There was no systematic difference between the measurements (Oksanen et al. 2007).

In all groups, intratester repeatability of the EMG activity of both trapezius muscles was good. However, repeatability of EMG activity was a bit weaker in the left trapezius muscle than in the right trapezius muscle. In migraine group, ICC and CV of right trapezius muscle activity were 0.99 and 5.6% and of left trapezius muscle activity 0.90 and 10.9%, respectively; in tension-type headache group, ICC and CV of right trapezius muscle activity were 0.99 and 3.3% and of left trapezius muscle activity 0.91 and 9.6%, respectively; in control group, ICC and CV of right trapezius muscle activity were 0.98 and 4.2% and of left trapezius muscle activity 0.90 and 9.9%, respectively (pilot study).

5.2.8. Cross-sectional area (Study V)

Magnetic resonance imaging (MRI) assessment of the cross-sectional area (mm^2) of the neck muscles was performed using a 1.5 T scanner (Siemens Symphony, Erlangen, Germany) **(Figure 8a)**. The subjects were placed in a supine position on the imaging table. The sagittal (T1-weighted and T2-weighted) images covering planes were obtained from the cervical spine (posterior fossa to the upper thoracic level) axial T1-weighted images ranging from C2 level to T1 level. The cross-sectional areas of the neck muscles were measured using Philips ViewForum R4.1 workstation.

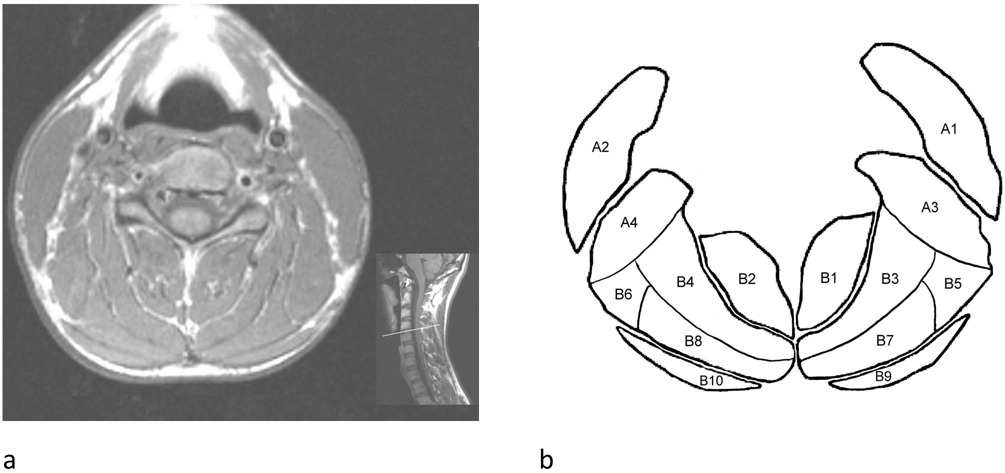


Figure 8. (a) Magnetic resonance images (MRI) of neck muscles. Transaxial MRI of the neck muscles in the intervertebral disc between C4 and C5. **(b)** Calculation of the cross-sectional area of the flexion and extension muscles. The image was traced, and the traced image was transferred to a computer to calculate the cross-sectional area of neck muscles: areas A1 and A2 show the sternocleidomastoid muscles, while A3 and B4 show scalenus muscles (anterior, medius, posterior). Areas B1 and B2 show deep posterior neck muscles (rotator, multifidus and semispinalis cervicis), B3 and B4 show semispinalis capitis, B5 and B6 show levator scapulae muscles and B7 and B8 contain splenius muscles (capitis, cervicis). B9 and B10 show the trapezius muscles.

The areas of A1 to A4 were defined as the neck flexion muscles of both sides (A1 right and A2 left sternocleidomastoideus; A3 right and A4 left scalenus muscles (anterior, medius, posterior). The area of B1 to B10 were defined as the neck extension muscles of both sides (B1 right and B2 left deep posterior neck muscles (rotators, multifidus, semispinalis cervicis); B3 right and B4 left semispinalis capitis; B5 right and B6 left levator scapulae; B7 right and B8 left splenius muscles (capitis and cervicis); B9 right and B10 left upper trapezius**.** The measurement and the analysis of the cross-sectional area of each separated muscles of both sides separately (A1 to A4 and B1 to B10) was performed at C4/C5 disc level **(Figure 8b)**. In addition, right and left flexion muscles and part of the right and left neck extension muscles were combined and the cross-sectional area of each group was analyzed. All the analyses were performed by the same trained analyzer (by the author).

In our work, intratester repeatability was assessed by measuring the cross-sectional area of levator scapulae and scalenus muscles of both sides for fifteen headache subjects (seven with tension-type headache and eight with migraine-type headache) and retesting them from the same images at an interval of one week from. The trial-to-trial repeatability of the cross-sectional area measurements appeared to be good. The ICC and the CV for the right scalenus muscle were 0.91 and 8.6% and for the left scalenus muscle 0.96 and 5.4%, respectively. The ICC and the CV for the right levator muscle were 0.98 and 3.6% and for the left levator muscle 0.89 and 11.0%, respectively.

5.3. Statistical methods

In the description of the data, mean values with standard deviations, mean differences, or frequencies and percentages were used. Statistical analyses were carried out using SAS System for Windows (SAS Institute Inc., Cary, NC). The level of significance was set at 0.05 for all tests.

In paper **I**, the gender adjusted univariate associations between headache and leisure activity variables were analyzed with multinomial logistic regression models. In these models, the headache grouping was the response variable. Multinomial (polychotomous) logistic analysis was used, as the response variable had three categories instead of two which is the case in the classical binary logistic regression. Multinomial modeling permits to compute one global p-value for each association even when the response has more than two categories. The results of the analyses were quantified with odds ratios (OR) and 95% confidence intervals (95%CI). For each association, two odds ratios were calculated corresponding to two headache categories, one for migraine compared with controls and one for tension type headache compared with controls. Multivariate logistic regression analysis was carried out applying the backward elimination method in the model building.

In paper **II**, the differences in gender distribution between the three study groups were tested by using Pearson's chi square test. Gender-adjusted comparisons of the study groups were performed by using the analysis of covariance (ANCOVA) in which the gender was a covariate. In pairwise comparisons of the groups, the p-values were post hoc Bonferroni corrected. The difference between boys and girls in different study groups was analyzed by testing the gender-group interaction in the ANCOVA models. The strength of association between the sides of the body was quantified by using the Pearson's correlation coefficient.

In paper **III**, the differences in gender distribution between the three study groups were tested using the Chi-square test. The difference between boys and girls in different study groups was analyzed by testing gender-group interaction in the ANOVA models. Due to the fact that there were different number of boys and girls in the groups the pairwise comparisons were calculated within gender. In pairwise comparisons of the groups within gender, the p-values were Bonferroni-corrected. Two-way ANOVA was used instead of one-way ANOVA by gender so that overall error term could be minimized. Residuals was checked for justification of analysis, and transformation was used when necessary (natural logarithm or square root).

In paper **IV**, the associations between two categorical variables were analyzed with Chi-square and Fisher's exact test. In comparison of the group means one-way analysis of variance was used. The gender-group interaction was checked with two-way ANOVA. Then, in comparison of the group means analysis of covariance (ANCOVA) was used, with gender and pain variables as covariates. Pairwise comparisons were adjusted using the Tukey-Kramer method. Spearman (r_s) and Pearson (r_p) 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). To evaluate the test-retest reliability of the two measurement sessions, the intraclass correlation coefficient, ICC with 95% confidence intervals, was calculated. To calculate odds ratios (OR) for belonging to different groups, for various explanatory variables by themselves and adjusted for gender, multinomial logistic regression with generalized logit link function was used.

In paper **V**, general linear mixed models with gender and group as fixed effects and side as repeated factor were used for analysis. All pairwise comparisons (between groups) were calculated within gender and side. To adjust these pairwise comparisons, Bonferroni-method was used. Log or square root transformation were used when necessary. To compare characteristic measures between groups, analysis of variance (ANOVA) was used. In case of non-normal distribution Kruskal-Wallis test was used to compare groups. In case of categorical measures to compare groups, Chi square or Fisher's exact test was used. To evaluate the test-retest reliability of the two measurement sessions, the intraclass correlation coefficient, ICC with 95% confidence intervals, was calculated.

6. RESULTS

The summary of the major findings obtained from the series of studies are shown in Table 7. The additional details are seen in the original papers (Studies I-V).

6.1. Leisure activities (Study I)

The type of leisure activity, classified to the four different groups on the basis of body loading, and the amount of the those activities among the headache and healthy control groups are shown in Table 1 in paper I. Children with migraine spent more time (≥4 hours/week) in sports activities than children with episodic tension-type headache or children without headache (test for trend, $p < 0.01$; migraine: OR 1.4, 95% CI 1.1-1.9). Of 59 migraine children 67.8%, of 65 tension-type headache children 49.2%, and of 59 headache-free children 40.5% spent at least four hours/week in sports activities. In addition, children with both migraine and episodic tension-type headache used computers more often (days/week) than children without headache (test for trend, $p < 0.05$; migraine: OR 1.2, 95% CI 1.1-1.5; tension-type headache: OR 1.3, 95% CI 1.1-1.5). The mean time using computer in children with migraine was 2.7 days/week (SD 2.5), in children with tension-type headache 3.0 days/week (SD 2.5) and in headache-free children 1.5 days/week (SD 1.9). The type of leisure activity was not significantly associated with headache type ($p > 0.05$) (Table II in paper I).

6.2. Strength and mobility of the neck-shoulder region (Study II)

The strength and mobility variables of the neck-shoulder region in adolescents with migraine, tension-type headache, and the control group, respectively, are shown in Table 1 in paper II.

6.2.1. Range of motion

Girls with tension-type headache had lower cervical rotation of the dominant side compared to the girls in the control ($P = 0.049$) and migraine groups ($P = 0.018$). The mean cervical rotation of the dominant side in girls with tension-type headache was 70.3° (SD 6.0), in girls with migraine 76.6° (SD 6.7) and in headache-free girls 75.8° (SD 6.7). Other cervical mobility variables (flexion, extension and lateral flexion) and the mobility of upper extremities did not differ in girls between different study groups. In boys, no significant differences were observed between the three study groups.

Table 7. Summery of the major findings obtained from the series of studies.

	Migraine group		**Tension-type headache group**	
Study I	- used computers (2.7 days/week) more often than HS (1.5 days/week) - spent more time (≥4 hours/week) in sports activities than TTH group or HS - no difference in the type of leisure activity (classified with body loading)		- used computers (3.0 days/week) more often than HS (1.5 days/ week) - no difference in the type of leisure activity (classified with body loading)	
	Girls	**Boys**	**Girls**	**Boys**
Study II	- lower UE endurance of non-dominant side than HS (repetitions: 28.0 vs. 35.5)	- no differences	- lower UE endurance of dominant and non-dominant sides than HS or MH group (repetitions: 20.9/24.9 vs. 31.2/35.5 vs. 26.5/28.0) - lower cervical rotation of the dominant side than HS or MH group (70.3° vs. 75.8° vs. 76.6°)	- no differences
Study III	- higher left agonist SCM muscle activity in the neck flexion than TTH group (EMG/force ratios 3.5 vs. 2.4) - higher left agonist SCM muscle activity in the neck rotation force to the right side than TTH group (EMG/force ratios 40.1 vs. 27.3) - higher right antagonist CES muscle co-activation during neck flexion force than HS (31% MVC vs. 16% MVC) - no difference in neck-shoulder muscles force production	- no differences	- lower left shoulder flexion force than MH group or HS (40.8 N vs. 50.0 N vs. 52.0 N) - no difference in neck muscle force production (tendency for lower values)	- no differences
Study IV	- no difference in SCM muscles fatigue (TMF) (MTH/HS) - no difference in the total endurance time (sec), IMF or VAS		- more fatigue (TMF) of both SCM muscles than HS - no difference in the total endurance time (sec), IMF or VAS	
Study V		- larger size of right SCM muscle than HS (643 mm^2 vs. 503 mm^2) - larger size of combined right SCM and scalenus muscles than HS (770 mm^2 vs. 616 mm^2) - larger size of left semispinalis capitis muscle than HS (501mm^2 vs. 392 mm^2) - larger size of combined left semispinalis capitis and splenius muscles than HS (810 mm^2 vs. 686 mm^2	- smaller size of combined right SCM and scalenus muscles than MH group (436 mm^2 vs. 540mm^2)	- smaller size of right SCM muscle than MH group (532 mm^2 vs. 643 mm^2)

Abbreviations: comparisons between MH, migraine/TTH, tension-type headache/MTH, migraine-type headache/HS, healthy subjects; UE, upper extremity; SCM, sternocleidomastoid muscle; CES, cervical erector spinae; EMG, electromyography; VAS, visual analogue scale; TMF, median frequency across the total contraction time; IMF, median frequency across the initial 30 s of the total contraction time

6.2.2. *Dynamic endurance strength*

Girls with tension-type headache displayed lower dynamic endurance strength of upper extremity (UE endurance) in both non-dominant (P = 0.005) and dominant sides (P = 0.004) compared to girls in the control group. Girls with migraine displayed lower UE endurance strength of the non-dominant (P = 0.024) side than girls in the control group. The mean total number of repetitions of the dominant side in girls with tension-type headache was 20.9 (SD 9.5), in girls with migraine 26.5 (SD 9.1) and in headache-free girls 31.2 (SD 10.3). Similarly, the mean total number of repetitions of the non-dominant side in girls with tension-type headache was 24.9 (SD 10.1), in girls with migraine 28.0 (SD 9.7) and in headache-free girls 35.5 (SD 10.9). In boys, no significant differences were observed between the three study groups.

6.3. Force production and EMG activity of neck-shoulder muscles (Study III)

The forces of neck and shoulder muscles, EMG/force ratio variables and co-activation percentages (antagonist and non-antagonist muscles, % MVC) of the neck muscles in different types of headache and in healthy subjects are shown in Table 2 in paper III.

6.3.1. *Force*

Girls with tension-type headache displayed significantly lower left shoulder flexion force than girls with migraine (P = 0.005) or without headache (P = 0.005) (print error in Table 2). The mean left shoulder flexion force in girls with tension-type headache was 40.8 N (SD 7.9), in girls with migraine 50.0 N (SD 10.2) and in headache-free girls 52.0 N (SD 11.9). Other force variables showed no significant differences between the girls in different study groups. In boys, no significant differences in the force variables were observed between study groups. The neck flexion/extension force ratio showed no significant differences between different study groups.

6.3.2. *EMG/force ratio*

Girls with migraine-type headache had significantly higher EMG/force ratio between the EMG of the left sternocleidomastoid muscle and the corresponding neck flexion force (P = 0.030) and the corresponding neck rotation force to the right (P = 0.024) compared with girls in the tension-type headache group. Other EMG/force ratios showed no significant differences between the girls in different study groups. The mean EMG/force ratio between the EMG of the left sternocleidomastoid muscle and the corresponding neck flexion force in girls with migraine-type headache was 3.5 (SD 1.8), in girls with tension-type headache 2.4 (SD 0.6) and in headache-free girls 2.9 (SD 0.9). Similarly, the mean EMG/force ratio between the EMG of the left sternocleidomastoid muscle and the corresponding neck rotation force to the right side in girls with migraine-type headache was 40.1 (SD 19.3), in girls with tension-type headache 27.3 (SD 12.5) and in headache-free girls 34.7 (SD 13.4). In boys, no significant differences in the EMG/force ratios were observed between the study groups.

6.3.3. Co-activation of the antagonist neck muscles

Especially in girls with migraine-type headache, the co-activation percentage of both left and right antagonist cervical erector spinae muscles during neck flexion force measurement were higher than in girls with tension-type headache or in headache-free girls. However, girls with migraine had significantly higher co-activation percentage of the right antagonist cervical erector spinae muscle than girls in the control group (P = 0.015). Co-activation percentages of other antagonist muscles showed no significant difference between the girls in different study groups. The mean co-activation percentage of the right and left antagonist cervical erector spinae muscle during neck flexion force measurement in girls with migraine-type headache were 31% (SD 14) and 29% (SD 14), in girls with tension-type headache 22% (SD 13) and 18% (SD 5) and in headache-free girls 16% (SD 6) and 18% (SD 7), respectively. In boys, no significant differences in the co-activation percentages were observed between the study groups.

6.3.4. Co-activation of non-antagonist neck muscles

In boys and in girls, no significant differences in the co-activation percentages of the non-antagonist muscles such as left cervical erector spinae and left sternocleidomastoid muscles during right shoulder flexion force measurement and right trapezius muscle during neck extension force measurement were observed between the study groups.

Adolescents did not report headache or neck-shoulder symptoms during the measurements, but some of them reported headache or neck-shoulder muscle pain on the examination day before or at midday (**Appendices 3 and 4**). Neither current headache nor muscular symptoms of the neck region had any effect on the differences of the measured variables between girls and boys in different headache groups (P > 0.05).

6.4. Neck flexion muscles fatigue (Study IV)

The statistics on total endurance time (sec), relative median frequency changes with time (total contraction time and with first 30 seconds of the total contraction time), and subjective perception and location of the neck-shoulder muscle discomfort/pain (VAS) in the different headache groups and in the control group are shown in Table 2 in paper IV. Because interaction with gender and group was not significant in the responses it was removed from the model and only main effects were used.

6.4.1. Endurance time

No significant difference (P = 0.050) emerged among the three study groups in the total endurance time (sec). In the pairwise comparisons**,** the tension-type headache group had significantly lower endurance values than the healthy controls (P = 0.04).

6.4.2. Changes in median frequency

During the total contraction time, median frequency of right and left sternocleidomastoid muscles decreased significantly faster in the tension-type group than in the control group (right sternocleidomastoid muscle, P = 0.03, mean difference 7.3, 95% CI 0.6-14.0; left sternocleidomastoid muscle, P = 0.005, mean difference (Square-root -transformation) 1.2, 95% CI 0.3-2.1). During the initial 30 seconds of the total contraction time, median frequency of both sternocleidomastoid muscles did not differ significantly among the study groups indicating that the time period was not sufficient to differentiate these study groups in respect to muscle fatigue. The rate of decline in median frequency across the total contraction time of both sides remained significantly associated with headache type (right sternocleidomastoid muscle, P = 0.030; left sternocleidomastoid muscle, P = 0.009). These raised the odds of belonging to the tension-type group compared with controls (right sternocleidomastoid muscle, OR 2.0, 95% CI 1.2-3.7; left sternocleidomastoid muscle, OR 2.5, 95% CI 1.4-4.9) when there was a ten-unit (10 Hz/min) decrease in median frequency values of total contraction time. The comparison between the migraine-type headache group and the control group was statistically non-significant (right sternocleidomastoid muscle, OR 1.2, 95% CI 0.7-2.1; left sternocleidomastoid muscle, OR 1.5, 95% CI 0.8-2.9) when the ten-unit decrease in median frequency values of total contraction time of right and left sternocleidomastoid muscles was observed.

6.4.3. Correlation between median frequency and endurance time

There was a significant correlation between the total endurance time (Log -transformation) and median frequency across the total contraction time of both right and left (Square-root -transformation) sternocleidomastoid muscle (right, r_p = -0.59, P = 0.0016; left, r_p = -0.65, P = 0.0003) in the tension-type headache group, and between the total endurance time (Log -transformation) and median frequency of total contraction time of right sternocleidomastoid muscle in the healthy control group (r_p = -0.41, P = 0.02) (Figure 2 in paper IV). There was no statistically discernible correlation between the total endurance time and median frequency of total contraction time of right and left sternocleidomastoid muscle in the migraine group (right, r_p = 0.01, P = 0.97; left, r_p = -0.04, P = 0.86) and between the total endurance time and median frequency of total contraction time of left sternocleidomastoid muscle in the healthy control group (r_p = - 0.24, P = 0.40).

Adolescents did not report headache or neck-shoulder symptoms during the measurements. Neither current headache nor muscular symptoms of the neck region had any effect on the differences of the measured variables between girls and boys in different headache groups ($P > 0.05$).

6.5. Neck muscles cross-sectional area (Study V)

The cross-sectional area (mm^2) of superficial and deep neck flexion and extension muscles of right and left sides at C4/C5 disc level in adolescents with different types of headache and in healthy controls are shown in Table 2 in paper V.

6.5.1. The size of neck flexion muscles

In boys with headache the cross-sectional areas were larger than in healthy controls. The cross-sectional area of right sternocleidomastoid muscle in boys was 27.9% larger in the migraine group than in the healthy control group ($P = 0.009$) and 17.3% larger than in the tension-type headache group ($P = 0.023$). The mean cross-sectional area of right sternocleidomastoid muscle in boys with migraine was 643 mm^2 (SD 36), in boys with tension-type headache 532 mm^2 (SD 88), and in headache-free boys 503 mm^2 (SD 68). The cross-sectional area of combined right sternocleidomastoid and right scalenus muscles was 25% larger in boys with migraine-type headache than in boys without headache ($P = 0.012$). The mean cross-sectional area of combined right sternocleidomastoid and right scalenus muscles in boys with migraine, tension-type headache and in healthy controls were 770 mm^2 (SD 24), 681 mm^2 (SD 93) and 616 mm^2 (SD 79), respectively. No statistically discernible differences were observed in the cross-sectional area of the left sternocleidomastoid muscles, the scalenus muscles of both sides and the combined left sternocleidomastoid and left scalenus muscles in the boys of different study groups.

The cross-sectional area of combined right sternocleidomastoid and right scalenus muscles in girls with tension-type headache was significantly smaller (19.2%) than that in girls with migraine-type headache ($P = 0.048$). The mean cross-sectional area of combined right sternocleidomastoid and right scalenus muscles in girls with migraine was 540 mm^2 (SD 131), in girls with tension-type headache 436 mm^2 (SD 96), and in headache-free girls 517 mm^2 (SD 83). Other cross-sectional areas were also smaller in girls with tension-type headache than in healthy controls, but the differences were not significant. In girls with migraine, the cross-sectional area of both scalenus muscles and both combined neck flexion muscles, was larger than in healthy controls, but the differences were not significant. Conversely, the cross-sectional area of both sternocleidomastoid muscles was smaller than in healthy controls, but the differences were not significant.

6.5.2. The size of neck extension muscles

In boys with migraine, the cross-sectional area of the left semispinalis capitis muscle (B4) ($P = 0.006$) and of combined left semispinalis capitis and left splenius muscles (B4+B8)

(P = 0.008) were significantly larger than those in boys without headache. The cross-sectional area of the left semispinalis capitis muscle was 27.9% larger, and combined left semispinalis capitis and left splenius muscles 18.1% larger, in boys with migraine than in boys without headache. The mean cross-sectional area of left semispinalis muscles in boys with migraine, tension-type headache and in healthy controls were 501 mm^2 (SD 47), 440 mm^2 (SD 91), and 392 mm^2 (SD 62), respectively. Similarly, the mean cross-sectional area of combined left semispinalis capitis and left splenius muscles in boys with migraine, tension-type headache, and in healthy controls were 810 mm^2 (SD 85), 719 mm^2 (SD 96), and 686 mm^2 (SD 74), respectively. The mean cross-sectional areas were larger in boys of both headache groups than in the healthy controls except for the cross-sectional areas of both deep neck extension muscles in boys with migraine and both splenius muscles in boys with tension-type headache. However, the differences were not significant.

Girls in the headache groups had mostly smaller cross-sectional areas than healthy controls. However, no significant differences were observed in the cross-sectional area of single or combined neck extension muscles in girls between different study groups.

7. DISCUSSION

The findings of the present cross-sectional studies indicated that young adolescents with both tension-type headache and migraine used computers significantly more often compared to healthy subjects, while adolescents with migraine spent more time in sports activity compared to both healthy subjects and adolescents with tension-type headache. The type of leisure activity classified by body loading did not differ between these study groups. On more specific examination (ages 13 or 17 years), the results showed that especially girls with tension-type headache had significantly lower bilateral or unilateral strength capacity of upper extremities and lower unilateral cervical rotation compared to both healthy and migrainous girls. The girls with migraine also had significantly lower unilateral endurance strength capacity of the upper extremities compared to the healthy girls. Neck force production did not differ significantly in girls between the study groups. The results also showed that girls with migraine had a significantly higher activity capacity of the unilateral agonist sternocleidomastoid muscle compared to the girls with tension-type headache, and a higher co-activation capacity of the unilateral antagonist cervical erector spinae muscle compared to healthy girls. In boys, neuromuscular function of the neck-shoulder region did not differ significantly among the study groups. Adolescents with tension-type headache as a whole group showed more fatigue of both sternocleidomastoid muscles compared to the healthy subjects. In addition, especially boys with migraine had a significantly larger size of unilateral neck flexion and extension muscles compared to the healthy boys. On the contrary, boys and also girls with tension-type headache, had a significantly smaller size of unilateral neck flexion muscle or combined neck flexion muscles compared to boys or girls with migraine, respectively.

7.1. Methods

Leisure activity questionnaire

The questions on physical activity have been used widely in the national health survey of schoolchildren coordinated by the World Health Organisation (WHO), and they have proved accurate in surveying the state of physical activity (Aarø et al. 1986). The children were asked with an open question about the number of days in a week they used the Internet or played computer games. Even though the access to computer equipment was available to all children, the question did not differentiate between computer use at home and at school, and nor did it clarify the exact use of the computer. The interview on headache and leisure activities was performed by the same pediatrician. In sports activities, the estimation of the loading of the extremities or whole body was performed subsequently on the basis of the type of sports activities. However, in practice, the subjects in different headache groups practiced different types of sports activities, which might confuse the result, and therefore could not differentiate the study groups. Although subjects were interviewed via both open and structured questions, the true activity was difficult to assess, and the use of a diary might also have provided more exact information.

Dynamic endurance strength and mobility measurements

The measurement protocol of upper extremity endurance strength and mobility was well standardized and blind observers were well trained. To minimize inter-tester variability of the endurance strength and mobility measurements, the same physiotherapist performed the UE endurance testing, and another physiotherapist the UE mobility testing, for all study children. To observe the movements from two angles of view the cervical spine mobility test was performed by both physiotherapists. The UE endurance test was first used in the University of Jyväskylä, Finland, as a part of a fitness testing battery in 2155 Finnish schoolchildren (Nupponen et al. 1999), and it has been shown to have good applicability for schoolchildren. Because a functional test of the upper extremities was needed for the study, the present test of UE mobility was included. The test is in general use in physical therapy practice and has been reported to measure simultaneously the mobility of both shoulders and the thoracic spine (Janda 1983, Cailliet 1991, Clarkson 2000). The anthropometric factors such as the length of fingers, hands, entire upper extremities or upper body, may have some effect on the performances of the UE mobility test. Previously, the cervical measurement instrument has been reported to be extremely reliable (Capuano-Pucci et al. 1991, Alaranta et al. 1994, Peolsson et al. 2000).

Isometric strength

In the present study, isometric muscles strength testing devices were used because of their well standardized and accurate testing positions, and due to the fact that isometric testing is generally known to be reliable. However, in our study (study III), we wanted to ensure the repeatability of the isometric measurements with simultaneous EMG measurements among our study groups before any comparisons were perormed among the study groups. Thus, the intra-tester repeatability of the measurements was examined and it proved to be good in all study groups (Oksanen et al. 2007). The isometric neck strength testing has also been reported to be reproducible in most of the other studies (Peolsson and Öberg 2001, Garcės et al. 2002, Strimpakos et al. 2004, Valkeinen et al. 2002, Ylinen et al. 2004). The device has a firm fixation of the head, with both shoulder and pelvis in a sitting position to ensure the standardized measurement position throughout the measurements. There are also studies (Gogia and Sabbahi 1994, Barton and Hayes 1996) where neck forces have been measured in a supine position when the weight of the head has to be overcome and thus considered in the force values. The present testing device has been developed on the basis of imaging studies examining motion of the upper cervical spine (Sutherland et al. 1995) and antropometric measures of the adult skull (Telkkä 1952). In a study by Ylinen et al. (1999), the biomechanical principles of the device have been reported.

Surface EMG measurements

EMG signals are used to assess the muscular activity level over a period of time, and they can be analyzed with respect to the amplitude (study III) or frequency (study IV). In study III, surface EMG activity was measured simultaneously with the maximal force measurements (EMG/force ratio) bilaterally from the neck-shoulder muscles using the well-known and reliable Muscle Tester ME8000P device. With on-line data acquisition, the advanced, acceptable EMG measurement technique was used. In the study (study III), the used standardized method reduced the bias due to the measurement factors. For comparisons of different muscles, EMG was normalized to reduce bias due to the physiological factors (i.a. effect of subcutaneous fat) (Yang and Winter 1983). Because the ability to maximally activate all motor units depends on many factors, such as the muscle activated, training level, warming-up before maximal effort, and motivation (Basmajian and DeLuca 1985), the subjects had performed the proper warming-up period and were trained with sub-maximal efforts before the maximal performance. The power spectral analysis of surface EMG was used to measure neck flexion muscle fatigability during the isometric neck endurance test (study IV). The analysis has been generally accepted and used as an objective assessment method for local muscle fatigability (Roy et al. 1995, Mannion et al. 1994, Peach and McGill 1998). The method monitors frequency changes of the EMG signal, with the main emphasis on the shift in the EMG power spectral indices (MF, MPF, ZCR) towards lower frequencies (Basmajian and DeLuca 1985, Solomonow et al. 1990, Merletti and Roy 1996). The faster shift in the myoelectric power density spectrum towards lower frequencies is considered to indicate increased muscle fatigue (Horita and Ishiko 1987). Change of median frequency (MF) has generally been used to describe fatigue and has been reported to have the greatest sensitivity to the alterations in motor unit firing rate (Basmajian and DeLuca 1985, Hägg 1992). Because the EMG frequency changes are observed as a function of time, the changes have been reported as relative changes over time (percentage of initial absolute value); the effect of subcutaneous tissue thickness is assumed to be minor when the results are compared (DeLuca 1984, DeLuca 1997, Cram and Ksman 1998).

Isometric endurance strength

The maximal endurance time (s) using a stopwatch was used to measure the endurance capacity and, thus, also fatigability (study IV) of neck flexion muscles. There are only few studies examining submaximal forces or endurance of neck flexion or extension muscles against gravity (Grimmer 1994, Jordan et al. 1997, Kumbhare et al. 2005). The published protocols have focussed mainly on the maximum isometric force that does not exhibit endurance and fatigability characteristics of the muscle. As in our study, also in another recent study (Kumbhare et al. 2005), the neck flexion muscle endurance time test while the subject is in a supine position, has been shown to be reliable and also valid. In our study, the EMG fatigue parameters were simultaneously recorded during the endurance time test to get more detailed fatigue data on the neck SCM muscles of both sides. In the previous studies, a high correlation has been reported between objective spectral EMG fatigue measurements and endurance time (Mannion and Dolan 1994, Merletti and Roy 1996).

Cross-sectional area

Measurement of muscle size from MR images has been shown to be an objective and reliable non-invasive assessment method of muscle atrophy or hypertrophy (Ranson et al. 2006, Clark et al. 2007). In our study (study V), while the repeated measures testing showed good repeatability for the method of measuring the CSA of the muscles, there was a minor potential for error in constructing the polygons around the margins of each muscle. However, measures were taken to minimize this error by having the same well trained person take all the CSA measurements. The measurement technique that was used gave a gross measurement of muscle CSA.

7.2. Results

7.2.1. Leisure activities associated with headache

At the age of 13 years, intensity of sports activity was associated with migraine, and frequent computer use with both migraine and tension-type headache. The type of leisure activity, classifying activities on the basis of body loading, was not associated with headache. Our results disagree with the finding that the amount of physical activity is not related to the adolescent headache (Kujala et al. 1999). However, in a population-based study on subjects aged 15 to 65 years, frequent physical activity was a common precipitant for tension-type headache (Zivadinov et al. 2003). In that study, as also in our study, the children with migraine spent the most hours in sports activities. This finding is in accordance with the previous studies (Bener et al. 2000, McCrory 2000, Turner 2003).

The migraine children generally practised more sports activities that they could practise alone. This may be stressful especially if the migraine adolescents are ambitious and self-demanding as they have been reported to be (McGrath 2001). In our study, the association between migraine headache and intensive sports activity may partly be explained by the stress and excessive exertion during sports activities. These factors have been indicated to provoke migraine or migraine-type headache (Spierings et al. 2001, Bener et al. 2000, McCrory 2000, Turner 2003).

There are no previous studies on the association between computer use and different types of headache in young adolescents. However, especially tension-type headache may be caused by muscular factors such as tense, tight and weak neck-shoulder muscles as a result of poor static and longstanding working postures at the computer (Harms-Ringdahl and Ekholm 1986, Jensen and Olesen 1996, Dalenbring et al. 1999, Fernández-de-las-Peñas et al. 2006a, 2007a) **(Figure 6).** During computer-working, an extreme flexion position of the lower-cervial-upper-thoracic spine, exerting a load on passive tissues, such as joint capsules and ligaments, may itself provoke headache (Harms-Ringdahl and Ekholm 1986, Harms-Ringdahl et al. 1986). On the other hand, migraine headache can be provoked by the flashing lights of computers (Vanagaite et al. 1997, Bener et al. 2000, Spierings et al. 2001). Especially sensitivity to flashing lights (e.g. computer or TV monitor) differentiates migraine from tension-type headache (Spierings et al. 2001). Eyestrain and excessive fatigue of eyes caused by staring at a computer monitor may also cause headache. Depressive symptoms and psychosocial factors have been reported to be associated with headache in children and adolescents (Karwautz et al. 1999, Anttila et al. 2002), and thus, factors such as lack of social relationships, social phobia and depression can increase the computer use.

According to the study, frequent computer use in young adolescents may be a tentative risk factor for both tension-type headache and migraine, and intensive sports for migraine. It is important to recognize risk factors concerning leisure activities already in children and adolescents so that the correct recommendations or instructions could be given early in life for the prevention of headache or its aggravation. However, longitudinal studies are required to establish the significance of these factors.

7.2.2. Neck muscle function associated with headache

There are no previous population-based studies on the association between neck-shoulder muscle function and different types of headache in children and adolescents. In previous studies in adults, the level or frequency of neck-shoulder symptoms (neck pain) had not been considered when selecting the subjects for the headache and control groups. In the present study, the boys and the girls seemed to behave differently, and there were also clear differences related to the primary headache type. A third trend was that most of the abnormal findings tended to be unilateral.

At the ages of 13 and 17 years, differences in the neck-shoulder muscles were found only in girls with headache. Low UE endurance strength of both sides, and decreased cervical rotation of the dominant side, were associated with tension-type headache, while low UE endurance strength of the non-dominant side was associated with migraine. Migrainous girls had both high left agonist SCM muscle activity and high co-activation of right antagonist CES muscle, while vice versa, girls with tension-type headache had low left agonist SCM muscle activity. Girls with tension-type headache had lower left shoulder flexion force and there was also a tendency toward lower neck muscle forces in this group. Increased fatigue of both SCM muscles was associated with tension-type headache. At the age of 17 years, there were also morphological changes of the neck musculature in the different headache groups both in girls and in boys. In boys, the small size of the right SCM muscle and, in girls, the small size of the right combined SCM and scalenus muscles were associated with tension-type headache. Similarly, in boys, the large size of the right SCM muscle and the right combined SCM and scalenus muscles, the large size of the left semispinalis capitis muscle and the left combined semispinalis and splenius muscles were associated with migraine.

Unilateral findings in migrainous girls could be due to the fact that migraine pain usually occurs unilaterally. Thus, the recurrent migraine pain itself may change and sensitize the persons's ability to exceptionally recruit and and activate the neck muscles, obviously on the pain side. On the other hand, in migrainous girls, all the differences in neck muscle function were on the non-dominant side. The muscles of this side are usually weaker than on the dominant side, which may change the activation capacity and coordination of neck muscles on this side. In girls with tension-type headache, the unilateral differences of the neck muscles function may partly be a consequence of ergonomically unfavourable working or movement habits when the neck muscles are activated and strained unequally.

Abnormal findings of the neck muscles were found most of all in girls with headache. There were no differences in neck muscular function between the boys among different study groups. This may be due to the fact that there were small numbers of boys in the different study groups, and thus the statistical power was weak. In addition, the explanation for the results of the boys may be due to differences in genetic factors between girls and boys. Both migraine and tension headache are more frequent in adult females with the differentiation between genders taking place during prepuberty and puberty, indicating that hormonal factors predispose to these headaches. Hormonal factors might also have an influence on the muscular function. It might also be that, in adolescent boys, the changes related to growth and puberty mask the subtle changes related to headache.

Especially in girls with tension-type headache, almost all the findings were logical and complemented each other, showing the decreased neuromuscular capacity of the neck-shoulder muscles. The small size of the right SCM muscle in boys with tension-type headache agrees with this finding. In adolescents with migraine, there seemed instead to be a trend towards excessive activity of muscles. Migrainous girls showed high left agonist SCM muscle activity and high co-activation of the right antagonist CES muscle. The large size of superficial flexion and extension muscles, especially in boys in the migraine groups, may be due to the subject's ability to activate and use these muscles by way of exception in their daily or leisure activities. An endogenous higher level of muscular activity might be related to the increased neuronal excitability of the central nervous system in migraine patients. However, we cannot rule out the possibility that the increased size of neck muscles with migraine is due to the increased intensity of sports activities in the boys with migraine.

Our findings are partly in accordance with some of the studies performed in adults with headache. Recently, decreased neck mobility for nearly all cervical movements has been found in both chronic tension-type headache (Fernándes-de-las-Peñas et al. 2006a) and also in episodic tension-type headache (Fernándes-de-las-Peñas et al. 2007a). Decreased muscle activity of pericranial muscles during maximal voluntary contraction have been shown to be associated with chronic tension-type headache, but not with the episodic form (Jensen et al. 1994, Jensen 1999). Increased muscle fatigue of SCM muscles has been reported in unilateral neck pain with tension-type headache (Barton and Hayes 1996), as well as of frontal and temporal muscles (Jensen et al. 1994) in chronic tension-type headache. Increased atrophy of the suboccipital muscles has been reported in chronic neck pain with associated headache (Hallgren et al. 1996) and, currently, of both rectus capitis muscles in chronic tension-type headache (Fernándes-de-las-Peñas et al. 2007c). There is also evidence that subjects with persistent headache and neck pain have altered coordination between deep and superficial muscles, greater neck muscle fatigue under sustained low loads, and deficits in the kinaesthetic sense of the cervical spine and head (a deficit in neck proprioseption) (Falla et al. 2003, Jull 2000, O'Leary et al. 2003). Decreased deep neck flexor muscle contraction has recently been reported in chronic tension-type headache subjects (Fernăndes-de-las-Penăs et al. 2007b).

It is possible that the headache pain symptoms themselves may change neck muscle function and may thus result in disturbance in muscle performance and activity capacity, and even in muscle structure. On the other hand, deficits or differences in muscular function or structure, among other things, due to a sedentary life-style, may predispose to headache. Especially in tension-type headache, the weakness and muscle atrophy of the neck-shoulder muscles, together with reduced muscle metabolism and blood flow, may be a predictor of headache. Studies support this view in adults (Levoska and Keinänen-Kiukaanniemi 1993), with the conclusion that active muscular training of the neck-shoulder muscles creates a protective effect against headache. In headache groups, differences in neck muscle function and even in structure may also be due to genetic factors as the neck muscles in different types of headache are originally different (e.g. Type I and Type II fibre distribution).

In adolescents, recurrent headache often appears with concomitant neck pain (Mikkelsson et al. 1997, Anttila et al. 2001, Anttila et al. 2002a, Ståhl et al. 2004, Laurell et al. 2005, Laimi et al. 2007a). In our study, both headache groups also had concomitant neck pain symptoms, and the groups were comparable regarding the frequency of such symptoms.

The frequency of neck muscular pain could be classified as moderate. In the study, it is obvious that neck pain or muscular symptoms may explain the muscular differences in tension-type headache, at least in girls. It is possible that subjects with tension-type headache due to neck muscle pain inhibit the activation and use of especially superficial neck muscles, and compensate for them with the use of other deeper muscles. However, the role of neck pain in muscle function in migrainous adolescents may be quite different from that in tension-type headache. The main reason for the different neuromuscular function of the neck muscles among the headache groups is the at least partially different pathology of these two headache types. It is also possible that, due to genetic factors, the neck muscles characteristics in tension-type headache are originally different from those in migraine. The pathogenesis of the migraine pain is primarily neurovascular, and it is obvious that the possible muscular findings in this headache group are secondary. In adults, increased pericranial and neck muscle tenderness has been found to occur during migraine attacks, indicating that the muscle tenderness may be induced by the headache (Jensen et al. 1988). Also children with migraine have been shown to be sensitized to pericranial and neck-shoulder muscle pain (Anttila et al. 2002b). Increased sensitization and thus also, exceptional recruitment of neck muscles in migraine may be connected with the increased neuronal excitability of the central nervous system (Valeriani et al. 2005). In our study, the migrainous girls had both increased agonist neck flexion muscle activity and increased antagonist neck extension muscle activity, which may demonstrate that the sensitized neck muscles respond increasingly when those muscles are loaded.

7.3. Limitations of the study

All the studies are part of a population-based follow-up study of headache in schoolchildren and thus the subjects of the studies were not weakened by selection bias related to clinical patients. In all phases of the study, the primary headache types of the subjects were classified carefully by the experienced neurologist using the IHS criteria from the year 1988 (ICHD 1). 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 was not diagnosed, because the diagnosis requires abolition of headache after successful treatment of the causative disorder, and the criteria do not allow this diagnosis in a population-based study (Bogduk 2004, ICHD 2 2004).

The design of the present studies was cross-sectional and, thus it remains unknown whether the results are primary or secondary to the adolescent headache. Longitudinal studies are needed to clarify the causal relationship between the neuromuscular factors and different types of headache. In studies III-V, although the subjects were randomly selected from subgroups with frequent symptoms, the results might have been clearer if only subjects with chronic headache (daily or almost daily symptoms) had been included. In addition, random samples of boys and girls separately would have made comparisons easier.

In study I, the interview on headache and leisure activities was performed by the same pediatrician, and, thus, the documentations were not blinded. However, this may be a minor weakness because most of the questions were structured and were asked apart from the questions concerning headache. The estimated loading of the extremities or the whole body in the classification of the type of sports activities, together with the practice of different types of sports activities, may confuse the results. The data on leisure activities were self-reported and gathered retrospectively.

In study II, the repeatability of the measurements was not completely assessed as was done in studies III-V. However, the measurement protocol was well standardized. It is probable that the endurance strength test did not measure exactly the same variable in boys and girls in this age group, because most of the girls were pubertal, but there was more heterogeneity in the stage of physical development in boys. Muscle strength is correlated with maturity (Beunen et al. 1988; Lefevre et al. 1993). Due to the previous fact, the loads of the weights should have been assessed more individually based, e.g. on maximal isometric strength or repetition maximum.

In study V, the magnetic resonance images (MRI) were all taken in supine positions. Images obtained in this position may not reflect the actual tissue relationship that may provoke headache symptoms, and may not accurately represent the muscle relationships that exist during functional activities. While the repeated measures testing showed good repeatability for the method of measuring the CSA of the muscles, there was a potential for error in constructing the polygons around the margins of each muscle. The measurement technique used only gave a gross measurement of muscle CSA, and did not allow any computation of muscle by fatty or connective tissues.

7.4. Future research needs

Because of the interesting, and partly suprising findings, of the neck muscles in adolescent headache, further studies are needed to confirm these findings. The studies should be performed separatively in girls and boys, and with a greater number of subjects, also during well standardized functional tasks.

Longitudinal and intervention studies are needed to determine the significance of the neck muscle differences in headache, and the causal relation between these muscular factors and different headache types. In addition, evidence of the function, including relaxation capacity, of neck muscles in adolescents with acute or chronic headache and in headache subjects without neck or mucle pain is lacking. There is also a need to study more accurately the role of the specific deep and short muscle function of the upper cervical region in adolescent headache.

8. CONCLUSIONS

In accordance with the hypothesis, the intensive (hours) overall sports activities were characteristic of adolescents with migraine (H 1.2.), and frequent computer use was associated with both tension-type headache and migraine (H 1.3.). The results contradicted the hypothesis that children with tension-type headache practised more non-sportive activities and less sportive activities than children with migraine or with no headache (H 1.1., H 1.2.). The type of leisure activity classified by body loading was not associated with the different headache types.

In accordance with the hypothesis, low endurance strength of both upper extremities and unilateral low cervical rotation, especially in girls, were associated with tension-type headache (H 2.1., H 2.2.). In addition, in girls, low unilateral UE endurance strength was associated with migraine.

In accordance with the hypothesis, unilaterally decreased shoulder flexion force, especially in girls, and increased fatigue of both neck flexion muscles, were associated with tension-type headache (H 3.1., 4.1.). The results contradicted the hypothesis that decreased maximal neck force production, increased EMG/force ratio of the agonist neck flexion and extension muscles, and increased co-activation of the neck muscles, were associated especially with tension-type headache (H 3.1.). On the contrary, unilaterally increased neural activation of the agonist neck flexion muscle and the antagonist neck extension muscle was associated with migraine, while unilaterally decreased neural activation of the agonist neck flexion muscle was associated with tension-type headache.

In accordance with the hypothesis, unilaterally decreased CSA of neck flexion muscle in boys and of combined neck flexion muscles in girls was associated with tension-type headache (H 5.1.). The results contradicted the hypothesis that small CSA of neck extension muscles was associated with tension-type headache (H 5.1.). On the contrary, in boys, a unilaterally large cross-sectional area of neck flexion and extension muscles was associated with migraine headache.

These preliminary results of the cross-sectional studies encourage us to examine more deeply, with a larger study population, the neuromuscular factors in different types of headache. The causal relation between these muscular factors and different headache types should, most importantly, be clarified before improving specific rehabilitation methods for different headache types in children and adolescents. These findings provide a basis for more exhaustive intervention and longitudinal studies to determine the significance of neck muscular differences, and the underlying causes behind these differences in adolescent headache.

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APPENDICES

APPENDIX 1.

Table 2. The International Headache Society (ICHD-2, 2004) diagnostic criteria for tension-type headache.

2.1 Infrequent episodic tension-type headache

A. At least 10 episodes occurring on <1 day per month on average (<12 days per year) and fulfilling criteria B–D
B. Headache lasting from 30 minutes to 7 days
C. Headache has at least two of the following characteristics:
  1. bilateral location
  2. pressing/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 (anorexia may occur)
  2. no more than one of photophobia or phonophobia
E. Not attributed to another disorder
  Note:
  1. History and physical and neurological examinations do not suggest any of the disorders listed in groups 5–12, or history and/or physical and/or neurological examinations do suggest such disorder but it is ruled out by appropriate investigations, or such disorder is present but headache does not occur for the first time in close temporal relation to the disorder.

2.1.1 Infrequent episodic tension-type headache associated with pericranial tenderness

A. Episodes fulfilling criteria A–E for 2.1 *Infrequent episodic tension-type headache*
B. Increased pericranial tenderness on manual palpation

2.1.2 Infrequent episodic tension-type headache not associated with pericranial tenderness

A. Episodes fulfilling criteria A–E for 2.1 *Infrequent episodic tension-type headache*
B. No increased pericranial tenderness

2.2 Frequent episodic tension-type headache

A. At least 10 episodes occurring on ≥1 but <15 days per month for at least 3 months (≥12 and <180 days per year) and fulfilling criteria B–D
B. Headache lasting from 30 minutes to 7 days
C. Headache has at least two of the following characteristics:
  1. bilateral location
  2. pressing/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 (anorexia may occur)
  2. no more than one of photophobia or phonophobia

E. Not attributed to another disorder

Note:

1. History and physical and neurological examinations do not suggest any of the disorders listed in groups 5–12, or history and/or physical and/or neurological examinations do suggest such disorder but it is ruled out by appropriate investigations,or such disorder is present but headache does not occur for the first time in close temporal relation to the disorder.

2.2.1 Frequent episodic tension-type headache associated with pericranial tenderness

A. Episodes fulfilling criteria A–E for 2.2 *Frequent episodic tension-type headache*

B. Increased pericranial tenderness on manual palpation

2.2.2 Frequent episodic tension-type headache not associated with pericranial tenderness

A. Episodes fulfilling criteria A–E for 2.2 *Frequent episodic tension-type headache*

B. No increased pericranial tenderness

2.3 Chronic tension-type headache

A. Headache occurring on ≥15 days per month on average for >3 months (≥180 days per year) and fulfilling criteria B–D

B. Headache lasts hours or may be continuous

C. Headache has at least two of the following characteristics:
  1. bilateral location
  2. pressing/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 more than one of photophobia, phonophobia or mild nausea
  2. neither moderate or severe nausea nor vomiting

E. Not attributed to another disorder

Notes:

1. 2.3 *Chronic tension-type headache* evolves over time from episodic tension-type headache; when these criteria A–E are fulfilled by headache that, unambiguously, is daily and unremitting within 3 days of its first onset, code as 4.8 *New daily persistent headache*. When the manner of onset is not remembered or is otherwise uncertain, code as 2.3 *Chronic tension-type headache*.
2. History and physical and neurological examinations do not suggest any of the disorders listed in groups 5–12, or history and/or physical and/or neurological examinations do suggest such disorder but it is ruled out by appropriate investigations, or such disorder is present but headache does not occur for the first time in close temporal relation to the disorder.

3. When medication overuse is present and fulfils criterion B for any of the subforms of 8.2 *Medication-overuse headache*, it is uncertain whether this criterion E is fulfilled until 2 months after medication has been withdrawn without improvement.

2.3.1 Chronic tension-type headache associated with pericranial tenderness

A. Headache fulfilling criteria A–E for 2.3 *Chronic tension-type headache*
B. Increased pericranial tenderness on manual palpation

2.3.2 Chronic tension-type headache not associated with pericranial tenderness

A. Headache fulfilling criteria A–E for 2.3 *Chronic tension-type headache*
B. No increased pericranial tenderness

2.4 Probable tension-type headache

2.4.1 Probable infrequent episodic tension-type headache

A. Episodes fulfilling all but one of criteria A–D for 2.1 *Infrequent episodic tension-type headache*
B. Episodes do not fulfil criteria for 1.1 *Migraine without aura*
C. Not attributed to another disorder

2.4.2 Probable frequent episodic tension-type headache

A. Episodes fulfilling all but one of criteria A–D for 2.2 *Frequent episodic tension-type headache*
B. Episodes do not fulfil criteria for 1.1 *Migraine without aura*
C. Not attributed to another disorder

2.4.3 Probable chronic tension-type headache

A. Headache occurring on ≥15 days per month on average for >3 months (≥180 days per year) and fulfilling criteria B–D
B. Headache lasts hours or may be continuous
C. Headache has at least two of the following characteristics:
   1. bilateral location
   2. pressing/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 more than one of photophobia, phonophobia or mild nausea
   2. neither moderate or severe nausea nor vomiting
E. Not attributed to another disorder but there is, or has been within the last 2 months, medication overuse fulfilling criterion B for any of the subforms of 8.2 *Medication-overuse headache*

APPENDIX 2.

Table 3. The International Headache Society (ICHD-2, 2004) diagnostic criteria for migraine.

1. Migraine	
1.1 Migraine without aura	
	A. At least 5 attacks fulfilling B-D
	B. Headache attacks, lasting 4-72 hours
	C. Headache has at least 2 of the following characteristics:
	1. Unilateral location
	2. Pulsating quality
	3. Moderate or severe intensity
	4. Aggravation by or causing avoidance of routine physical activity
	D. During headache at least one of the following:
	1. Nausea and/or vomiting
	2. Photophobia and phonophobia
	E. Not attributed to another disorder
1.2 Migraine with aura	
	A. At least 2 attacks fulfilling criterion B.
	B. Migraine aura fulfilling criteria B and C for one of the subforms 1.2.1-1.2.6
	C. Not attributed to another disorder

The questions used in original publications and in this thesis are published here.

APPENDIX 3.

Headache variables *(in English, translated by Laimi 2007 and the author)*

Clinical interview at the ages of 13 and 16 years
Papers I-V:
Have you had headache in previous 6 months? No / Yes
How many times a month have you had headache in previous 6 months ?___
Papers I-V: *Headache type was diagnosed by criteria of IHS (ICHD-1, 1988).*

Clinical interview at the ages of 13 and 17 years
Papers II-IV: *When did you last have headache episode/attack ? ______(date)*
Papers II-IV: *How intensive is your headache now? (VAS)*
No pain I____I worst possible pain

APPENDIX 4.

Self-reported neck pain *(in English, translated by Laimi 2007 and the author)*

Clinical interview at the age of 13 years
Paper II:
Do you have situations in daily life where you feel neck pain or stiffness of the neck region?
1. Hardly ever
2. Sometimes
3. Often

Questionnaire at the age of 16 years
Papers III-V:
Have you had following symptoms in preceding six months and how often:
Neck pain
1. Not at all
2. Less than once a month
3. 1-3 times a month
4. Once a week or more often

Clinical interview at the ages of 13 and 17 years
Papers II-IV: *When did you last have neck pain? ______(date)*
Papers II-IV: *How intensive is your neck pain now? (VAS)*
No pain I____I worst possible pain

APPENDIX 5.

Self-reported variables of leisure time activity *(in English, translated by Laimi 2007 and the author)*

Clinical interview at the age of 13 years

Paper I:

Outside school hours: Which are your three most important leisure time activities in order of importance?

Paper I:

Outside school hours: How many hours a week do you usually spend in sports/non-sports activities so intensively that you are breathless or sweating?

1. *not at all*
2. *about half an hour*
3. *about one hour*
4. *2-3 hours*
5. *about 4-6 hours*
6. *7 hours or more*

Paper I:

Outside school hours: How often (times) do you usually spend in sports activities so intensively that you are breathless or sweating?

1. *daily*
2. *about 4-6 times/week*
3. *about 2-3 times/week*
4. *once a week*
5. *once a month*
6. *less than once a month*
7. *not at all*

Paper I:

Outside school hours: How often (times) do you usually spend in non-sports activities?

1. *daily*
2. *about 4-6 times/week*
3. *about 2-3 times/week*
4. *once a week*
5. *once a month*
6. *less than once a month*
7. *not at all*

Paper I:

*In how many days a week do you play with the computer or surf the Internet?*_____*d*

APPENDIX 3.

Päänsärkymuuttujat *(in Finnish)*

Kliininen haastattelu 13- ja 16-vuotiaana
Artikkelit I-V:
Onko sinulla ollut päänsärkyä viimeisten 6 kuukauden aikana? Ei / Kyllä
Kuinka monta kertaa sinulla on ollut päänsärkyä viimeisten 6 kk aikana keskimäärin kk:ssa?___
Artikkelit I-V*: Päänsärkytyyppi luokiteltiin IHS kriteereiden mukaan (ICHD-1, 1988).*

Kliininen haastattelu 13- ja 17-vuotiaana
Artikkelit II-IV: *Milloin sinulla oli viimeksi päänsärkyä?_________(date)*
Artikkelit II-IV**:** *Kuinka voimakasta on tämänhetkinen päänsärkysi? (VAS)*
Ei lainkaan kipua I___________________________________I pahin mahdollinen kipu

APPENDIX 4.

Tutkittavan raportoimat niskakipumuuttujat *(in Finnish)*

Kliininen haastattelu 13-vuotiaana
Artikkeli II:
Syntyykö jokapäiväisessä elämässä tilanteita, joissa niskahartiaseutusi kipeytyy tai tuntuu jäykältä?
1. Ei juuri koskaan
2. Toisinaan
3. Usein

Kyselylomake 16-vuotiaana
Artikkelit III-V*:*
Onko viimeisen puolen vuoden aikana ollut seuraavia oireita ja kuinka usein:
Niskahartiaseudun kipua
1. Ei lainkaan
2. Alle kerran kuukaudessa
3. 1-3 kertaa kuukaudessa
4. Kerran viikossa tai useammin

Kliininen haastattelu 13- ja 17-vuotiaana
Artikkelit II-IV: *Milloin sinulla oli viimeksi niska- ja hartiakipuja ?_________(date)*
Artikkelit II-IV: *Kuinka voimakasta on tämänhetkinen niska- ja hartiakipusi? (VAS)*
Ei lainkaan kipua I___________________________________I pahin mahdollinen kipu

APPENDIX 5.

Tutkittavan raportoimat vapaa-ajan harrastemuuttujat *(in Finnish)*

Kliininen haastattelu 13-vuotiaana

Artikkeli I:

Koulutuntien ulkopuolella: Mitkä ovat kolme tärkeintä vapaa-ajan harrastustasi tärkeysjärjestyksessä?

Artikkeli I:

Koulutuntien ulkopuolella: Kuinka monta tuntia viikossa tavallisesti harrastat liikuntaa vapaa-aikanasi niin, että hengästyt ja hikoilet?

1. *en yhtään*
2. *noin ½ tuntia*
3. *noin tunnin*
4. *2-3 tuntia*
5. *noin 4-6 tuntia*
6. *7 tuntia tai enemmän*

Artikkeli I:

Koulutuntien ulkopuolella: Kuinka usein (kerrat) tavallisesti harrastat liikuntaa vapaa-aikanasi niin, että hengästyt ja hikoilet?

1. *päivittäin*
2. *4-6 kertaa viikossa*
3. *2-3 kertaa viikossa*
4. *kerran viikossa*
5. *kerran kuukaudessa*
6. *harvemmin kuin kerran kuukaudessa*
7. *en koskaan*

Artikkeli 1:

Koulutuntien ulkopuolella: Kuinka usein (kerrat) tavallisesti harrastat muita harrastuksia kuin liikuntaa vapaa-aikanasi?

1. *päivittäin*
2. *4-6 kertaa viikossa*
3. *2-3 kertaa viikossa*
4. *kerran viikossa*
5. *kerran kuukaudessa*
6. *harvemmin kuin kerran kuukaudessa*
7. *en koskaan*

Artikkeli I:

Kuinka monena päivänä viikossa harrastat tietokonepelien pelaamista tai internetissä surffailua?_____pv