MEDS Clinical Medicine (2023)
Clausius Scientific Press, Canada

DOI: 10.23977/medsc.2023.040507
ISSN 2616-1907 Vol. 4 Num. 5

Muscle Fatigue Judgement Based on Neck Electromyogram Signals

Yujie Liu

Jiangsu Tianyi High School, Wuxi, China

Keywords: Muscle fatigue, neck electromyogram signals, normal working state, sitting posture

Abstract: Chronic cervical flexion can have serious effects on the cervical spine. In order to quantitatively assess the effects of prolonged bowing on cervical fatigue, 16 healthy participants were selected and maintained normal working posture for 3h. The sternocleidomastoid muscle, the neck clamp muscle and the shoulder trapezius muscle were selected to measure the surface EMG signal. After filtering and amplitude standardization, the EMG value of every 60s is integrated and its mean power frequency is calculated. It was found that the integrated EMG value fluctuated regularly, and the decrease after the initial increase indicated that the muscle entered the fatigue state. The mean power frequency (MPF) value of different muscles is significantly different, which determines the duration of fatigue tolerance of the muscles, and MPF is not a simple linear relationship in the whole process of neck flexion. The results show that the negative accumulation of MPF can be a good judge of muscle fatigue. Therefore, the EMG sensor can be programmed to connect to the computer. When the negative accumulation of MPF is detected, the program can display a pop-up window to prompt people to take a proper rest, thus reducing the probability of cervical spine injury.

1. Introduction

As delineated by Cuccia and Caradonna, posture constitutes the configuration of the body or the spatial organization of body segments relative to each other.[1] Posture is a dynamic concept, constantly adjusting to maintain balance and adapt to external forces. Conversely, poor posture, often referred to as malalignment, is a circumstance in which the body is not properly oriented, leading to a cascade of potentially detrimental physiological effects. Poor posture can manifest in myriad ways, but research tends to categorize it into four principal types: swayback, flatback, kyphosis, and forward head posture. Each of these postural deviations is distinct in its structural characteristics and potential health implications. Swayback posture is characterized by an exaggerated curvature of the lumbar spine (lower back), shifting the body's alignment out of its ideal vertical axis. This position may cause undue stress on the lower back muscles and joints, potentially leading to pain and discomfort. In contrast, flatback posture involves a diminished lumbar curve, pushing the pelvis backward and disrupting the body's natural balance. This condition often results in excessive strain on the muscles and structures of the lumbar region, potentially leading to chronic pain and functional impairments. Kyphosis, on the other hand, is typified by an excessive outward curvature of the thoracic spine (upper back), resulting in a hunchbacked appearance. This postural deviation may cause a range of issues, from muscle fatigue and back pain to respiratory difficulties in severe cases. Finally, forward head posture is identified by the positioning of the head anterior to the body's centre of gravity. This posture places a disproportionate amount of strain on the muscles of the neck and shoulders, leading to a higher likelihood of musculoskeletal disorders in these areas, including tension headaches, neck pain, and potentially cervical spine degeneration.

This research focus on the forward head posture, a postural deviation increasingly prevalent in today's digital society where adults routinely engage with computers for extended periods. This habitual engagement often leads to a detrimental posture termed prolonged forward neck flexion. According to Swann's study, this posture does not only pose a risk to an individual's musculoskeletal integrity but also adversely affects respiratory function and chest capacity.[2] Swann's findings suggest that sustained forward neck flexion can result in a reduction in chest capacity, likely due to the constricted anterior chest wall. This, in turn, can impede the efficiency of the respiratory system, potentially leading to a diminished oxygen supply to the body's tissues, including the brain. Moreover, the consequent changes in the musculoskeletal structures of the neck and upper back might result in chronic pain and functional impairments, hindering an individual's quality of life. In tandem with Swann's findings, Lee and his colleagues' research further elucidate the potential musculoskeletal implications of maintaining a forward head posture. They argue that persistent forward neck flexion, akin to a long-term bow, significantly predisposes individuals to muscle fatigue and chronic injury of the neck musculature.[3] Over time, these continuous stresses can instigate the development of cervical spondylosis, a degenerative condition characterized by the deterioration of the cervical spine's joints and discs. This condition can result in chronic pain, reduced range of motion, and potentially, neurological complications if not managed appropriately.

Cervical spondylosis, a degenerative condition affecting the cervical spine, has become a global health concern. As shown in Zhao's report, in the World Health Organization recently announced the "global top ten intractable diseases", cervical spondylosis ranked second. According to the latest report, the incidence rate of this disease is 17.3%, and there are more than 200 million patients in China. The annual cost for the treatment of cervical spondylosis is up to 500 million yuan which accounts for a large part of the medical expenses. A recent survey in Zhao's report of 2,000 patients with cervical spondylosis in China shows that the number of teenagers and office workers suffering from cervical spondylosis is only increasing, and the proportion of patients under 30 years old is 22% higher than those between 30 and 50 years old. In the past 20 years, the high incidence age of cervical spondylosis has dropped from 55 years old to 39 years old, which further states that the patients with cervical spondylosis is getting younger and younger.[4] Also, based on Bai and his colleagues' study, according to statistics, the number of cervical spondylosis patients under 30 years old has increased significantly, from 26% in 1996 to 37% in 2016. This study has also proved the trend of younger patients with cervical spondylosis. Given these alarming trends, it is crucial to address the issue of bad posture, particularly forward head, among individuals under 40 years old. This research aims to provide insight into the causes and consequences of prolonged forward neck flexion, as well as possible prevention and intervention strategies to mitigate its adverse effects on individuals' health and well-being.

According to Burhan and his colleagues' study, surface electromyographic signal (SEMG) is a kind of physiological electrical signal that can reflect muscle activity and fatigue degree to a certain extent when the muscle system contracts. Monitoring this signal has been widely used in clinical diagnosis, muscle strength evaluation, muscle fatigue judgment and other fields. In addition, the EMG sensor is portable to carry which means people can detect muscle fatigue whenever they want. It is worth noticing that the majority of current studies focus on the evaluation of cervical extensor balance and neck pain. Less attention is paid to cervical fatigue caused by prolonged neck flexion. Also, as mentioned before, current instruments are not portable. Hence, based on the muscle fatigue monitoring by portable surface electromyography (sEMG), this research focuses on the influence of long-term working neck flexion on neck muscles, determine the fatigue change state and severity of the participants, and finally provided a scientific real-time monitoring and prevention program.

2. Materials and Methods

2.1 General information

Sixteen participants were selected in this research from the Dongfeng Yihe Technology Development Company. In order to get a more credible conclusion, 8 males and 8 females are chosen to minimize the influence of gender on this experiment. The ages, weight and height of the participants are from 30 years old to 50 years old, about 60 kg and 170cm on average in order to decrease the effect of individual differences.

This experiment simulates the normal working state of people in sitting position, adopting the static human size standard (Figure 1). According to GB10000-88 standard mentioned in Portero and his colleagues' research[5], body measurement hundred digit 90 is selected. Based on the proportion of each part of the body, the neck forward bend position maintains between 40 °and 60 °by calculation when the participants are sitting at their normal working state as shown in Figure 1.

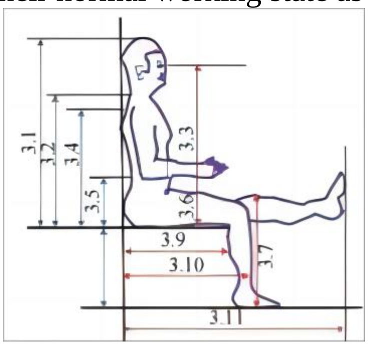

Figure 1: Dimensional figure of human sitting posture

2.2 Method

For the measurements in the experiment, 12 channel muscle electrical signal sensor and STM32 are used to collect data. The sampling frequency of the instrument is 9600 Hz. According to Al-Alangari and his colleague's research, the distance between the measured electrodes will affect the bandwidth and amplitude of the EMG signal.[6] Furthermore, based on Ren's study, if the distance between measuring electrodes is too small, it can cause signal superposition or short circuit. By contrast, if the distance is too large, the data is susceptible to interference from nearby muscle signals.[7] As a result, in order to get accurate data, the silver - silver chloride electrode from Xun Da company is selected, and the center distance of the control electrode was 2cm. Moreover, according to Artz and his colleagues' research, the muscles that maintain the movement and stability of the cervical spine include the clamps muscle, the sternocleidomastoid muscle, the trapius muscle, and the cephalic hemispinous muscle based on the characteristics of muscle architecture.[8] According to Merletti and his coworkers' study, previous researches have shown that as the head half spinous muscle is below the clamp muscle, the general clinical test neck clamp muscle, trapezius muscle and sternocleidomastoid muscle.[9] Therefore, in this experiment, the left and right sides of the neck clamp muscle, sternocleidomastoid muscle and shoulder trapezius muscle (a total of six muscles) are selected as test pairs. (Figure 2)

2.3 Outcome measures

Before conducting this experiment, all the participants are required to complete a questionnaire including their age, gender, weight, height, career and willingness in order to carry on the experiment. (Appendix A) Before the experiment, the participants' muscles are required to be wiped with an exfoliator and an alcohol cotton ball in order to remove the skin exfolation an dirt. In this way, the skin impedance can be reduced which can decrease the noise generated during measurement according to Vesa and Ilie's research, and therefore further reduces the difficulty of analyzing the data and improves the accuracy of the data collected.[10] After the measuring position is completely dry, 12 electrodes were placed in the sequence of channel number (channel 1-6) of the EMG sensor on the midpoints of participants' muscles (stick on the green points as shown in the Figure 2) and a red electrodes stick was chosen to place on the neck clamp muscle too. During the experiment, participants are required to keep sitting in a sponge-backed seat with forward neck flexion position and perform normal work for three hours. Also, they are prohibited to chat with each other in order to avoid the interruption between the participants. During the experiment, SerialPlot is used to record the data. For each person, the experiment is repeated for two times at the same time of a day which aims to reduce the measuring error. After the experiment, the data undergoes the preprocess of rectification and amplitude normalization in order to extract characteristic value. For the analysis part, integral electromyographic (Figure 3) and mean power frequency (Figure 4) are used since MPF index is more sensitive to muscle activity and function than MF index in the practical use according to Min and his colleagues' research. In this way, the data can be analysed both according to the time domain and frequency domain. What's more, matlab is chosen for analyzing data and computing the analysis program.

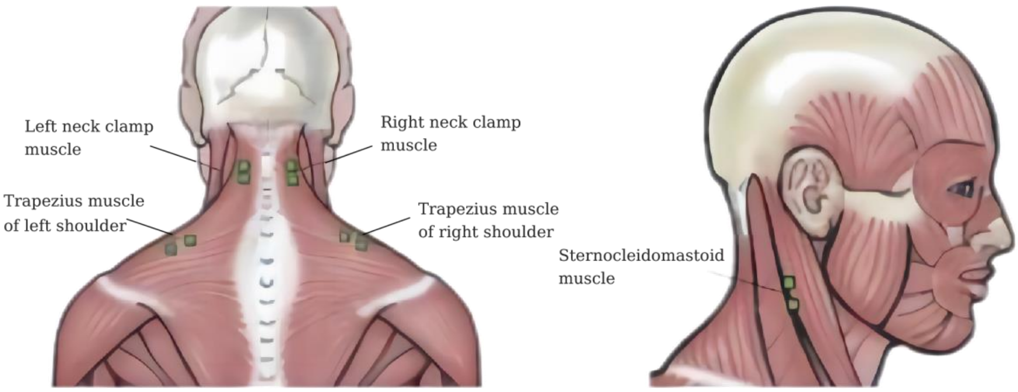

Figure 2: muscle measurement position in the experiment

$$\mathrm{MPF} = \int_{f_1}^{f_2} f \times \mathrm{PS}(f) \Big/ \int_{f_1}^{f_2} \mathrm{PS}(f)\,\mathrm{d}f$$

$$\mathrm{iEMG} = \sum_{i=1}^{N} |X_i| = \int_{T}^{T+60} X_i\,\mathrm{d}t$$

Figure 3: formula of integral electromyographic

Figure 4: formula of mean power frequency

3. Results

Since the EMG signal does not change noticeably when people are in normal office state, it is necessary to process the EMG signal to extract the necessary characteristic value. In this research, two pre-processing approaches are used. The first one is rectification. Because the positive and negative amplitudes of the surface EMG signal are almost equal, so if the value of the original signal is directly averaged, the average value will be approximately zero. Therefore, full-wave rectification of the signal should be added, that is, the absolute value of the signal is taken. After rectification, the signal retains all the information in the electromyographic signals. Moreover, its pattern changes can well reflect the intensity of muscle activity based on Skun and Raoofs’ study. (Slim & Raoof, 2010) The second pre-processing method applied is amplitude standardization. The placement of electrodes and the quality of skin treatments can cause lots of differences. Hence, amplitude standardization is needed in order to reduce the difference between experimental results of multiple participants. In this experiment, max voluntary contraction (MVC) is adopted for this amplitude standardization. After the application of these two data pre-processing the data, the surface electromyographic signals were analyzed in two perspectives, the time domain and frequency domain, which aims to evaluate if the signals can represent muscle fatigue. For the purposes of this study, data collection and analysis specifically tested this potential use of EMG signals on neck muscles.

3.1 Analysis of the time domain

For the analysis of the time domain, integral electromyographic (iEMG) is selected as the analysis method in this paper. According to Merletti and his workmates’ paper, by definition, iEMG is the total amount of discharge of the action potential of all the corporeal motor units involved in the activity within a certain activity time. Based on the information from the Merletti’s study, it can be concluded that iEMG contains a large amount of information about muscle activity, including the performance of muscle activity in amplitude and the reflection of electromyography conduction in time. The sampling time for data processing used in this research is 60s under the premise of eliminating the interference of neck micro-movements and ensuring that the time domain information of electromyographic signal is not lost. The calculation formula for iEMG is shown in the Figure 5. In the formula, N is the number of points within the sampling period, Xi is the surface EMG value, T is the sampling start time, and t is the sampling time. For symmetrical muscles, an average value is calculated.

$$\mathrm{iEMG} = \sum_{i=1}^{N} |X_i| = \int_{T}^{T+60} X_i \, \mathrm{d}t$$

Figure 5: formula of integral electromyographic

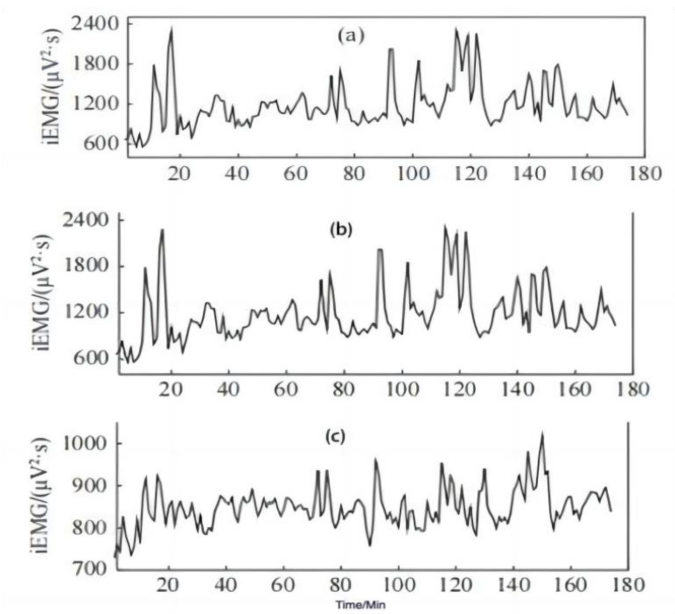

Figure 6: iEMG of different muscles

Figure 6 is the iEMG of one participant. (a) to (c) are the EMG integral value curves of sternocleidomastoid muscle, neck clamp muscle and shoulder trapezius muscle of one participant. (Full data set can be seen in the appendix A) As shown in Figure 6, iEMG has obvious fluctuation, which is small at the beginning and then increases rapidly, remaining constant for a period of time and continuing to decrease and then increases again. Similar patterns can be observed according to the statistics of the time for all 16 participants. (Appendix B) The iEMG of the sternocleidomastoid muscle increases significantly at about 17 minutes, the iEMG of the neck clamp muscle increases significantly at about 18 minutes, and the iEMG of the trapius muscle of the shoulder increases significantly at about 20 minutes. For all participants, the approximate time when iEMG of the three muscles increases significantly again is about 62min, 82 min and 72 min.

3.2 Analysis of the frequency domain

For the analysis of the frequency domain, mean power frequency (MPF, formula is shown in Figure 7) is selected since compared to median frequency, in practical use, MPF is more sensitive to muscle activities and function based on Xu and Xiao's research. (Xu & Xiao, 2000) According to Oberg and his colleagues' study, by definition, MPF is used to evaluate the frequency shift of the EMG signals associated with muscle fatigue. (Öberg et al., 1991) In this research, the setting window is 60s. Afterwards, the MPF of three muscles is averaged. In the formula, PS (f) is the spectrum of sEMG signal, f1 and f2 are the frequency range of sEMG signal, f is the sampling frequency. In this research, the frequency range is 0 ~ 100 Hz, and the time gradient is used in minute for frequency domain analysis.

$$\mathrm{MPF} = \int_{f_1}^{f_2} f \times \mathrm{PS}(f) \Big/ \int_{f_1}^{f_2} \mathrm{PS}(f)\,\mathrm{d}f$$

Figure 7: formula of mean power frequency

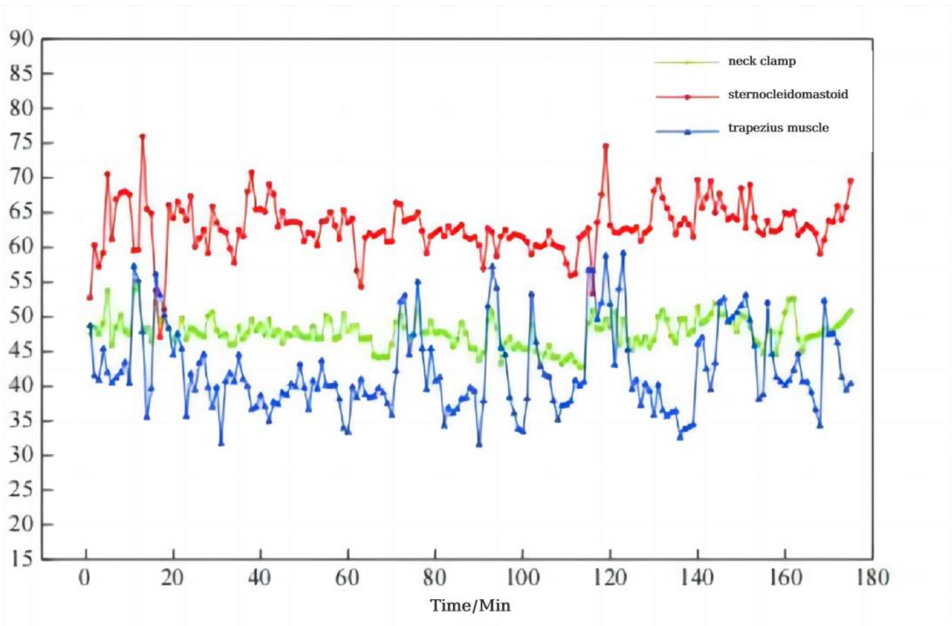

Figure 8: MPF of different muscles

The MPF of all participants is shown in Figure 8. As can be seen from the graph, MPF in different muscles varies greatly. According to variance analysis, the MPF of cervical clamp muscle, sternocleidomastoid muscle and trapezius muscle are 48, 65.6 and 41,5 which means the MPF of sternocleidomastoid muscle > Neck clamp muscle > trapezius muscle. The standard deviation σ of MPF of neck clamp muscle, sterncleidomastoid muscle and trapezius muscle are 2. 17, 3.89 and 6.09, respectively, indicating that MPF of the three muscles had different fluctuations. Also, it can be found from the graph that MPF presents a nonlinear distribution rule.

According to Nimbarte and his colleagues' research, the decrease of MPF can be seen as a sign of muscle fatigue, and the negative slope of regression line represents muscle fatigue. (Nimbarte et al., 2014) In this study, the derivative of MPF curve is calculated so that the positive and negative values of the derivative can be used as the indication of fatigue. The derivative of MPF curve is shown in Figure 9. As shown in Figure 9, negative concentration areas of MPF derivatives appear in both regions A and B. The more negative accumulation of MPF derivative, the higher the degree of muscle fatigue in this time area. Hence, the window is set for 5 minutes, and the superposition value of MPF derivative values within 5 minutes is taken as the evaluation standard to calculate the negative aggregation degree.

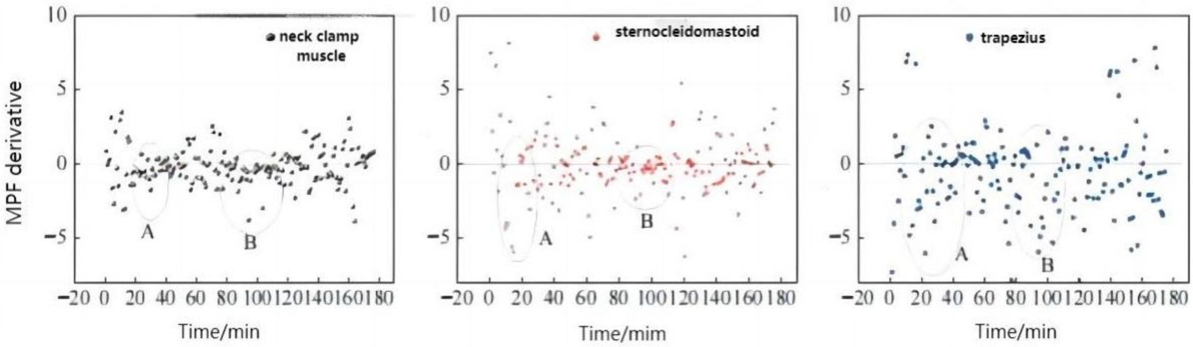

Figure 9: MPF derivative

4. Discussion

According to the time-domain analysis and statistical results, iEMG of sternocleidomastoid muscle increases significantly in the 17th minute, iEMG of neck clamp muscle increases significantly in the 18th minute, and iEMG of shoulder trapezius muscle increases significantly in the 20th minute. It indicates that the iEMG value of the three muscles showed an obvious increasing trend in 15-20 min. According to Wing-wei and his colleagues' research, iEMG increases gradually with the increase of time. With the increase of the duration of neck flexion, the muscles are gradually in a state of tension, the degree of fatigue is aggravated, the number of motor units involved in the movement is gradually increased, the amplitude of electromyographic signal is increased, and the unit energy consumption of muscle movement is increased, resulting in the increase of iEMG. (Ming-wei et al, 2019) The data analysis obtained in this study is consistent with that. Therefore, in summary, the mutation of muscle iEMG can be seen as fatigue state.

According to the analysis of frequency domain results, MPF is not a simple linear relationship. This is because in static muscle fatigue such as neck forward flexion for a long time, the fatigue status is complicated, which not only involves the amount of muscle recruitment, but also involves the proportion of fast and slow muscles in the muscle. Therefore, in order to analyze MPF, the concentration degree of the derivative of MPF curve is used to characterize the degree of muscle fatigue in this research. The graph has shown that different contents of slow and fast muscle fibers in different muscles lead to different MPF values in different muscles (as shown in Figure 8). The data obtained in the experimental are consistent not only with the characteristics of fast and slow muscle fibers, but also with the time period when iEMG changes, which means the accumulation degree of the windowed MPF derivative is an effective indicator of muscle fatigue.

The current research study, although providing valuable insights, is limited by a number of factors that need to be considered in the interpretation of the findings. One major limitation is the small sample size of only 8 men and 8 women, which may not be representative of the broader population. In addition, the experiment was only repeated twice, which could result in deviations and limit the generalizability of the results. Therefore, future studies should aim to increase the sample size and replicate the experiment multiple times to enhance the reliability and validity of the results. Moreover, the current study focused solely on the normal sitting posture during working time, which may not be reflective of other postures and states of individuals. Further research should explore different body postures and states to expand the usability of the conclusions. Furthermore, it is worth noting that there may be measuring errors due to various factors such as dermal resistance. This can lead to inaccuracies in the data collection process, potentially affecting the reliability and validity of the results. Thus, future studies should take these factors into consideration and adopt appropriate measures to minimize the impact of measurement errors. In summary, while the present study provides important preliminary findings, further research is necessary to address the limitations identified in order to fully understand the implications of the results and to extend the conclusions to a broader population.

5. Conclusion

The current research provides an insightful examination of the modifications in surface electromyography (sEMG) characteristics linked to the muscles of the cervical vertebra during a long-term cervical flexion posture. Moreover, the study advances a diagnostic procedure for cervical fatigue, premised on electromyography, which can offer beneficial references and directions for the prevention and future research on cervical fatigue.

(1) The changes of iEMG in long-term neck flexion posture can reflect neck fatigue to some extent, and the increase of iEMG reflects muscle fatigue to some extent. With the aggravation of muscle fatigue, iEMG fluctuation in the later stage is a sign of severe muscle fatigue.

(2) MPF has better nonlinear characteristics. Using the negative derivative accumulation of windowed MPF to determine muscle fatigue has a good evaluation effect.

(3) The cervical fatigue diagnosis procedure based on electromyography can be used for the prevention of cervical fatigue.

References

[1] Cuccia, A., & Caradonna, C. (2009). The relationship between the stomatognathic system and body posture. Clinics, 64(1).https://doi.org/10.1590/s1807-59322009000100011

[2] Swann, J. (2009). Good positioning: the importance of posture. Nursing and Residential Care, 11(9), 467–469. https://doi.org/10.12968/nrec.2009.11.9.43734

[3] Lee, C. I., Kim, J. S., Lee, Y. K., Lim, S. C., Jung, T. Y., Lee, B. H., & Lee, H. J. (2015). A Correlation Analysis of Neck Pain, Neck Disability Index and Fear-avoidance Beliefs in Patients with Neck Pain Caused by Traffic Accidents. The Acupuncture, 32(1), 109– 118. https://doi.org/10.13045/acupunct.2015010

[4] Zhao Y. (2016) The prevalence of cervical spondylosis in young Chinese is higher than that in middle-aged people [J/OL]. People's Political Consultative Conference Network http://www.rmzxb.com.cn/c/2016-01-14/672352. shtml.

[5] Portero, R., Quaine, F., Cahouet, V., Léouffre, M., Servière, C., & Portero, P. (2015). Influence of Cervical Muscle Fatigue on Musculo-Tendinous Stiffness of the Head-Neck Segment during Cervical Flexion. PLOS ONE, 10(9), e0139333. https://doi.org/ 10. 1371/journal.pone.0139333

[6] Al-Angari, H. M., Kanitz, G., Tarantino, S., & Cipriani, C. (2016). Distance and mutual information methods for EMG feature and channel subset selection for classification of hand movements. Biomedical Signal Processing and Control, 27, 24–31.

[7] Ren, Z., & Yang, W. (2015). A Miniature Two-Plate Electrical Capacitance Tomography Sensor. IEEE Sensors Journal, 15(5), 3037–3049. https://doi.org/10.1109/jsen. 2014.2383491

[8] Artz, N. J., Adams, M. A., & Dolan, P. (2015). Sensorimotor function of the cervical spine in healthy volunteers. Clinical Biomechanics, 30(3), 260–268. https://doi.org/10.1016/j.clinbiomech. 2015.01.005
[9] Merletti, R., & Cerone, G. L. (2020). Tutorial. Surface EMG detection, conditioning and pre-processing: Best practices. Journal of Electromyography and Kinesiology, 54, 102440.
[10] Vesa, E. P., & Ilie, B. (2014). Equipment for SEMG Signals Acquisition and Processing. International Conference on Advancements ofMedicine and Health Care through Technology; 5th – 7th June 2014, Cluj-Napoca, Romania, 187–192.