J. Biomed. Eng. Res : 362-372, 2009

SEMG-based Upper Trapezius-specific Emotional Assessment System: Design and Implementation

Gang Li, Hai-feng Chen, Yeong-joon Gil, Wan-qing Wu, Jung-tae Lee

Department of Computer Science and Engineering Pusan National University Busan, Republic of Korea

(Received May 11, 2009. Accepted September 28, 2009)

Abstract

Some serious neck diseases are closely related to negative emotion. In order to explain the etiology deeply, we assumed that upper trapezius is innervated by emotional motor system (EMS), a special motor system. And then we developed an upper trapezius-specific surface electromyography acquisition system concerned with its special innervation to prove our assumption. Through a targeted experiment, we found that upper trapezius is indeed innervated by EMS.

Key words: Cervical healthcare, Negative emotion, Emotional motor system, Upper trapezius, SEMG acquisition system

I. INTRODUCTION

It is known that some serious cervical diseases, which manifest as organic diseases, are closely related to the psychological situation, especially negative emotion. For TemproMandibular joint Disorders (TMD), and Work-related Musculo-Skeletal Disorders (WMSD), it has been verified that negative emotion played an important role in the aspect of etiology [1-4].

In past years, many researchers have successfully extracted emotional information via electroencephalogram (EEG) and electrocardiogram (ECG), which was the representative psychological signal of the limbic system and Autonomic Nervous System (ANS) respectively. Both the limbic system and ANS plays a very important role in emotional control and response [5]. However, no matter EEG or ECG, it only can reflect emotional features inside human body, which are unable or insufficient to explain emotion-specific behavior. In another word, EEG and ECG cannot reflect the information of human somatic nervous system which is mainly composed of motor units. And the motor units are very responsible for human behavior.

As the core technology to study motor units, surface electromyography (SEMG) technology should have played a key role in human emotional research. However, few studies focused on SEMG signal. Additionally, Gert G. Holstege, George Paxinos and Jurgen K. Mai have found that a special type motor system exists in the human body, called the emotional motor system (EMS), which utilizes the same motoneurons and premotor interneurons as the somatic or voluntary motor system [6,7]. It means the muscles innervated by EMS can also be kept active even if without voluntary contraction and extra physical load. That is to say, these muscles are always work overload. Simply put, just like a person is doing a job which needs two persons to do. Unfortunately, Gert G. Holstege et al just proved facial muscles are innervated by EMS. If we could find more muscles innervated by EMS, it will not only provide useful precaution information for healthcare, but also improve the organizational framework of emotional motor system.

According to the knowledge of Applied Kinesiology (AK), the upper trapezius muscle has been termed the "coat hanger" muscle as it suspends the shoulder girdle from the axial skeleton like a coat hanger hangs a suit jacket from a coat stand. Thus, in order to maintain the proper posture of the neck and shoulder joints of the body, the upper trapezius muscle is almost used every second except sleep. From this point of view, we can see how important it is to human cervical healthcare. Furthermore, if we can prove the upper trapezius is also innervated by EMS, it will be of great significance to the health of the neck.

Taking into account the somatic innervation of the upper trapezius, it includes a sole fine branch of a Spinal Accessory Nerve (SAN) [8]. The motor units contained in the fine branch are low-threshold motor units [9], that is, they are slow-contracting and fatigue-resistance motor units (type S), according to the

Corresponding Author : Jung-tae Lee
Department of Computer and Science Engineering, Pusan National University, 609-735, Korea
Tel : +82-51-518-0397 / Fax : +82-51-517-2431
E-mail : jtlee@pusan.ac.kr
"This work was supported for two years by Pusan National University Research Grant."

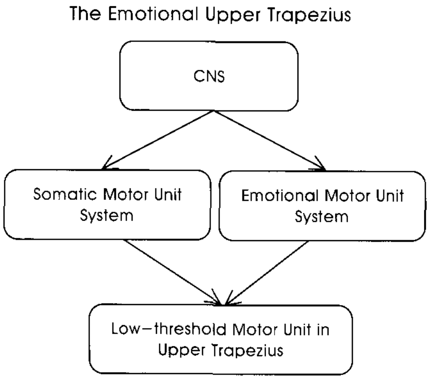

Fig. 1. The emotional upper trapezius

S-FR-FF motor unit recruitment scheme [10]. Judging from SEMG's power spectrum of slow-contracting muscle fibers controlled by slow-contracting motor units, the upper limit of the dominant power's width is less than 90Hz [11]. With respect to the low-threshold motor units in the upper trapezius, a concrete upper limit remains unclear. Nevertheless it is widely accepted that the firing rate of single motor unit in the trapezius is only 8~12Hz [12], while the mean firing rate is 35~40Hz in the first dorsal interosseus, 30Hz in the adductor polliis, 29Hz in the deltoid etc [10]. Based on the results of the studies mentioned above, a big picture of our study named "The emotional upper trapezius" was assumed, as shown in Figure 1.

The special somatic innervation of upper trapezius makes it difficult to measure emotional signal component in conventional SEMG acquisition. Generally, the commercial SEMG acquisition device is designed for the study of biomechanics or applied kinesiology (AK), the SEMG signal of which is relative strong with higher amplitude and larger width of frequency band of upwards to 500Hz. Thus, in order to avoid movement artifacts, the cutoff frequency of high pass filter (HPF) in commercial device is set to 20Hz. However, in the 5-20Hz frequency range, the SEMG spectrum contains information concerning the firing rates of the active motor units. In movement analysis, this information can be ignored, but in our analysis, it must be preserved. The reason is that movement artifacts problem doesn't exist here (only emotional activation) and we absolutely care about the motor firing rate which can indicate motor unit type so as to verify our assumption demonstrated in Figure1. Therefore according to trapezius' motor firing rate (8~12Hz), we set cutoff frequency of HPF to 5Hz rather than commercial device's 20 Hz. Additionally, given larger width of power spectrum, large SEMG signal contributions at 60 Hz and neighboring frequencies when perform biomechanics activities [13,14]. The result of notch filtering is the loss of important EMG signal information, so notch filter is avoided as a general rule in commercial device. However, the amplitude of SEMG under lower activation condition (emotional activation) is very low, so commercial device's signal to noise ratio (SNR) will dramatically decline if no 60Hz notch filter.

Consequently, it is necessary to design an upper trapezius-specific SEMG acquisition system in order to provide the lower cutoff frequency of HPF and the higher SNR.

Although previous studies had verified the upper trapezius is highly sensitive to a negative emotional stimulus among many skeletal muscles [15,16], they didn't explain the phenomenon based on EMS. And given the effect of "coat hanger", the upper trapezius is very vulnerable to fatigue. In this case, it cannot simply prove like [15] or [16] that the increase of RMS value is just determined by emotion. This is because if someone is fatigue, he will instinctively adjust his upper trapezius via rotation movement. At this point, RMS values certainly increase. Particularly in [15], the stress induction session was up to one hour. Furthermore, no matter [15] or [16], they only analyzed signal in time-domain, which cannot reflect the features in frequency-domain and time-frequency domain. And thus unable to understand which type of motor units are working under negative emotion situation.

In this study, our goal was to develop an upper trapezius-specific SEMG acquisition system to prove that upper trapezius is also innervated by EMS and verify motor units recruited by EMS are low threshold motor units so as to provide more accurate information for cervical healthcare..

II. METHOD

A. Design of SEMG acquisition system

The mentioned system consists of two main components: a SEMG acquisition unit and a computer-based module. The signal acquisition unit includes the active electrodes, pre-amplifier (instrumentation amplifier, INA128) , a low and high pass filter (butterworth, LM6464), a main amplifier and 2nd amplifier (non-inverting, LM6464) and an A/D converter (ADC) module. The acquisition unit amplifies weak SEMG signals in order to effectively serve the ADC. The total gain is about 60dB, the default sampling rate is 1200Hz and there is a 12-bit resolution for four-channel SEMG signals. The computer-based module (*Microsoft VB.net, 2005*), is mainly composed of a 60Hz adaptive notch filter and a waveform display module. The hardware notch filter is not robust to slight changes in the frequency of the power supply, so the adaptive notch filter is necessary.

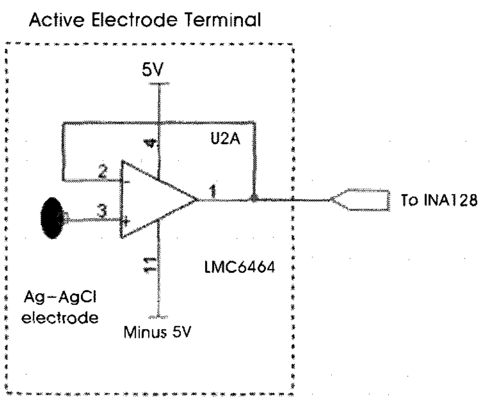

Fig. 2. The terminal of one active electrode

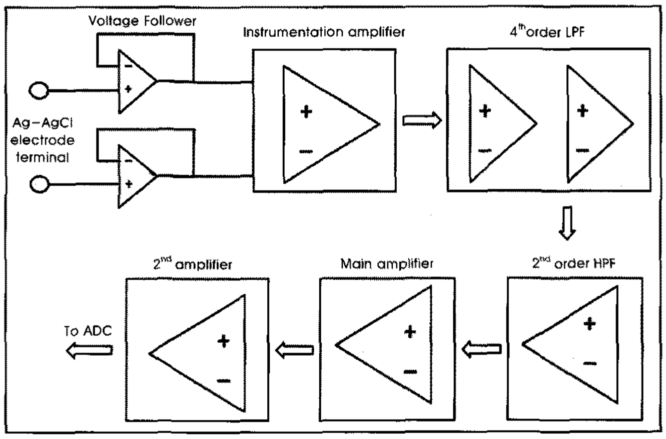

Fig. 3. The structure of amplifier and filter

1) Active electrode.

Power-line noise (60Hz in South Korea) and its harmonics constitute the greatest interference in the raw SEMG signal [17]. This noise may have a serious impact on the raw SEMG signal in magnetic and electric form [17,18]. With respect to the power-line noise arising from the magnetic field, we used the electrode line in twisted-pair form, aimed at reducing the surface area of loop circuit which is constituted by electrode lines, according to Maxwell's equations. Regarding the noise caused by the electric field, we used active electrodes (composed by voltage followers) in place of conventional Ag-AgCI electrodes. As high input impedance is voltage follower's feature, active electrodes are able to overcome the imbalanced electrode-skin impedance which results in the noise's transform from common mode to differential mode [19]. Therefore, even if with the higher common mode rejection ratio (CMRR), noise can still be magnified. Figure 2 shows the terminal of one active electrode.

2) Analog component.

Generally, the lower limit of dominant power spectrum of low threshold muscle fibers is less than 90Hz, but no confirmed upper trapezius-specific conclusion, so for insurance we set the cutoff frequency of low pass filter as 200Hz, shown in table1. In future work, we plan to change this device into portable type, so both INA128 and LMC6464 is low power chip. The structure of active electrode, amplifier and filter is shown in Figure 3. The specifications of the unit's amplifier and filter components are given in Table 1.

3) Digital component.

The digital component comprises a micro-processor unit (AT89C51) circuit, a multiplexor (MC14067BCP), a 12-bit ADC (LTC1274) and a serial communication (RS232 Standard) circuit. Given the bipolar feature when bipolar electrodes are used [20], a dual-power mode of ADC was adopted. Additionally, the upper limit on the frequency of interest is 200Hz (shown in Table 1), so there is no need to go beyond 1 KSPS (kilo samples per second), however LTC1274's sample rate could be upwards to 100 KSPS which is sufficient [21]. Figure 4 shows the block diagram of the digital component of the SEMG acquisition system. Figure 5 demonstrates the

Table 1. Specifications of unit Amplifier & Filter

Component	Character	Gain
Pre-amplifier	Differential input impendence: 10Gohm || 2Pf, CMRR: 120 dB	40dB
High pass filter	2nd-order Butterworth filter Cutoff frequency :5Hz	0dB
Low pass filter	4th-order Butterworth filter Cutoff frequency :200Hz	0dB
Main amplifier	Non-inverting amplifier	12dB
2nd amplifier	Non-inverting amplifier	6dB

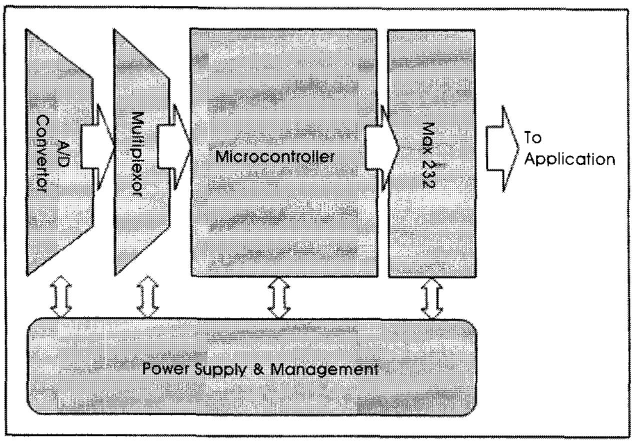

Fig. 4. Block diagram of digital part of SEMG acquisition system

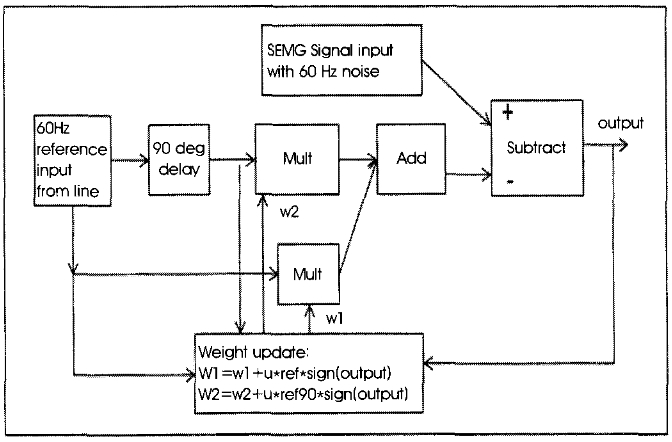

Fig. 6. Algorithm of 60Hz adaptive notch filter

implemented SEMG acquisition system.

4) Computer-based module.

The computer-based module is comprised of a 60Hz adaptive notch filter, a waveform display and a signal analysis component.

The default sampling rate is 1200Hz, thus for 60Hz power line noise we obtain 20 samples per second. Furthermore, we can conclude that each five samples indicate a 90-degree phase. If we define reference noise as ref_noise(n) and 90-degree delayed reference noise as ref_noise90(n), then it follows that:

$$ref\_noise90(n)=ref\_noise(n+5) \quad (1)$$

where n indicates the n^{th} sample point. Figure 6 demonstrates the algorithm of the 60Hz adaptive notch filter, where *value* is noisy SEMG data; *reference* is reference noise (60Hz power supply); and *reference90* is the 90-degree delayed reference noise. Figure 7 illustrates the main code of the algorithm of the 60Hz adaptive notch filter.

In the signal analysis component, various methods in the time domain are integrated, such as the RMS, Relative Rest Time (RRT), Mean Power and Median Frequency (MPF and MDF), where RRT was defined as the percentage of consecutive time periods in which RMS_{RRT} was below 6μV for at least 0.125s, and describes the relative duration of the gaps [12,22]. The RMS values were used to express the muscle activation of the upper trapezius, while the RRT values indicated the muscle relaxation. The difference between RMS and RMS_{RRT} is that the window for RMS is 6s while for RMS_{RRT} it is 0.125s. Fast Fourier Transform (FFT) is also integrated with the software. An examination of the frequency spectrum can provide information not readily available in the

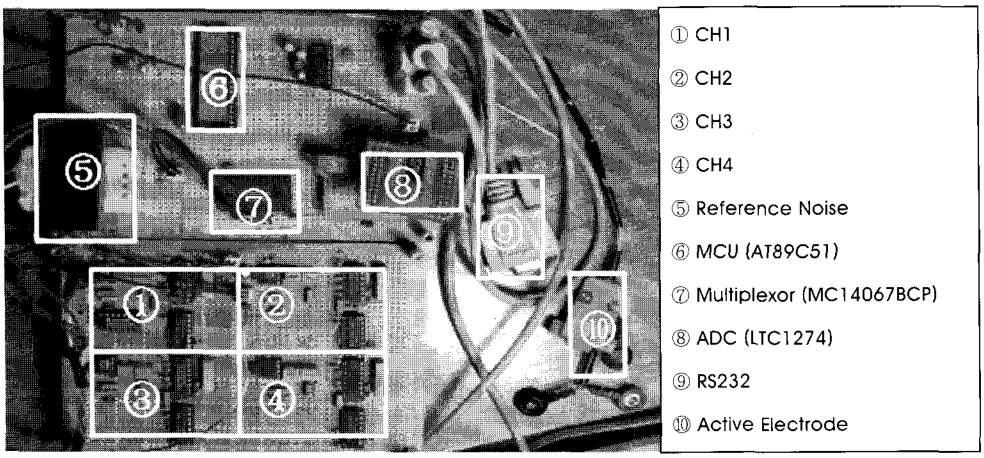

Fig. 5. Implemented SEMG acquisition system

```
Private Function AdaptiveFilter4(ByVal value As Single, ByVal reference As
Single, ByVal reference90 As Single)
    Static output As Double
    Static w1 As Double
    Static w2 As Double
    Dim u As Double = 2 ^ -17
    output = value - (reference * w1 + reference90 * w2)
    w1 = w1 + u * output * sign(reference)
    w2 = w2 + u * output * sign(reference90)
    Return output
End Function
.........................................................................
Private Function sign(ByVal val As Double)
    If val > 0 Then
      Return 1
    ElseIf val < 0 Then
      Return -1
    Else : Return 0
    End If
End Function
```

Fig. 7. First component: weight update Second component: code of sign function

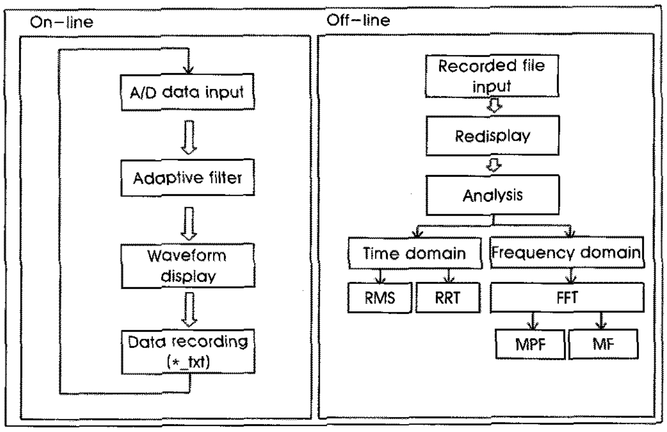

Fig. 8. The Computer-based module functions

time domain, such as muscle fatigue which causes a decline in both MPF and MDF [10]. However, these indicators are relevant only for isometric contraction (i.e., sustained contraction with no movement) [10], which is the very type of contraction in the upper trapezius that occurs under the emotional activation condition. All functions of the computer-based module are shown in Figure 8.

In Figure 7, we can note that the first function name in the top is called "*AdaptiveFilter4*". This is because that the mentioned system is 4-channel system, so each channel needs one filter respectively.

B. Materials and subjects

The electrodes applied were active bipolar ones with 2cm in diameter, and an inter-electrode spacing of 2cm. One pair of electrodes was located on the right side of the neck. As for each differential electrode of one pair, one was located over the one-third of the muscle length distal to the insertion and the other one over the one-third of the muscle length distal to the origin. Since the endplates are usually located near the middle of the muscle fibers, the selected locations could stay clear of the innervations zone so as to reduce the probability of obtaining unreliable results. In order to provide a good reference potential, it is better to place the reference electrode as far away as possible and on electrically neutral tissue (say over a bony prominence) [13]. Thus, a ground (reference) electrode was attached to the right elbow. The skin overlying the muscle was prepared by 70% Isopropynol alcohol before placing the electrodes to lower the electrical impedance.

In addition, in order to prove the function of EMS, we must meet some requirements:

1) no voluntary contraction
2) no physical load
3) non-fatigue

Thus, we used an inflatable cervical vertebra tractor to fix neck and avoid physical load imposed on target muscle. We did all experiments between 9 am and 11 am to avoid the fatigue phenomenon produced by daily work as far as possible.

(a) (b)

Fig. 9. Inflatable cervical vertebra tractor

Constellation-related fortunetelling	→	Looking for non-existent radio channel	→	punishment for intelligence test

Fig. 10. Illustration of negative emotion induction

Figure 9 (a) and (b) shows the inflatable cervical vertebra tractor and typical application demonstration for subjects respectively.

There were 13 young subjects (nine women and four men, ages 20-22) in this study, all of whom were paid for their participation. All the subjects were freshman of the Department of Computer Science & Engineering at Pusan National University. None of them had neurological disorders or neck disorders. All the subjects gave their informed consent before experiment.

C. Procedure

We verified system performance via two indicators. One is the higher SNR, which is easily verified via the power spectrum. The other one is the type S motor unit, which can be verified via the lower RRT and fatigue under the negative emotion condition and the narrower width of dominant power. Thus, each subject was induced to feel positive and negative emotion. The positive emotion sharply contrasted with the negative emotion, for the purposes of comparison. The design was a simple one-factor, two-level (positive/negative) design, which is suitable for a 2-tailed paired t-test.

1) Emotion induction protocol.

In previous studies [23], the induction of human emotion was based on hard-wired or on demand response in ANS, nevertheless we still decided to adopt more natural means to induct target emotion. It means that the target emotion was elicited by a stimulus or situation outside the subject's efforts.

Fig. 11. Illustration of negative psychological hint session

The international affective picture system (IAPS) seems the international standards in the field of study of emotion. However those still images were not sufficient for effective emotion induction, according to Wataru Sato [24].

Our protocol utilized a multimodal (psychological hint, audio, visual and interaction game) approach to evoke specific targeted emotional statuses. It is worth noting that the interaction between stimulus and subjects is contingent on task performance, leads the subjects to become more engaged in actively coping with the task, which might results in an enhancement of autonomic activity. Figure 10 illustrates one of the stimuli, the purpose of which was to induce the status of negative emotion.

The protocol of negative emotion induction consisted of psychological hint session which is based on the fortunetelling of 12 constellations, audio session based on radio noise and interactive intelligence test (made via flash clip). Before SEMG recording, the subject was required to write down her/his constellation and read constellation-related fortunetelling

Table 2. Responses to Emotional Induction

Emotion	Stimulus protocol		t (min)	SEMG Recording
Positive (happy, confiden-ce)	Psychological hint	Constellation-related fortunetelling which are all positive personality summary	1	N
	Trigger point	Reward for intelligence test	2	N
	Breakout	Watching the "Just for Laughs"	5	Y
Negative (stress, anxiety, anger)	Psychological hint	Constellation-related fortunetelling which are all unpleasant personality summary	1	N
	Trigger point	Looking for non-existent radio channel	2	N
	Breakout	Punishment for intelligence test	5	Y

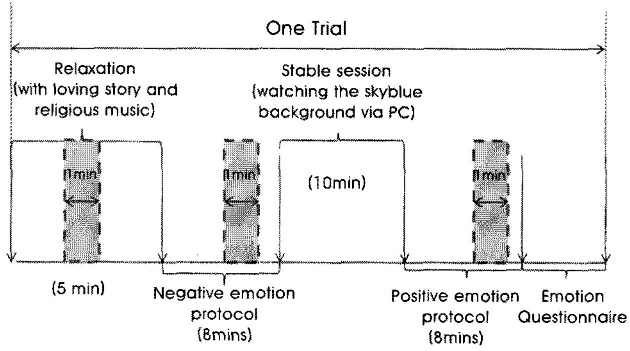

Fig. 12. Specific experimental procedure

which are all unpleasant personality summary which made by ourselves, as shown in Figure 11, purpose of which is to create a negative psychological hint. And then we required subject to use the AM radio player to search one channel which he or she likes. Actually, within the required timeframe (2 min), the subject couldn't find any broadcasts, due to the loss of demodulation module in that radio player. Finally, we started to record SEMG signal, and simultaneously, the subject was asked to perform an intelligence test which has a regulation made by us that if got the wrong answers 3 questions above, the participation payment will be reduced, aiming to the breakout of the negative emotion. During the intelligence test, subjects didn't perform any movement, but need to remember, calculate and think in mind. The negative and positive emotion inductions protocols are summarized in Table 2. According to the mood-maintenance hypothesis [25], the order of stimulus presentation was negative protocol first. Reason for this is that persons in a positive emotional state are motivated to desire maintaining those positive emotions. Similarly, it can also be asserted that in negative emotional states, persons will be willing to alter or mitigate their negative affective state. Thus, if the positive protocol represents first, it will take a bit longer to stop its effect and may have a bad impact on the performance of negative emotion induction protocol.

2) Experimental procedure.

After electrode placement, the subjects were required to close their eyes and engage in a 5-minute relaxation session by listening to peaceful religious music designed to calm the original emotion. This relaxation session was used as a reference. And then the subjects were asked to perform our emotion induction protocol for about 8 minutes. There was a 10-minute stable session between the negative and positive emotion induction protocol, as the effects of epinephrine need a slightly longer time to subside. After the emotional induction session, the subjects were asked to fill out an emotion questionnaire, which was used to rate their emotional status. Figure 12 illustrates the specific experimental procedure used. The scales had end-points of 1= "extremely negative" to 5= "extremely positive", as shown in Figure 13.

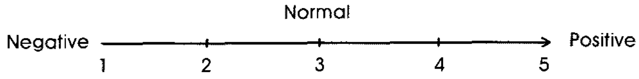

Fig. 13. Emotion questionnaire

D. Analysis

1) Responses to the emotional stimulus.

Both the positive and negative stimulus was effective for all subjects. Self-ratings made during the emotional stimulus are illustrated in Table 3, which shows that our emotion-induction protocol was effective. Subsequently, we could analyze SEMG signals as planned.

2) Time domain analysis (offline).

The SEMG signal was recorded during the relaxation and emotion induction sessions.

We extracted the SEMG raw data within the period represented by the gray area displayed in Figure.9. The constraint for extracting the raw data is that we choose the middle part of every epoch in order to avoid the start-up and end effects.

RMS and RRT values were obtained from the relaxation, negative and positive emotion induction sessions. RMS values obtained during the three sessions were all calculated for 10 epochs, each with a time window of 6s, which was considered to give a proper indication of the average RMS values. The

Table 3. Responses to Emotional Induction

	Positive	Negative
Mean Score	4.38	1.5
Grade	0.46	−0.5

*Grade=(Mean Score−3)/3

RRT values were calculated for the three selected one-minute periods. For each session (relaxation, negative and positive emotion induction) and each outcome parameter (RMS and RRT), epochs were averaged per subject. Consequently, we obtained three RMS values and three RRT values from each subject. In total, we obtained 39 RMS values and 39 RRT values. Each subject's reference value (RMS_{ref}. and RRTref) was based on his/her RMS and RRT values from the relaxation session. The normalized $RMS_{emotion\_nor}$ and $RRT_{emotion\_nor}$ values are defined as:

$$RMS_{emotion\_nor} = (RMS_{emotion}/RMS_{ref})*100\% \quad (2)$$

$$RRT_{emotion\_nor} = (RRT_{emotion}/RRT_{ref})*100\% \quad (3)$$

3) Frequency analysis of SEMG (offline).

This step is concerned with the MDF and frequency bandwidth of muscle activity of the upper trapezius. The time-frequency analysis was performed by *Matlab adaptive time-frequency analysis toolkit.*

4) Data exploration.

Through formula (2) and (3), 26 normalized RMS values and the RRT values were obtained. They showed predominantly non-normal distributions at the group level (negative and positive emotion status), therefore our statistical analysis had to adopt a non-parametric paired t-test, which is Wilcoxon paired t-test. Likewise, 26 normalized MDF values were obtained, which were not significantly different from a normal distribution.

Ⅲ. RESULTS

A. Time domain

Statistical results show that there is a significant difference between positive and negative emotion status (for RRT, $p<0.0161$; for RMS, $p<0.0008$). Confidence Intervals (CI)

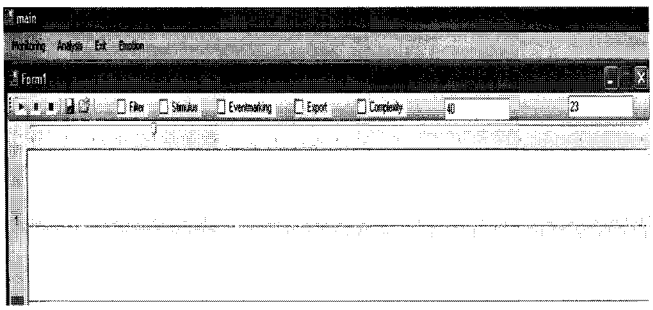

Fig. 14. Waveform of SEMG data of one subject in negative emotion status

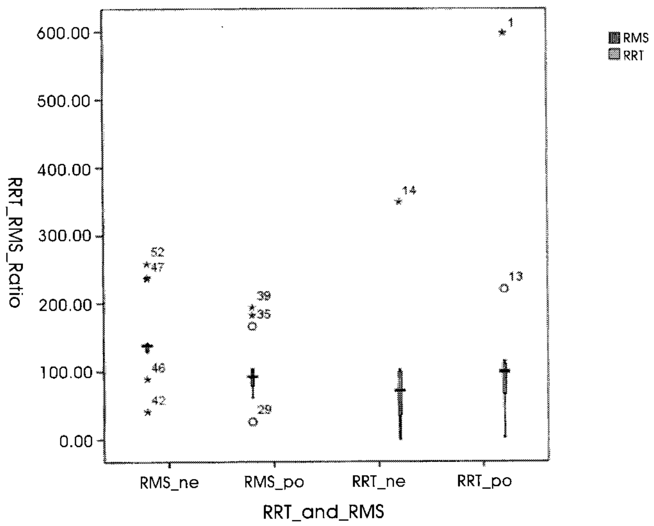

Fig. 15. Normalized RRT and RMS's box-and-whisker plot

were set to 95%. The Wilcoxon test was performed in *Prism* 5.02.

Figure 14 demonstrated the waveform of one subject's SEMG data obtained in emotion status. Based on Figure 15 we can conclude that the normalized RRT values in the negative emotion status are lower than those in the positive emotion status, while the normalized RMS values in the negative emotion status are higher than those in the positive emotion status.

B. Frequency domain

1) Normalized Median Frequency.

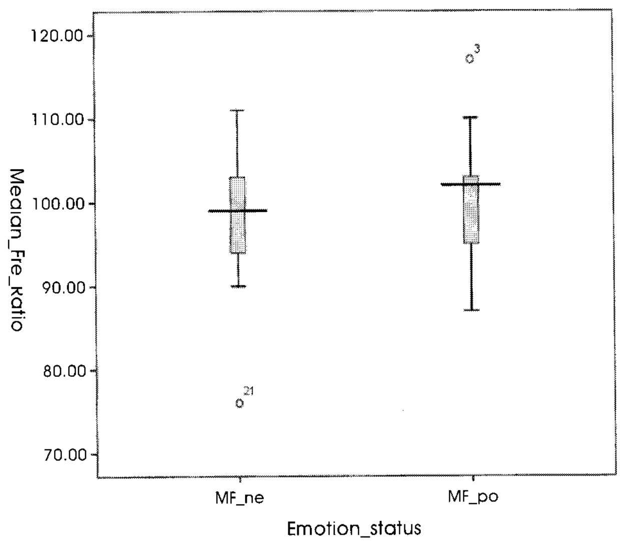

Fig. 16. Normalized MDF's box-and-whisker plot

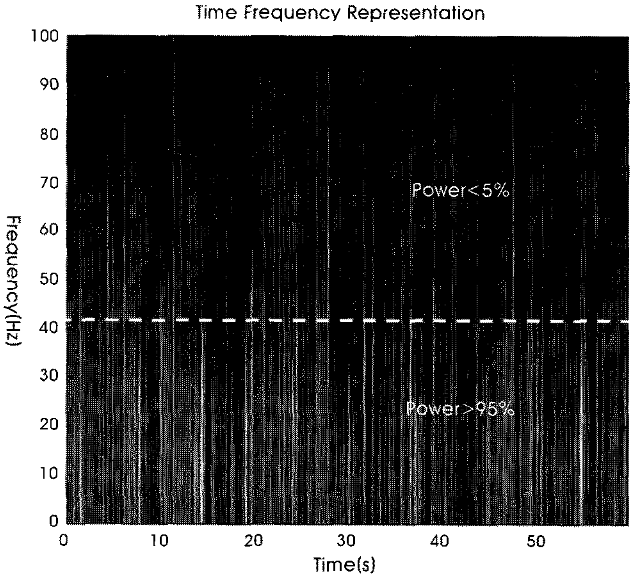

Fig. 17. One-minute time-frequency analysis of one subject in negative emotion status

The statistical results show that there is no significant difference between positive and negative emotion status (t(12)=-1.596, p<0.136). Confidence Intervals (CI) were set to 95%. The paired t-test was performed in SPSS for windows (version 16.0).

Based on Figure 16 it is clear that normalized MDF values in the negative emotion status are slightly lower than those in positive emotion status, which is similarly expressed in Table 3; this shows the grade of emotional induction (-0.50 for negative vs 0.46 for positive).

2) Frequency bandwidth.

Figure.17 illustrates one of the subjects' time-frequency images from the negative emotion status. It is clear that the dominant power (power>95%) is below 40Hz, which is in the very range of slow-contracting fibers. From the viewpoint of the firing rate and SEMG bandwidth, it is proved that the activated motor units under negative emotion are absolutely type S, which in this experiment wasn't defined by the SEMG amplitude like in [26]. This is because that the stability of SEMG amplitude is lower than the frequency which is only determined by the motor unit firing rate if there is no electrical cross-talk problem. While the upper trapezius is only innervated by a fine branch of SAN where no other motor nerve, there is indeed no electrical cross-talk problem.

Based on Figure 18(a) it is clear that if the cutoff frequency of HPF was set to 10 or 20Hz, a wealth of SEMG information would be lost. In addition, as the dominant power is below 40Hz, the usage of the 60Hz filter wasn't the cause of the loss of important SEMG signal information. Furthermore, it is also clear that the upper limit of SEMG signal of upper trapezius innervated by EMS contributions around 100Hz. Thus, in the next work, we may lower the cutoff frequency of low pass filter to about 100Hz and reduce the sampling rate. In this case, the MCU's interruption rate (per second) can also be reduced in order to the usage of low power system. From Figure 18 (a) and (b), it is clear that the SNR of the proposed system is significantly higher than that of the commercial one.

IV. DISCUSSION

In this study, we have verified that the muscle activation of the upper trapezius is higher in the negative emotion status than in the positive emotion status, which is a result of the higher RMS and lower RRT values. In the frequency domain, the upper trapezius is more prone to fatigue in the negative emotion status than in the positive emotion status, which is a result of the rapid decrease of MDF over 8 minutes.

Although the statistical result of MDF is not significantly different (p<0.136), we think this is only due to the short duration of the emotion protocol. During such a short period, the MDF difference between the positive and negative emotional session was already presented. Furthermore, the narrower width of dominant power demonstrated via the power spectrum and time-frequency plots also verified that the activated motor units are type S. Additionally, Figure 18 (a) and (b) verified that the SN ratio of the proposed system is significantly higher than that of the commercial one. In conclusion, we proved that upper trapezius is also innervated by EMS. And, at that moment, the recruited motor units are low threshold motor units.

Recently, professor Matsui, a famous nervous system expert on brain surgery from Tokyo, has defined a disease named Cervical Neuromuscular Syndrome (CNMS). He stressed that the cervical muscle is the most important muscle in the human body. Sustained physical or negative emotional load is prone to cause a neuromuscular disorder [13]. We speculate that the disorder mainly occurs in the upper trapezius. Firstly, it is too fine to contain an adequate number of motor neurons as storage, because of the sole fine branch of SAN. Once the motor neurons here are recruited, they have to be activated all the time without rest. Secondly, both the somatic and EMS uses the same motoneurons. Even when there is no physical load, muscle fibers in the upper trapezius remain active under the negative emotion condition. Thus, in addition to avoiding head-related overloading, it is also important to maintain a positive emotion status to protect

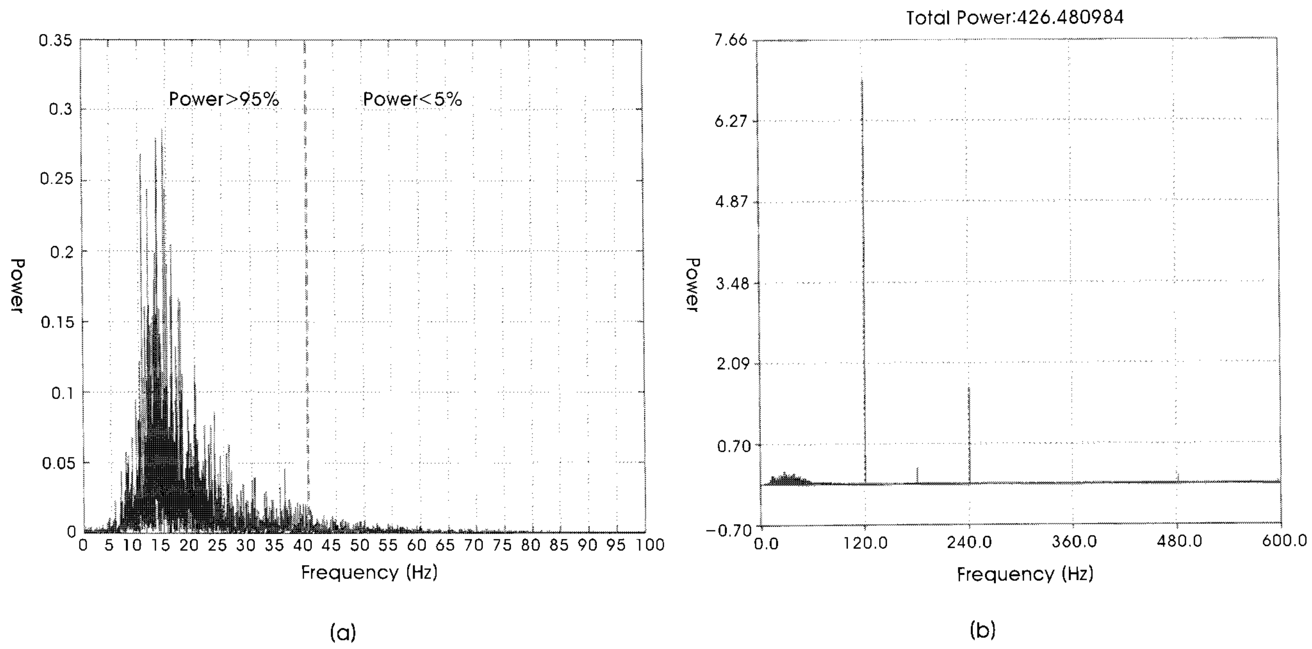

Fig. 18. FFT spectrum of 1- minute SEMG signal of one subject in negative emotion status. (a) and (b) were obtained from our proposed system and the commercial system, respectively.

against upper trapezius neuromuscular disorders effectively and prevent CNMS.

In future work, we plan to design a portable visual neurofeedback system and develop a therapy based on the RMS, RRT and MDF values in order to facilitate personal cervical healthcare.

REFERENCES

[1] G. E. Voerman. M. M. R. Vollenbroek-Hutten, H. J. Hermens, "Upper trapezius muscle activation patterns in neck-shoulder pain patients and healthy controls," *Eur J Appl Physiol* vol.102, no.1, pp. 1-9, 2007.

[2] A. Petrock, S. Reisman, S. Weiner, A. Siegel, "Wavelet Analysis of Masseter Muscle Activity Resulting from Stimulation of Hypothalamic Behavioral Sites," in Proc 28th *IEEE Northeast Bioengineering Conference, Philadelphia, Pennsylvania*, April, 2002, pp. 49-50.

[3] A. Petrock, S. Reisman, "Wavelet Analysis of Masseter Muscle EMG During Emotional Provocation," in Proc 29th *IEEE Northeast Bioengineering Conference, New Jersey, USA, March*, 2003, pp. 132-133.

[4] Matsui Yoshitaka, "Neck determines the health," *Liaoning Science and Technology Press*, 2009, pp. 5-89.

[5] C. George Boeree, "The Emotional Nervous System," http://webspace.ship.edu/cgboer/limbicsystem.html.

[6] Holstege, G, "The emotional motor system," *Eur. J. Morph*. vol. 30, no. 1, pp 67-81, 1992.

[7] George Paxinos, Jurgen K. Mai, "The human nervous system (Second Edition)," *Elsevier Academic Press*, 2002, pp 1306-1324.

[8] Antonius C. Kierner, Irmgard ZelenKa, Martin Burian, "How Do the Cervical plexus and the Spinal Accessory Nerve Contribute to the Innervation of the Trapezius Muscle," *Arch Otocaryngol Head Neck Surg*, vol.127, no.10, pp. 1230-1232,2001.

[9] C. Westad, P.J. Mork, R.H. Westgaard," Firing patterns of low-threshold trapezius motor units in feedback-controlled contractions and vocational motor activities," *Exp Brain Res* vol. 158, no.4, pp. 465-473, 2004.

[10] Roger M. Enoka, "Neuromechanics of human movement (Third Edition)," *Human Kinetics Press*, 2002, pp. 291-292.

[11] Jee Hong Quach, "Surface Electromyography: Use, Design & Technological Overview", *December*, 2007, pp. 24-25.

[12] G.A. Hansson, "Sensitivity of trapezius electromyography to differences between work tasks-influence of gap definition and normalization methods," *Journal of Electromyography and Kinesiology*, vol. 10, no. 2, pp. 103-115, 2000.

[13] Electromyography: The European project 'Surface EMG for non-invasive assessment of muscles (SENIAM)' 1999, pp. 109-111.

[14] Scott Day, "Important Factors in Surface EMG Measurement", pp. 11, http://www.bortec.ca/Images/pdf/EMG%20measurement%20and%20recording.pdf.

[15] Lundberg U, Kadefors R, Melin B, Palmerud G, Hassmen P, Engstrom M, Elfsberg I, Dohns E," Psychophysiological stress and EMG activity of the trapezius muscle," *Int J Behav Med*, vol.1, no.4, pp. 354-370, 1994.

[16] Waersted M, Westgaard RH, "An experimental study of shoulder muscle activity and posture in a paper version versus a VDU

version of a monotonous task," *Int J Indus Ergon*, vol.19, no.3, pp. 175-185,1997.

[17] Enrique M.Spinelli, Miguel A. Mayosky, "Two-Electrode Biopotential Measurements: Power Line Interference Analysis," *IEEE Transactions on Biomedical engineering*, vol. 52, no. 8, 2005.

[18] James C. Huhta, John G. Webster, "60-Hz Interference in Electrocardiography," *IEEE Transactions on Biomedical engineering*, vol. bme-20, no. 2, 1973.

[19] Ji Jun, Yu Meng-sun, " Analysis of 50Hz interference in the bio-potential amplifier circuit and circuit design," *Journal of Clinical Rehabilitative Tissue Engineering Research*, vol. 12, no. 9, pp. 1782-1783, 2008.

[20] Peter Konrad, "The ABC of EMG," in *A Practical Introduction to Kinesiological Electromyography* Version 1.0, Noraxon INC, USA, 2005, pp.26-43.

[21] LTC1274 datasheet, Linear Technology, http://www.linear.com/pc/downloadDocument.do?navId=H0,C1,C1155,C1001,C1158,P1170,D1077.

[22] Hermens HJ, Vollenbroen-Hutten MMR," Effects of electrode dislocation on electromyographic activity and relative rest time: effectiveness of compensation by a normalization procedure," *Med Biol Eng Comput*, vol.42, no. 4, pp. 502-528, 2004.

[23] Robert W. Levenson, Paul Ekman, Karl Heider, Wallace V. Friesen, "Emotion and Autonomic Nervous System Activity in the Minangkabau of West Sumatra," *Journal of Personality and Social Psychology*, vol. 62, no. 6, pp. 972-988, 1996.

[24] Wataru Sato, "Enhanced facial EMG activity in response to dynamic facial expressions," *International Journal of Psychophysiology*, vol. 70, no. 1, pp. 70-74, 2008.

[25] Isen, A. M., and Patrick, R., "The effects of positive feelings on risk taking: When the chips are down," *Organizational Behavior and Human Decision Process*, vol. 31, 1983, pp. 194-202, 1983.

[26] Westgaard RH, De Luca CJ, "Motor control of low-threshold motor units in the human trapezius muscle," *J Neurophysiol*, vol.85, no. 4, pp. 1777-1781, 2001.