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A novel way of functional retraining of cervical motor control in a water polo player with combined cervicogenic and tension type headaches

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Case Report

A novel way of functional retraining of cervical motor control in a water polo player with combined cervicogenic and tension type headaches

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This case report introduces an innovative and novel way of functionally retraining the sport specific cervical function in a 13-year-old elite water polo player with a combined tension type headache and cervicogenic headache. After an evidence based assessment and manipulative physical therapy management regime, consisting of manual mobilization and exercise focused on retraining the deep cervical flexors and sub-occipital extensors, the patient was left with persistent residual complaints inhibiting competitive level sport participation. Re-assessment and subsequent retraining of a specific provocative functional task was facilitated by using the Cervical Trainer^{TM}. Using a wireless sensor worn on the head, this device registers three-dimensional movement and displays this on a computer screen, providing direct feedback on movement performance. After a 6-week period of training sessions, the residual complaints subsided and her score on the Headache Impact Test-6 questionnaire improved from 51 to 36 signifying no impact of her headache on daily life activities.

Keywords: Cervicogenic headache, Tension type headache, Manual therapy, Deep neck flexors, Functional retraining, Cervical trainer, Water polo

Background

Pediatricians have found that overtraining and specialization on one activity or sport can have negative consequences for youth sports participants.[1] Water polo is a popular sport in Europe and is a growing sport in North America and Australia.[2] Approximately 28% of all injuries among swimming athletes are due to overuse. During the Olympic games in 2012, about 13% of all athletes in the water polo competition experienced symptoms associated with a sports injury.[3] Injuries after contact-trauma were also reported, e.g. after a direct blow from an opponent player, an acute acceleration/deceleration injury to the cervical spine can occur.[4] Repetitive cervical spine rotation required for breathing in freestyle swimming may also produce neck pain in water polo players.[4]

Patients with neck pain show a particular movement pattern. The superficial neck and scapular muscles (SCM, anterior scalenes, and lower trapezius) show a neuromuscular insufficiency during activities with a 'low biomechanical load' and functional tasks. They are also less adequate in timely relaxation following activity.[5,6] This new movement pattern, consisting of an overuse of the superficial muscles and a disuse of the deep muscles, results in a loss of the ability of precise three-dimensional (3D) movement of the cervical spine.[7] Perpetuation of the altered motor control strategy may lead to functional, as well as histological, changes in the muscles, which may prolong the clinical disorder.[8] Studies have shown a dysfunction of the deep cervical flexor muscles (DCF) not only in patients with neck pain[9] but also in patients with cervicogenic headache (CGH).[10] This has also been proposed to exist in patients with tension type headache (TTH).[11,12]

The International Headache Society has proposed the 'International Classification of Headache Disorders' (ICHD), a classification system for headaches, which was revised in 2004 (ICHD-II).[13,14] This classification separates primary headaches from secondary headaches, cranial neuralgias, facial pain and other headaches. It defines specific headache types with distinctive features and diagnostic criteria.[13,14] Chronic tension type headache (CTTH) is a primary headache characterized by its occurrence on more than 15 days per month for more than 3 months and fulfilling the following criteria:

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- the headache lasts hours or may be continuous and has more than two of the following characteristics:
  - a bilateral location;
  - is of a pressing/tightening (non-pulsating) quality;
  - is of mild or moderate intensity;
  - is not aggravated by routine physical activity.
- It also has both of the following:
  - not more than one of either photophobia, phonophobia or mild nausea;
  - neither moderate or severe nausea, nor vomiting.
- It is also not attributable to another disorder.[14]

In contrast, CGH is a secondary headache characterized by unilateral headache and signs and symptoms of neck involvement.[14,15] It is often worsened by:

- neck movement;
- sustained awkward head position or;
- external pressure over the upper cervical or occipital region on the symptomatic side.[15,16]

Two epidemiological studies in Norway noted a TTH prevalence of 34% and a CGH prevalence of 4.1% in adults.[17,18] An overall 3-month prevalence of headaches in adolescents of 69.4% (boys 59.5%, girls 78.9%) has been reported. Some 13.4% of girls and 9.4% of boys reported headaches recurring more than 14 days per 3 months.[19] There is low to moderate level evidence that craniocervical endurance and low load cervical-scapular endurance exercises reduce pain, improve function and have a positive outcome on the global perceived effect for patients with CTTH[20] and CGH.[21] There is some support for comprehensive retraining protocols, which include eye and neck motion targeting tasks and coordination exercises, as well as co-contraction exercises, to reduce impairments.[22]

The aim of this case report is to describe the diagnostic process and the effect of manual therapy complemented by an innovative functional retraining strategy of the sub-occipital stabilizers and head and neck position sense, using the Cervical Trainer™, in a young elite athlete with persistent, combined CGH and TTH headaches.

Patient Characteristics

History

A 13-year-old female patient presented to our clinic complaining of severe left-sided temporal and frontal headaches combined with idiopathic, ipsilateral neck pain spreading to the occipital area. This was sometimes accompanied by a 'tight band' feeling across the entire forehead. The patient had initially been screened by her general practitioner who had referred her to an ear-nose-throat specialist and an ophthalmologist who cleared her medically, after which a pediatrician assessed her thoroughly and suggested that her headache could stem from her neck.

The patient trained and played water polo 7 days a week at a national team level and was preparing for tryouts for the Olympic team. Bright lights, long walks, riding a bicycle to school and studying for extended periods aggravated the symptoms. After sleeping well, the patient experienced momentary relief on waking up the next day. The patient had not yet tried to take any medication for her headache and had been keeping a headache diary for the past three months. During water polo, the patient confessed to being too distracted to mind the headache, but noted that it did aggravate symptoms afterwards. A headache diary showed that the patient had been having headaches nearly every other day and that she experienced more pain after training explosive speed, using the freestyle swimming technique, than after tactical training sessions with more head-up front crawl swimming. Further extensive history taking revealed nothing more than some smaller injuries to the extremities, to be expected with competing at high level, but no prior head trauma.

Tests and measures

The Headache Impact Test-6 (HIT-6) questionnaire was used to assess the impact of the patient's headache on activities of daily life. Scores on the HIT-6 range from 36 to 78.[23] A numeric rating scale (NRS) was used to measure pain, where 0 represents 'no pain' and 10 'the worst pain possible'.[24] The reported minimal clinically important change for the NRS ranged between 1.5 and 2.5.[25] The patient completed the NRS for least pain, worst pain, and average pain for the day of the examination. Active range of motion (AROM) was assessed using a cervical range of motion (CROM) device which has been shown to be clinimetrically sound and have good to high inter-rater and intra-rater reliability.[26] The standard error of measurement of the CROM is between 2.5 and 4.1°.[27] The minimal detectable change varies between 5 and 10° for each direction.[27,28]

TTH is diagnosed mainly as a result of history taking, ruling out serious pathology and fulfilling diagnostic criteria.[14] A diagnostic criterion of CGH is that there is evidence that the pain can be attributed to the neck disorder based on demonstration of at least one of the clinical signs that implicate a source of pain in the neck.[13,14] In order to further assess the likelihood of a diagnosis of CGH, the Flexion Rotation Test (FRT) was performed, again using the CROM device for accurate measurement. This test of passive upper cervical rotation in maximum cervical flexion, is a valid and reliable test for CGH.[29] A sensitivity of 90% and specificity of 88% has been reported with a 92% agreement for experienced examiners. An overall diagnostic accuracy of 89%

has also been reported[30] with a minimal detectable change of at least 7°[31] and a cut-off value of 30°.[32]

The cranio-cervical flexion test (CCFT) is a well established and validated clinical test of the coordination and endurance of the DCF using a pressure biofeedback unit (Stabilizer™, Chattanooga Ltd) in a supine position.[10,33] In an attempt to quantify compensation strategies, the activity of the SCM was monitored with surface EMG (sEMG) feedback using a NeuroTrac™ Simplex (Verity Medical Ltd) sEMG device. A pair of bipolar surface electrodes, 10 mm in diameter and with a fixed interelectrode distance of 20 mm, were attached on the skin overlying individual muscles and a ground electrode was attached to the skin above the clavicle. The electrodes were located over the bellies of the muscles.[33]

Recent electronic developments have enabled clinicians to use affordable sensors to help patients with neck pain visualize their 3D spinal movements on a computer screen. The Cervical Trainer™ (VelDon™, The Netherlands) is a potential method of aiding cervical spine posture and movement awareness. A receiver registers the movement of a wireless sensor which is attached to a lightweight strap worn on the head. This is displayed as a 'dot' on the computer screen. The seated patient receives direct feedback on movement performance. A similar method of head tracking of a moving 'fly', which appears on a computer screen, provides reliable and valid measures for movement control of the cervical spine.[34,35]

Examination Findings

The patient's initial score on the HIT-6 questionnaire was 51/78, signifying moderate influence on the ability to function in daily life (Table 1).[36] A clinically relevant improvement in patients with CTTH is reflected by a decrease of at least eight points on the HIT-6.[23] The patient rated the worst severity of her headache at 8/10 on an NRS. AROM testing revealed that left rotation was painfully limited (50°) compared to the right (85°). Right-sided lateral flexion was (30°) comparable to the contralateral side (35°), pain free and within normal range, extension was painfully limited at 55°, flexion was pain free and within normal range (65°). Further segmental assessment using passive accessory intervertebral motion tests (PAIVMs) and passive physiological intervertebral motion tests (PPIVMs) as, described by Maitland,[37] established a painful limitation of the left C1-2 and C2-3 zygapophyseal joints, which provoked temporal and frontal headaches. The reliability of passive assessment of segmental intervertebral motion of C1-C2 and C2-C3 is reported to be fair.[38] In performing the FRT, the patient had a right rotation of 45° and a left rotation of 25°, signifying the possibility of a CGH.

Although the coordination of the DCF showed no deficit (the patient was able to correctly target every incremental stage from 20 to 30 mmHg while performing the CCFT), the patient demonstrated a diminished endurance function of the DCF as she could only do 8 out of 10 correct repetitions of 10 second holds at 24 mmHg. At rest, the SCM sEMG feedback values were comparable left to right (2.8 and 2.9 mV, respectively) while the upper trapezius sEMG values showed a marked difference left to right: (3.9 and 10 mV, respectively), indicative of increased continuous muscle activity.[39] Passive stretching of the right upper trapezius muscle was more painful and limited than the left.

The patient also had difficulty in correctly activating her upper cervical extensors. While the patient was propped up on her elbows in a prone position, she was unable to maintain a fully flexed position in the upper cervical spine, while performing a mid- and low cervical extension movement. This movement requires a co-contraction of upper cervical flexors and extensors[40]

Clinical Impression

The consistency of aggravating factors in the patient's history combined with a positive FRT,

Table 1 Comparison of baseline clinical measurements to follow-up measurements at 3-, 6- and 9 weeks

	Baseline	3 week follow-up	6 week follow-up	9 week follow-up
NRS	8/10	4/10	2/10	1/10
Cervical AROM		65°	65°	65°
• Flexion	65°	65°	65°	65°
• Extension	55°	90°	90°	90°
• Right rotation	85°	80°	85°	85°
• Left rotation	50°	35°	35°	35°
• Right lateral flexion	30°	35°	35°	35°
• Left lateral flexion	35°			
HIT-6	51/78	42/78	38/78	37/78
FRT left/right	25°/45°	40°/45°	40°/45°	40°/45°
CCFT; level of correct 10 repetitions of 10 second holds	24 mmHg	30 mmHg	30 mmHg	30 mmHg
Surface EMG; at rest of upper trapezius right/left	10/3.9 mV	n/t	n/t	3.9/3.7 mV

Note: NRS=numerical rating scale; AROM=active range of motion; HIT-6=headache impact test-6; FRT=flexion rotation test; CCFT=cranio cervical flexion test; n/t=not tested.

limited cervical ROM in extension, painful dysfunction of the C1-2 and C2-3 joints provoking temporal and frontal headaches and the diminished function of the DCF, indicated a diagnosis of CGH, consistent with criteria from the ICHD-2.[10,14,15] It was hypothesized that the repetitive loading of upper cervical tissues during free style and head-up crawl technique swimming could be a potential cause. It was also hypothesized that a ‘chronic TTH’ could be present due to the timing and type of the patient’s complaints (consistent with ICHD-2 criteria), the tight and overactive upper trapezius and SCM muscles and the accompanying ‘tight band’ sensation across the patient’s forehead. The patient’s other signs and symptoms could not rule out this working diagnosis.[14]

Interventions

Due to the possibility of serious adverse effects of spinal manipulation in adolescents, it was decided not to use high velocity techniques.[41] Initial grade III and IV mobilization using PAIVMs and PPIVMs,[37] of the left C1-2 (in rotation) and C2-3 (in rotation, lateral flexion and extension) joints swiftly improved the patient’s headache to an average NRS of 4/10 (Table 2). In week 1, this was combined with retraining the DCF, starting with 10 correct repetitions of 8 second holds at 24 mmHg, working towards 10 correct repetitions of 10 second holds at 30 mmHg.[42,43] Additionally, along with postural advice, specific exercises of correct activation of the sub-occipital extensors in prone were added.[42,43] The patient’s training schedule was adapted, decreasing the number of hours by a third and deleting any extensive swimming.

In the next two weeks, function of the DCF rapidly improved to a level of the patient being able to do 10 correct repetitions at 30 mmHg with minimal SCM activity on sEMG feedback. Meanwhile, correct activation of the DCF was being integrated into several of the patient’s functional activities. Nevertheless, the patient’s headache remained at a continuous NRS score of 4/10 and, as mobilization of the upper cervical joints did not seem to have an added effect, it was decided to cease utilization of those interventions at the end of the second week.

Reassessment

At the 3-week follow-up, the patient’s score on the HIT-6 questionnaire had improved by 9 points to 42, signifying little influence during daily life.[36] The patient’s headache intensity had improved to a NRS 4/10. The patient’s AROM was no longer painful or limited (Table 1) and the FRT was no longer positive with a right rotation of 45° and a left rotation of 40°; mobilization of left C1-2 and C2-3 zygapophyseal joints no longer provoked the patient’s temporal and frontal headaches. It was hypothesized that a CTTH could be responsible for the remaining symptoms of a continuous pressure (‘tight band’) feeling.

The patient’s tight and overactive SCM and upper trapezius muscles had not been addressed, as the focus had been on retraining the DCF first. Therefore, sEMG feedback was now used on the overactive muscles and hold-relax stretching techniques were added along with instructions on how to perform these at home.[44–46]

Although the DCF muscles seemed to be restored to their normal efficiency, the patient’s high level of water polo training demanded more than just average control. Since the patient is the member of the water polo team who races the swim-off, she also uses the freestyle technique at each competition. As a result, her training also was devoted, in part, to this swimming stroke. This movement includes 3D coupled movement of the cervical spine to flexion, left rotation and right sided lateral flexion. Although the patient was no longer limited in her range of motion, she still had difficulty in performing a controlled 3D movement in this direction. The Cervical Trainer™ was used to objectify this. The patient had the most difficulty in making a controlled movement of the lower left quadrant of a circle.

Innovative treatment

In order to increase the level of training of functional 3D movements, the patient progressed through increasingly more difficult exercises using the

Table 2 Treatment progression

No. of sessions/week	2	2	3	3	3	3	2
Treatment	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7–9
Manual Therapy PPIVMs & PAIVMs	X	X					
DCF endurance training in supine	X	X	X				
Postural advice		X	X				
DCF integration into functional activities		X	X				
Sub-occipital extensors in prone		X	X	X			
Stretching exercises			X	X	X		
Cervical Trainer™			X	X	X	X	X

Note: PPIVMs=passive physiological intervertebral motion tests; PAIVMs=passive accessory intervertebral motion tests (PAIVMs); DCF=deep cervical flexors.

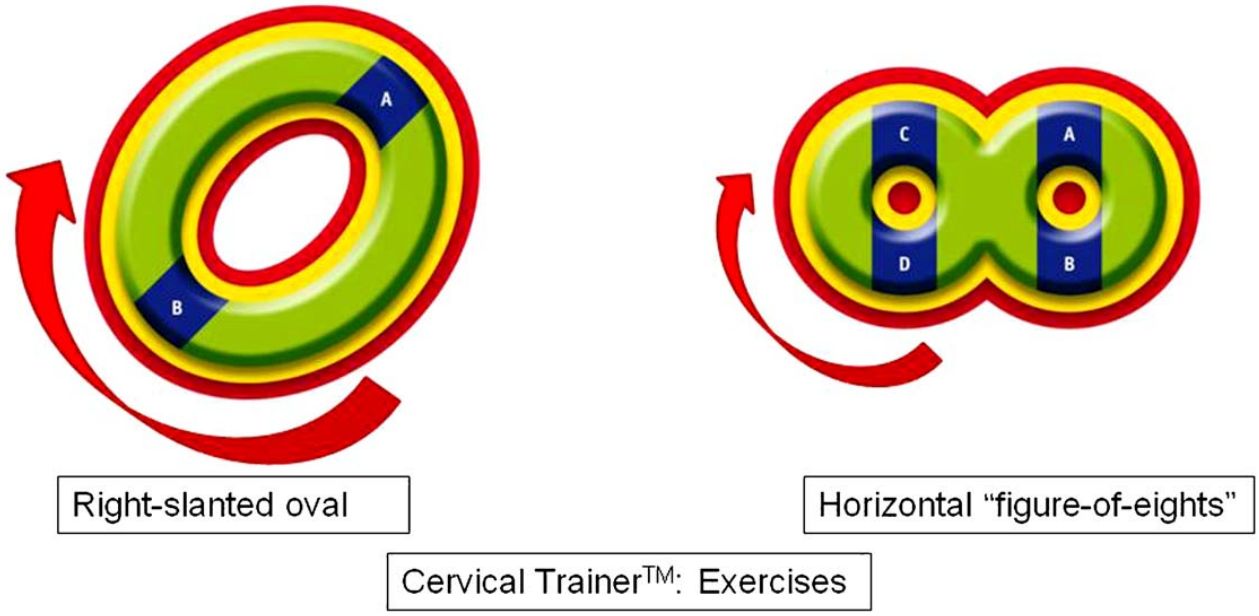


Figure 1 Cervical Trainer^{TM} computer screen showing ovals and 'figures-of-eight'. The sensor on the patient's head will make a dot appear on the screen. The patient is then asked to trace the green track of the figure with the dot: clockwise from A to B to A or A–B–C–D–A. The red arrow represents the direction of movement in the lower left-hand quadrant turn: the part of the trajectory where the patient had marked difficulty and poor motor control. This is the same movement sequence as the patient uses during the breathing phase of freestyle swimming.

Cervical Trainer^{TM} starting in week 3. The patient started with moving the computerized 'dot' in circles and then progressed the level of difficulty by performing controlled movements across slanted ovals and 'figures-of-eight'. Software registered the number of correct repetitions of the moving 'dot' over a pre-defined figure on the computer screen. A 'total score' is calculated from the number of correct traverses along the figure on the Cervical Trainer^{TM} screen, taking into account the level of deviation from the perfect green line onto the less correct yellow or incorrect red zones. The number of 'correct repetitions' are also registered and are defined as one complete traverse along the figure on the Cervical Trainer^{TM} screen, not veering off into or outside of the red line of the figure (Fig. 1). Initially, the patient could do 32 correct repetitions but with a total score of 35. The relative lower score was due to a more erratic movement pattern, making her veer off the correct green and into the yellow or even red track. The objective was to be able to do at least 30 correct A to B movement repetitions in 2 minutes on the most difficult movement patterns. The patient only experienced difficulty in making the lower left-hand quadrant turns of all ovals (horizontal, vertical and slanted) and especially the horizontal 'figures-of-eight', a movement similar to one-sided breathing while swimming.

In order to increase endurance in the muscles that are used during freestyle and head-up swimming, two of the exercises (using the Cervical Trainer^{TM}) were adapted. A Theraband^{TM} was used, together with The Cervical Trainer^{TM} exercises, to add slight resistance to the cervical movements in an effort to mimic those activities (Fig. 2). This initially decreased the patient's score and the number of correct repetitions to 17.5 and 9, respectively (Fig. 3). The objective was to increase the number of correct repetitions to (at least) the original of 35 and 32 over a period of three weeks.

Outcomes

At the 6-week follow-up, the patient hardly ever experienced headaches (NRS 2/10) and the occasional ones seemed to stem from a lack of sleep due to the upcoming school test weeks and national team qualifying trials. The patient's score on the HIT-6 had improved to 38/78, signifying almost no influence during daily life (Table 1).[23] The initial limitations of cervical AROM had resolved (flexion 65°, extension 65°, right rotation 90°, left rotation 85°, right and left lateral flexion 35°), the FRT ROM was 40° to the left and 45° to the right.

At the 9 week follow-up, the patient had increased her performance on the Cervical Trainer^{TM} exercises to a level where she could do an average of 32 correct repetitions of horizontal 'figures-of-eight' with 'added resistance' with a total score of 58 (Fig. 3). The relatively larger increase in 'total score' compared to 'correct repetitions' indicates the patient's increased ability to effectively stay on the exact middle of the designated track. This is a result of improved motor control and more precise movements while moving at greater speed. At this juncture, her resting sEMG

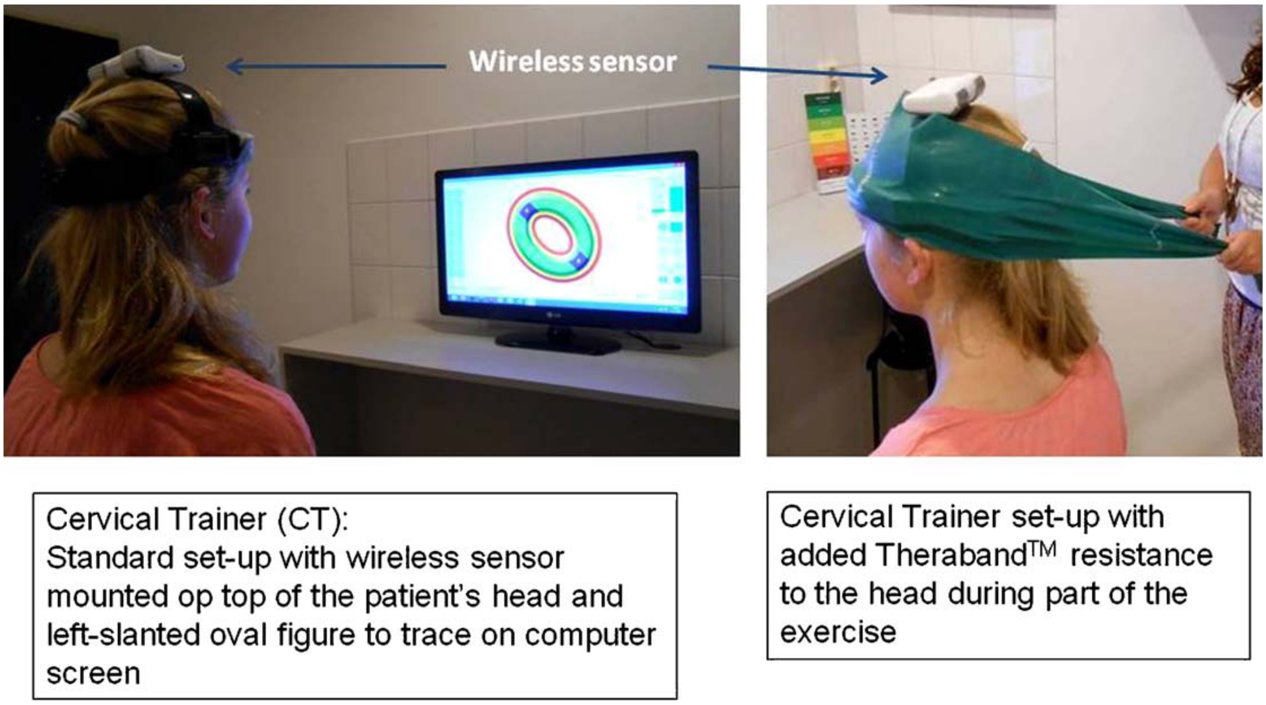
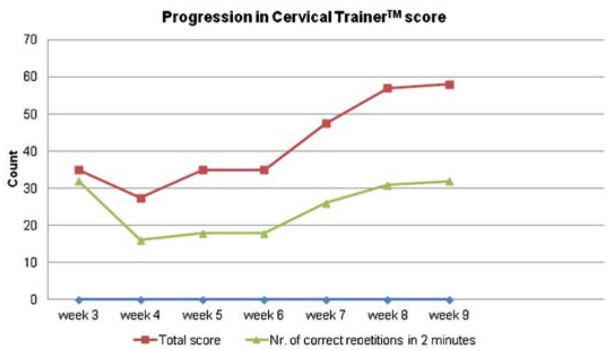


Figure 2 Cervical Trainer™ showing initial setup and the adding of Theraband™ resistance.

values of the left and right upper trapezius were comparable at 3.7 and 3.9 mV, respectively (Table 1). In total, over a period of 9 weeks, the patient was seen for 20 treatments (Table 2).

Discussion

The purpose of this case report was to describe the diagnostic process and the effect of an innovative functional retraining strategy on head and neck position sense, as well as the sub-occipital stabilizers, on an adolescent swimmer with persistent, combined CGH and chronic TTH. This case report is the first to describe the use of the Cervical Trainer™. It outlines its potential added value in identifying problems in specific movement directions. The visual representation on a computer screen of a patient's 3D head movement, can assist clinicians in their assessment of individual motor control impairments This case report highlights the need for individualized functional retraining of the cervical spine in patients with neck pain and also describes the value of integrating this type of visual feedback in retraining specific movement directions.



Note: the 1st measurement is without Theraband™ resistance; the 2nd and consecutive measurements are with the added Theraband™ resistance.

Figure 3 Progression in Cervical Trainer™ score. 'Total score' is calculated from the number of correct traverses along the figure on the Cervical Trainer™ screen, taking into account the level of deviation from the perfect line. 'Correct repetitions' are defined as traverse along the figure on the Cervical Trainer™ screen, not veering off the red line of the figure.

The patient described in this case report had an interesting mix of CTTH and CGH, possibly due to specific cervical spine dysfunctions. There are two separate sport-specific cervical movement patterns inherent to water polo, as water polo players incorporate different swimming techniques during the game. A freestyle technique is used during the swim-off. In an effort to stay as aerodynamic as possible while using a freestyle stroke, elite-athlete swimmers, tend to turn their head to the same side to breathe only once in every second to fourth stroke at the end of the pulling phase. A proposed perfect technique of breathing involves breathing into the trough by the side of one's head to keep it as low as possible without actual head rotation.[47] This specific 3D movement of rotation, contralateral side flexion and slight flexion is mainly initiated by the SCM and upper trapezius muscles.[48] During play, water polo swimmers will try to keep their head out of the water in a head up front crawl, because they also need to see their teammates, opponents and the position of the ball.[47] This combination of either being in a hyper-extended cervical spine position (in the head up front crawl) and/or the repetitive, fast 3D rotation of the neck during the freestyle swimming, may put adverse stress on the upper cervical (as well as the mid-cervical) spine, while at the same time also over-emphasizing the use of SCM and upper trapezius muscles.

Besides changes in the superficial muscles, patients with neck pain also show some changes of the deep cervical muscles in coordination and endurance.[49] Altered motor control patterns may cause a loss of tonic or postural supporting capacity and the ability of precise 3D movement.[8,50] Innovative use of computer software such as the Cervical Trainer^{TM} can assist clinicians in establishing the presence and direction of imprecise 3D movements. Recent evidence suggests that active trigger points in neck and shoulder muscles contribute to tension-type headache, but to date there are no valid tests to validate pain referral from muscles as a source of pain.[51]

While the consensus of contemporary evidence on the non-invasive management of CGH seems directed at treating the upper cervical dysfunctions,[46] this is not so clear-cut for the management of TTHs. Here, a multitude of treatments have been suggested.[44,52] Manual therapy for TTH is under critical review and, as yet, there is no robust scientific evidence for the effectiveness of physical therapy but some effectiveness has been documented.[53] It is the clinician's obligation to integrate scientific evidence on effectiveness of interventions with his/her own clinical expertise in assessing and managing patients, while being aware of the unique perspectives of the individual patient.[54]

The ICIDH-2 does not define valid tests or examination findings to underpin the TTH diagnosis, so the diagnosis is based mainly on findings from the history. It is important to also assess a patient's individual dysfunctions and their potential of being a contributing factor to the patient's headaches. The Cervical Trainer^{TM} might prove useful in this regard as shown in this case. In order to establish a diagnosis of TTH, sound clinical reasoning strategies and utilization of the precise definition of headaches in the ICHD-2 should assist the clinician.

Limitations

The level of evidence (level IV) and generalizability of case reports are generally considered very low. There is a need for robust randomized clinical trials on conservative non-pharmaceutical management of TTH. Future research should focus on establishing normative data for the Cervical Trainer^{TM}. In addition, evaluation of potential correlations between performance on the CCFT and the Cervical Trainer^{TM} might also provide meaningful information, as comparisons between asymptomatic and symptomatic individuals are drawn.

Disclaimer Statements

Contributors Both authors contributed equally substantially to the preparation of this paper. M Thoomes-de Graaf provided all interventions; E. Thoomes acted as the independent outcome assessor.

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Conflicts of interest The authors declare no conflict of interest also not with respect to any of the instrumentation utilized in this study.

Ethics approval None.

References

1 Intensive training and sports specialization in young athletes. American Academy of Pediatrics. Committee on Sports Medicine and Fitness. Pediatrics. 2000;106:154–7.
2 Webster MJ, Morris ME, Galna B. Shoulder pain in water polo: a systematic review of the literature. J Sci Med Sport. 2009;12:3–11.
3 Engebretsen L, Soligard T, Steffen K, Alonso JM, Aubry M, Budgett R, *et al.* Sports injuries and illnesses during the London Summer Olympic Games 2012. Br J Sports Med. 2013;47:407–14.
4 Franic M, Ivkovic A, Rudic R. Injuries in water polo. Croat Med J. 2007;48:281–8.
5 Falla D, Jull G, Edwards S, Koh K, Rainoldi A. Neuromuscular efficiency of the sternocleidomastoid and anterior scalene muscles in patients with chronic neck pain. Disabil Rehabil. 2004;26:712–7.
6 Falla D, Jull G, Rainoldi A, Merletti R. Neck flexor muscle fatigue is side specific in patients with unilateral neck pain. Eur J Pain. 2004;8:71–7.
7 Oddsdottir GL, Kristjansson E. Two different courses of impaired cervical kinaesthesia following a whiplash injury. a one-year prospective study. Man Ther. 2012;17:60–5.
8 O'Leary S, Falla D, Elliott JM, Jull G. Muscle dysfunction in cervical spine pain: implications for assessment and management. J Orthop Sports Phys Ther. 2009;39:324–33.
9 Falla D, Jull G, Hodges PW. feedforward activity of the cervical flexor muscles during voluntary arm movements is delayed in chronic neck pain. Exp Brain Res. 2004;157:43–8.
10 Zito G, Jull G, Story I. Clinical tests of musculoskeletal dysfunction in the diagnosis of cervicogenic headache. Man Ther. 2006;11:118–29.
11 Oksanen A, Poyhonen T, Metsahonkala L, Anttila P, Hiekkanen H, Laimi K, *et al.* Neck flexor muscle fatigue in adolescents with headache: an electromyographic study. Eur J Pain. 2007;11:764–72.
12 Uthaikhup S, Sterling M, Jull G. Cervical musculoskeletal impairment is common in elders with headache. Man Ther. 2009;14:636–41.
13 Classification and diagnostic criteria for headache disorders, cranial neuralgias and facial pain. Headache Classification Committee of the International Headache Society. Cephalalgia. 1988;8 Suppl 7:1–96.
14 The international classification of headache disorders: 2nd Edition. Cephalalgia. 2004;24 Suppl 1:9–160.
15 Sjaastad O, Fredriksen TA. Cervicogenic headache: criteria, classification and epidemiology. Clin Exp Rheumatol. 2000;18:S3–6.
16 Antonaci F, Fredriksen TA, Sjaastad O. Cervicogenic headache: clinical presentation, diagnostic criteria, and differential diagnosis. Curr Pain Headache Rep. 2001;5:387–92.
17 Sjaastad O, Bakketeig L. Tension-type headache: comparison with migraine without aura and cervicogenic headache. the vaga study of headache epidemiology. Funct Neurol. 2008;23:71–6.
18 Sjaastad O, Bakketeig LS. Prevalence of cervicogenic headache: vaga study of headache epidemiology. Acta Neurol Scand. 2008;117:173–80.
19 Fendrich K, Vennemann M, Pfaffenrath V, Evers S, May A, Berger K, *et al.* Headache prevalence among adolescents–the German DMKG headache study. Cephalalgia. 2007; 27:347–54.
20 Castien RF, van der Windt DA, Grooten A, Dekker J. Effectiveness of manual therapy for chronic tension-type

headache: a pragmatic, randomised, clinical trial. Cephalalgia. 2011;31:133–43.
21 Kay TM, Gross A, Goldsmith CH, Rutherford S, Voth S, Hoving JL, *et al*. Exercises for mechanical neck disorders. Cochrane Database Syst Rev. 2012;8:CD004250.
22 Armstrong B, McNair P, Taylor D. Head and neck position sense. Sports Med. 2008;38:101–17.
23 Castien RF, Blankenstein AH, Windt DA, Dekker J. minimal clinically important change on the headache impact test-6 questionnaire in patients with chronic tension-type headache. Cephalalgia. 2012;32:710–4.
24 Williamson A, Hoggart B. Pain: a review of three commonly used pain rating scales. J Clin Nurs. 2005;14:798–804.
25 Kovacs FM, Abraira V, Royuela A, Corcoll J, Alegre L, Tomas M, *et al*. Minimum detectable and minimal clinically important changes for pain in patients with nonspecific neck pain. BMC Musculoskelet Disord. 2008;9:43.
26 Williams MA, McCarthy CJ, Chorti A, Cooke MW, Gates S. A systematic review of reliability and validity studies of methods for measuring active and passive cervical range of motion. J Manipulative Physiol Ther. 2010;33:138–55.
27 Youdas JW, Garrett TR, Suman VJ, Bogard CL, Hallman HO, Carey JR. Normal range of motion of the cervical spine: an initial goniometric study. Phys Ther. 1992;72:770–80.
28 Fletcher JP, Bandy WD. Intrarater reliability of crom measurement of cervical spine active range of motion in persons with and without neck pain. J Orthop Sports Phys Ther. 2008;38:640–5.
29 Hall TM, Briffa K, Hopper D, Robinson KW. The Relationship between cervicogenic headache and impairment determined by the flexion-rotation test. J Manipulative Physiol Ther. 2010;33:666–71.
30 Hall TM, Robinson KW, Fujinawa O, Akasaka K, Pyne EA. Intertester reliability and diagnostic validity of the cervical flexion-rotation test. J Manipulative Physiol Ther. 2008;31: 293–300.
31 Hall T, Briffa K, Hopper D, Robinson K. Long-term stability and minimal detectable change of the cervical flexion-rotation test. J Orthop Sports Phys Ther. 2010;40:225–9.
32 Hall TM, Briffa K, Hopper D, Robinson K. Comparative analysis and diagnostic accuracy of the cervical flexion-rotation test. J Headache Pain. 2010;11:391–7.
33 Jull GA, O'Leary SP, Falla DL. Clinical assessment of the deep cervical flexor muscles: the craniocervical flexion test. J Manipulative Physiol Ther. 2008;31:525–33.
34 Kristjansson E, Oddsdottir GL. 'The Fly': a new clinical assessment and treatment method for deficits of movement control in the cervical spine: reliability and validity. Spine (Phila Pa 1976). 2010;35:E1298–305.
35 Oddsdottir GL, Kristjansson E, Gislason MK. Database of movement control in the cervical spine. Reference Normal of 182 Asymptomatic Persons. Man Ther. 2013;18:206–10.
36 Kawata AK, Coeytaux RR, Devellis RF, Finkel AG, Mann JD, Kahn K. Psychometric properties of the HIT-6 among patients in a headache-specialty practice. Headache. 2005; 45:638–43.
37 Maitland GD, Hengeveld E, Banks K, English K. Maitland's vertebral manipulation. New York: Butterworth-Heinemann Limited; 2005.
38 van Trijffel E, Anderegg Q, Bossuyt PM, Lucas C. Inter-examiner reliability of passive assessment of intervertebral motion in the cervical and lumbar spine: a systematic review. Man Ther. 2005;10:256–69.
39 Hidalgo-Lozano A, Calderon-Soto C, Domingo-Camara A, Fernandez-de-Las-Penas C, Madeleine P, Arroyo-Morales M. Elite swimmers with unilateral shoulder pain demonstrate altered pattern of cervical muscle activation during a functional upper-limb task. J Orthop Sports Phys Ther. 2012;42:552–8.
40 Cagnie B, O'Leary S, Elliott J, Peeters I, Parlevliet T, Danneels L. Pain-induced changes in the activity of the cervical extensor muscles evaluated by muscle functional magnetic resonance imaging. Clin J Pain. 2011;27:392–7.
41 Vohra S, Johnston BC, Cramer K, Humphreys K. Adverse events associated with pediatric spinal manipulation: a systematic review. Pediatrics. 2007;119:e275–83.
42 Jull G, Sterling M, Falla D, Treleaven J, O'Leary S. Chapter 14 - therapeutic exercise for cervical disorders: practice pointers. whiplash, headache, and neck pain. Edinburgh: Churchill Livingstone; 2008. p. 207–29.
43 Jull G FD, Treleavan J, Sterling M, O'Leary S. A therapeutic exercise approach for cervical disorders. In: Boyling JD JG, editors. Grieve's modern manual therapy. Edinburgh: Churchill Livingstone; 2004.
44 Bendtsen L, Evers S, Linde M, Mitsikostas DD, Sandrini G, Schoenen J, *et al*. EFNS guideline on the treatment of tension-type headache - report of an EFNS task force. Eur J Neurol. 2010;17:1318–25.
45 Nestoriuc Y, Martin A, Rief W, Andrasik F. Biofeedback treatment for headache disorders: a comprehensive efficacy review. Appl Psychophysiol Biofeedback. 2008;33:125–40.
46 Bronfort G, Nilsson N, Haas M, Evans R, Goldsmith CH, Assendelft WJ, *et al*. Non-invasive physical treatments for chronic/recurrent headache. Cochrane Database Syst Rev. 2004:CD001878.
47 Newsome P, Young A. Swim smooth: the complete coaching system for swimmers and triathletes. New York: Wiley Nautical; 2012.
48 Johnson G, Bogduk N, Nowitzke A, House D. Anatomy and actions of the trapezius muscle. Clin Biomech (Bristol, Avon). 1994;9:44–50.
49 Falla D, O'Leary S, Farina D, Jull G. The change in deep cervical flexor activity after training is associated with the degree of pain reduction in patients with chronic neck pain. Clin J Pain. 2012;28:628–34.
50 Falla D, Farina D. Neuromuscular adaptation in experimental and clinical neck pain. J Electromyogr Kinesiol. 2008;18:255–61.
51 Alonso-Blanco C, de-la-Llave-Rincon AI, Fernandez-de-las-Penas C. Muscle trigger point therapy in tension-type headache. Expert Rev Neurother. 2012;12:315–22.
52 Jensen R, Zeeberg P, Dehlendorff C, Olesen J. Predictors of outcome of the treatment programme in a multidisciplinary headache centre. Cephalalgia. 2010;30:1214–24.
53 Posadzki P, Ernst E. Spinal manipulations for tension-type headaches: a systematic review of randomized controlled trials. Complement Ther Med. 2012;20:232–9.
54 Sackett DL, Rosenberg WM, Gray JA, Haynes RB, Richardson WS. Evidence based medicine: what it is and what it isn't. 1996. Clin Orthop Relat Res. 2007;455:3–5.