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Evaluation of a single accelerometer based biofeedback system for real-time correction of neck posture in computer users

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Abstract— **The worldwide adoption of computers is closely linked to increased prevalence in neck and shoulder pain. Many ergonomic interventions are available; however, the lifetime prevalence of neck pain is still estimated as high as 80%. This paper introduces a biofeedback system using a novel single accelerometer placement. This system allows the user to react and correct for movement into a position of bad posture. The addition of visual information provides artificial proprioceptive information on the cranial-vertebral angle. Six subjects were tested for 5 hours with and without biofeedback. All subjects had a significant decrease in the percentage of time spent in bad posture when using biofeedback.**

I. Introduction

There is sound evidence available showing the association between computer use and the risk of developing musculoskeletal pain and disorder [1]. Consistent use of computers is one of the major risk factors for neck and shoulder disorders in the workplace [2, 3]. One of the most recent forecasts of computer adoption estimates that there were more than a billion computers in use at the end of 2008 [4]. This report also forecasts a 12.3% compound annual growth rate between 2003 and 2015. Driven by lower prices and global demand especially in developing countries it is expected that there will be over 2 billion computer users by 2015 [4]. A study of 512 office workers found the 12 month prevalence of neck pain to be 45.5% [5]. Reports of the lifetime prevalence of neck pain in the general population range from 67-80% [6]. As computer adoption increases we can expect a corresponding increase in the prevalence of neck pain if appropriate countermeasures are not employed.

Over time poor posture results in pain, muscle aches, tension and headache and can lead to long term complications such as osteoarthritis [7]. Physiological and biomechanical stress due to sustained postures limit important musculoskeletal stimuli that are essential for normal musculoskeletal development [8]. Most upper extremity disorders and symptoms (neck, shoulder, elbow and wrist pain) are associated with computer use at workstations in positions of poor posture [9]. Along with the sitting position, placement of computer monitors and keyboards and the number of hours spent working at computer workstations are important factors in the etiology of cervical disorders associated with computer use [10]. Other workplace risk factors include the number of hours per week of computer use and the time spent in a non-neutral posture at a computer [11-13].

A detailed survey at Harvard University showed that more then half of students experienced pain and discomfort while using a computer [10]. The three factors significantly associated with computer-related upper extremity and neck pain among the students were female gender, eight or more years of using a computer 10 or more hours a week, and using a computer for more than 20 hours per week [10]. Most of the students in the study reported that pain in the neck and upper extremity was related to computer use and the posture assumed while using a computer. Most of them adopted a better posture by adjusting the workstation and keyboard, while some took a break when feeling uncomfortable during their work on the computer. Workplace studies, of both cross-sectional and prospective design, consistently identified a relationship between the number of hours per week of computer use and musculoskeletal pain and disorders or the upper extremity and neck [14].

Trapezius Myositis/Spasm, Paraspinal/Rheomboid Spasm, Cervical Radiculopathy, Thoracic Outlet Syndrome, Bicipital Tendonitis, and Rotator Cuff Tendonitis are all common upper extremity and cervical musculoskeletal disorders associated with use of computers in poor posture [15]. Tension neck syndrome and thoracic outlet syndrome are the most common problems associated with computer use and the major cause is prolonged sitting with the neck and back in flexed positions. These conditions are commonly reported for a person sitting in front of a computer for more then 4 hours which is common in office environments [16].

Cervical flexion is a complex mechanism as there are eight joints involved in head/neck flexion, the skull and C1 through T1 vertebrae. The angle between a vertical line passing through C7 and the line from C7 to the tragus is called the cranial-vertebral angle or C7-tragus angle [17]. In a normal sitting posture, the cranial-vertebral angle is usually 30°, 40° is considered more appropriate during computer

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use, a posture beyond 40° is not recommended [18]. A normal posture is observed if the subject is standing erect and they are looking at a visual target 15 degrees below eye level [18]. The C6-C7 vertebrae are the most mobile vertebrae in the spine and most prone to be affected by poor posture adapted while using a computer. C6-C7 are also important because they support and stabilize the head during its movement in all planes of motion. Moreover, the line of gravity passes through the C6-C7 vertebrae while sitting in a good posture. For these reasons we measured head and neck angle by placing an accelerometer device at the C7, directly measuring the cranial-vertebral angle.

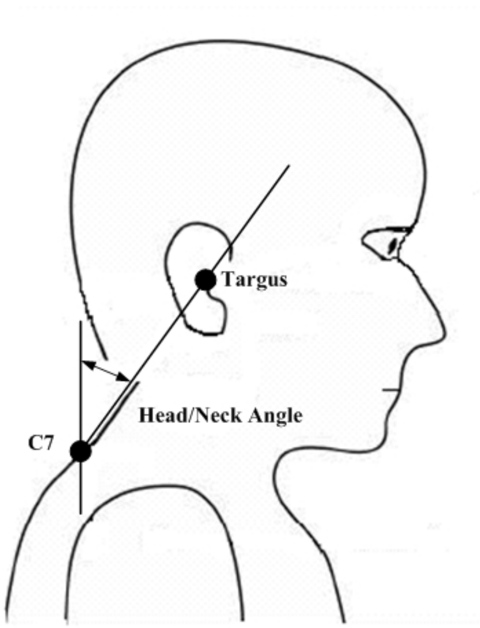

Fig.1. Cranial-vertebral angle between the targus and C7 vertebrae.

Accelerometers are miniature, inexpensive and low-power [19]. They have been used extensively for the measurement of human movement [20, 21] and are entirely suitable for monitoring posture. While a number of posture monitoring systems have been described, our intention was to create a single sensor biofeedback system, thus reducing the cost and inconvenience of the system. By using an accelerometer, cranial-vertebral angle could be directly measured. Feedback was to initially consist of a colour coded signal and beep when outside of acceptable thresholds. However, proprioceptive acuity of cervical spine rotation has been shown to be related to neck pain [22]. The addition of a visual biofeedback reference was included as a means to improve the subject's recognition of their neck angle.

II. Method

A biofeedback system was created consisting of an accelerometer placed at the C7 vertebrae connected via a microcontroller (ADUC812) to the user PC. The accelerometer readings are sampled using the microcontroller board and relayed via a UART to a graphical user interface (GUI) running on the user's PC (Fig. 2). The accelerometer signal was sampled at 40Hz and low-pass filtered at 10Hz. Thresholds for neck flexion were set by the investigator. The device was calibrated when the user was seated with the device attached. With the user seated in an ideal posture determined by the investigator, vertical angle displacement was calculated. This angle was used as a reference for determining when the user was within threshold. The GUI interfaces with the user and using the information returned to the system the user can be informed of incorrect posture (position outside the thresholds). The GUI communicates both visual and auditory feedback. Visual feedback consisted of a replicated image of the user showing their current neck position, also with a colour indicator (Green = Good Posture, Red = Bad Posture). The visual feedback GUI could be minimised to free up the computer screen so the user could work normally. In the event of bad posture being detected the window would expand alerting the user to their posture via a "beep", color coded indicator and visual representation of their neck angle.

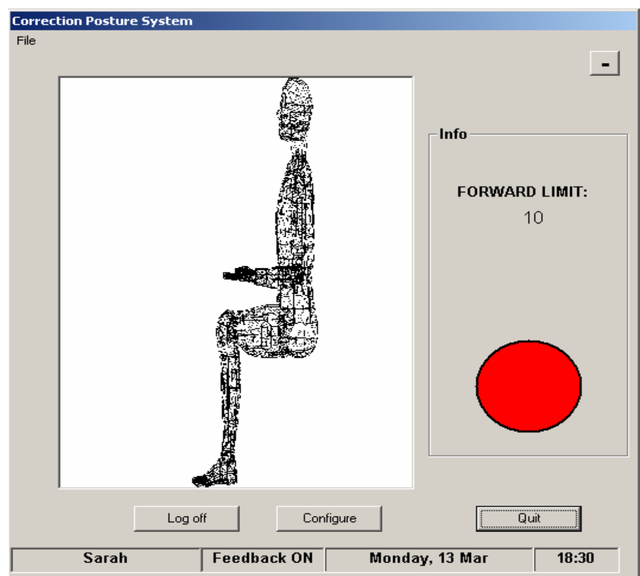

Fig.2. Graphical User Interface used to provide biofeedback.

In the first session, the sensor was applied on the C7 cervical vertebrae and the accelerometer was calibrated. In this session the subject had to work on the computer with the system attached, but biofeedback was turned off. The biofeedback system recorded the cervical movement in the saggital plane during this 5 hour period.

In the second session, the sensor was applied to the same location and system was again calibrated. This time biofeedback was on and a threshold was set in the system. The threshold was set at -5° to 10° from the neutral cervical position in the saggital axis. Again, the biofeedback system recorded the cervical movement in the saggital plane during this 5 hour period.

All six participants were regular computer users as a part of their job/study program. They had a daily routine of long periods of regular sitting in front of computer. None of the participants had any past history of neck or back pain. The subjects were evaluated for their posture in two sessions of five hours each with and without the application of the biofeedback system at their desktop computer.

All participants had to give written informed consent to participate in this study, which was approved by the University of Limerick Research Ethics Committee.

III. Results

The percentage of time spent in positions defined as bad posture (outside of the set thresholds) was compared with and without biofeedback. Over the 5 hour periods the percentage of time spent in bad posture decreased significantly from 35.73 ± 15.26% without biofeedback to 6.5% ± 9.6% with biofeedback, $p < 0.05$. This represents an 82% overall decrease in time spent in bad posture.

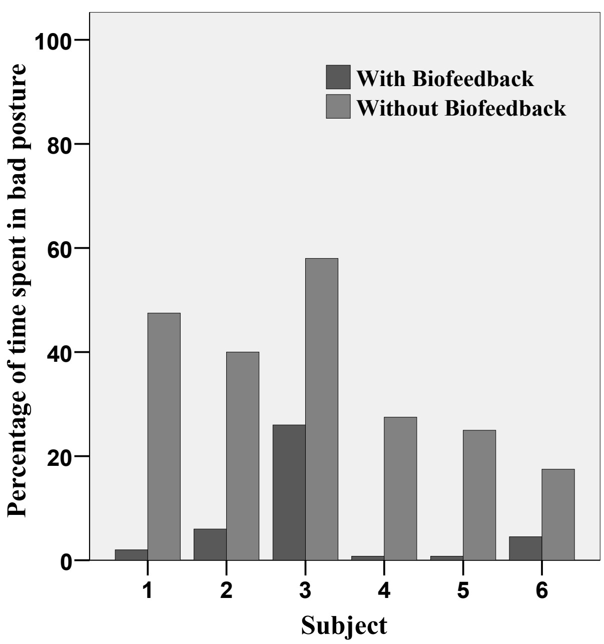

Fig.3. Percentage of time each subject spent in bad posture with and without biofeedback over a 5 hour period.

In Fig. 3, we can observe the difference between both sessions with and without biofeedback for each of the six subjects. All subjects experienced a significant reduction in time spent in positions of bad posture.

IV. Discussion

This system is designed to measure the changes in neck angle while working on a computer workstation and to alert the user to correct their position when they are outside of this threshold. The results from data collected during this study suggest that participants were able to maintain better cervical posture when working with the biofeedback system.

Other issues remain which have not been evaluated in this study. In the system evaluated the cervical angle relative to gravity was the only parameter measured and does not take the thoracic or lumbar regions into account. Time lapse monitoring of sitting posture over time suggests that cervical and thoracic postural changes occur in a similar manner [23]. Further evaluation of the effect of cervical feedback on the lumbar and thoracic spine would clarify if the impact on these regions is similarly positive as reported here. In this study cervical movement was only monitored in the saggital plane, however, a complete system could provide feedback in other planes of movement.

The Cinderella Hypothesis suggests that the cause of chronic muscular pain in computer use is due to the combination of low but static loads and activation of muscle fibres outside the normal recruitment pattern [24]. The lack of sufficient rest in the active muscles, causes damage to the muscle fibres belonging to the early recruited “Cinderella” motor units. Future work will examine EMG activity with and without biofeedback to determine if improved cervical posture results in greater rest of the trapezoid muscle in particular.

V. Conclusion

Prevention of workplace injuries due to poor ergonomics is a rapidly growing area of interest to health care professionals, employers and employees in this modern era. This study describes the preliminary evaluation of a new minimally invasive system for the correction of posture at the workplace. The rational for sensor placement based on cervical geometry has been discussed. The developed system provides the user with biofeedback data to assist in the maintenance of good computer workstation posture. Further work will address the other issues related to the evaluation of this single accelerometer based biofeedback system.

References

[1] O. Evans and K. Patterson, "Predictors of neck and shoulder pain in non-secretarial computer users," *International Journal of Industrial Ergonomics*, vol. 26, pp. 357-365, 2000.

[2] K. Fredriksson, L. Alfredsson, C. B. Thorbjornsson, L. Punnett, A. Toomingas, M. Torgen, and A. Kilbom, "Risk factors for neck and shoulder disorders: a nested case-control study covering a 24-year period," *Am J Ind Med*, vol. 38, pp. 516-28, 2000.

[3] A. Vikat, M. Rimpela, J. J. Salminen, A. Rimpela, A. Savolainen, and S. M. Virtanen, "Neck or shoulder pain and low back pain in Finnish adolescents," *Scand J Public Health*, vol. 28, pp. 164-73, 2000.

[4] S. Yates, E. Daley, B. Gray, J. Gownder, and R. Batiancila, "Worldwide PC Adoption Forecast, 2007 To 2015," Forrester Research, 2007.

[5] B. Cagnie, L. Danneels, D. Van Tiggelen, V. De Loose, and D. Cambier, "Individual and work related risk factors for neck pain

among office workers: a cross sectional study," *Eur Spine J*, vol. 16, pp. 679, 2007.
[6] B. Green, "A literature review of neck pain associated with computer use: public health implications," *J Can Chiropr Assoc*, vol. 52, pp. 161-167, 2008.
[7] L. Twomey and J. Taylor, *Physical therapy of low Back*, 3rd ed. Austrailia.
[8] A. M. Greig, L. M. Straker, and A. M. Briggs, "Cervical erector spinae and upper trapezius muscle activity in children using different information technologies," *Physiotherapy*, vol. 91, pp. 119-126, 2005.
[9] A. J. Haufler, M. Feuerstein, and G. D. Huang, "Job stress, upper extremity pain and functional limitations in symptomatic computer users," *Am J Ind Med*, vol. 38, pp. 507-15, 2000.
[10] E. Schlossberg, S. Morrow, A. Llosa, E. Mamary, P. Dietrich, and D. Rempel, "Upper extremity pain and computer use among engineering graduate students," *American Journal of Industrial Medicine*, vol. 46, pp. 297-303, 2004.
[11] L. Punnett and U. Berqvist, "Visual display unit work and upper extremity musculoskeletal disorders: A review of epidemiological findings.," Arbetslivsininstitutet. , Solna, Sweden 1997.
[12] P. Tittiranonda, S. Burastero, and D. Rempel, "Risk factors for musculoskeletal disorders among computer users," *Occupational Medicine*, vol. 14, pp. 17-38, 1999.
[13] M. Marcus, F. Gerr, C. Monteilh, D. Ortiz, E. Gentry, S. Cohen, A. Edwards, C. Ensor, and D. Kleinbaum, "A prospective study of computer users: II. Postural risk factors for musculoskeletal symptoms and disorders," *American Journal of Industrial Medicine*, vol. 41, pp. 236-249, 2002.
[14] F. Gerr, M. Marcus, C. Ensor, D. Kleinbaum, S. Cohen, A. Edwards, E. Gentry, D. J. Ortiz, and C. Monteilh, "A prospective study of computer users: I. Study design and incidence of musculoskeletal symptoms and disorders," *Am J Ind Med*, vol. 41, pp. 221-35, 2002.
[15] "Environmental and Occupational Health and Safety Service." New Jersey: U.M.D. , 2006
[16] I. I. M. Monsey, A. Beatini, B. Lukey, A. Santiago, A.B. James "Increasing compliance with stretch breaks in computer users through reminder software," *Work (IOS Press)*, vol. 21, pp. 107-111, 2003.
[17] K. J. N. D.R. Ankrum, "Head and neck posture at computer workstation-What's neutral?," presented at 4th Triennial Congress of Internation Ergonomics Association, 2000.
[18] L. McAtamney and E. Corlett, "Head and neck posture at computer workstation-What's neutral?," *Applied Ergonomics*, vol. 24, pp. 91-99, 1993.
[19] K. M. Culhane, M. O'Connor, D. Lyons, and G. M. Lyons, "Accelerometers in rehabilitation medicine for older adults," *Age Ageing*, vol. 34, pp. 556-60, 2005.
[20] A. Godfrey, R. Conway, D. Meagher, and O. L. G, "Direct measurement of human movement by accelerometry," *Med Eng Phys*, vol. 30, pp. 1364-86, 2008.
[21] G. M. Lyons, K. M. Culhane, D. Hilton, P. A. Grace, and D. Lyons, "A description of an accelerometer-based mobility monitoring technique," *Med Eng Phys*, vol. 27, pp. 497-504, 2005.
[22] N. Artz, "Proprioceptive Acuity of the Cervical Spine in Subjects with and without a History of Neck Pain," *Physiotherapy*, vol. 89, pp. 189-189, 2003.
[23] D. Falla, G. Jull, T. Russell, B. Vicenzino, and P. Hodges, "Effect of neck exercise on sitting posture in patients with chronic neck pain," *Phys Ther*, vol. 87, pp. 408-17, 2007.
[24] G. Hägg, Static workload and occupational myalgia—a new explanation model. Amsterdam: Elsevier Science Publishers, 1991.