Original Article

Journal of the Tsuruma Health Science Society Kanazawa University Vol. 31 (1)
27～33 2007

Muscle coordination of the upper extremity in sanding motion

Toshiyasu Inumaru, Hiroko Kai*, Munehiro Ikuta, Katsuyuki Shibata, Seiji Nishimura, Hisanori Kojima**

Abstract

In occupational therapy, sanding is a frequently used activity requiring the modifications of muscle weakness or of voluntary contractions in upper extremity muscles. However, many studies of electromyography (EMG) in sanding motions are qualitative, and only a few are assessed as being quantitative. We undertook the examination of muscle coordination during sanding motions, a subject on which no study has previously been reported, and we quantitatively investigated the temporal similarities in muscle activities.

Nine healthy males participated in our study. The muscle activities during sanding motions were measured by surface electrodes in 6 muscles of the upper extremity. The start and end data points of motion were decided by the hand velocity calculated from joint angle data. From the EMG waveform between the interval data points, we calculated the correlation coefficient by a combination of 2 of the 6 muscles. As the conditions of sanding motions, we changed incline boards and weight loads during sanding.

Hypothesizing that muscle coordination is high when high correlation coefficient is obtained, we found a tendency for high muscle coordination to impose performance with a small weight load on a horizontal plane. When the incline board was elevated, there was a tendency for high muscle coordination to impose performance with a heavy weight load.

From the results of this study, we were able to provide important information with which to select the conditions of sanding during the treatment process of voluntary movement recoveries in sanding activities.

Key words

muscle coordination, sanding, electromyography, correlation coefficient

Introduction

In occupational therapy, the sanding activity is used not only to modify the range of motion and muscle weakness, but also to aid the functional recoveries of voluntary movements for patients with cerebral vesicular accidents. Therefore if the muscle activity is to be explored during sanding motions, it becomes medically necessary information in a treatment process of voluntary movement recoveries.

The recovery of motor functions after a stroke typically follows characteristic stages as proposed by Brunnstrom[1]. The early stages are defined by spasticity and stereotypic movement patterns, and the later stages are defined by declines of spasticity and these patterns. In a recent study, Rohrer et al.[2] stated that the movements of stroke patients seem to grow smoother with recovery and suggested that smoothness is a result of learned coordination. We find that not only from the view of movements, but also coordination between muscles is an important factor in

Division of Health Science, Kanazawa University Graduate School of Medical Science
* Kousei Rihabili Hospital
** School of Comprehensive Rehabilitation, Osaka Prefecture University

recovery after stroke. For instance, muscle synergies as the coherent activation, in space or time, of a group of muscles can be treated as a patterned muscle coordination to perform natural motor behaviors. With regard to muscle synergies, d'Avella et al.[3] have investigated muscle synergies in frog leg movements. This group showed that the variety of muscle patterns underlying the control of a natural behavior in an intact animal can be reconstructed as combinations of a small number of discrete elements. These results also reveal that muscle coordination can be treated as combinations between muscles.

As a result of studies by electromyogram (EMG) during sanding motions, Spaulding and Robinson[4] have reported characteristics of EMG patterns in normal, paraplegic, and quadriplegic subjects. Endoh[5] has compared the EMG of healthy subjects with hemiplegic subjects. Also, in an EMG study of muscle coordination, Li and Caldwell[6] examined the neuromuscular modifications to changes in grade and posture during cycling. However, neither healthy subjects nor stroke subjects have shown the investigation on muscle coordination in sanding motions.

The aim of this study is to examine muscle coordination during bilateral sanding motions in healthy subjects. Especially, we calculated the correlation coefficient between two muscle activities during sanding motions and investigated the temporal similarities.

Methods

1. Subjects

The subjects in this experiment were healthy, male university graduate students. Informed consents were obtained from each subject before the experiment. The average age, height, and weight of the subjects were, respectively, 22.2 ± 2.2 (mean ± SD) yr, 170.4 ± 6.3 cm, and 63.2 ± 5.8 kg. The average lengths of the upper arm and the lower arm were, respectively, 30.8 ± 2.9 cm and 24.9 ± 1.2 cm.

2. Apparatus

The desktop-type sanding board (K2270, Minato Medical Science, Japan) was placed on a desk 76 cm high. The subject was seated on a bucket seat 38cm high and the torso of the subject was fixed by a 4-point seatbelt to restrict the movement of the upper body. The distance between the least important end of the sanding board and the subject's chest was set at 10 cm. The surface EMG was used to measure muscle activity. EMG signals were amplified with a time constant of 0.03 s and a 100 Hz high-cut filter (BA1008, TEAC, Japan). After general preparations for adhesive electrodes were completed, surface electrodes (P-00-S, Medicotest, Denmark) were placed on 6 belly muscles in the upper extremity as follows: the anterior deltoid muscle (DAN), the posterior deltoid muscle (DPO), the brachioradialis muscle (BRD), the lateral head of the triceps brachii muscle (TLA), the biceps brachii muscle (BIC), and the long head of the triceps brachii muscle (TLO). The positions of the electrodes were referenced as recommended by Perotto[7]. To measure the angles of shoulder horizontal flexion and elbow flexion, we placed the electrogoniometers (M180, Penny + Giles, UK). EMG and angle signals were recorded on the computer with an AD converter by 200 Hz sampling and 16-bit resolution (DaqBoard 2000, IOtech, USA). DASYLAb 4.0J software (ADTEK System Science, Japan) was used to record all signals.

3. Procedures

Prior to performing sanding motions, we recorded the EMG activities during maximum isometric voluntary contractions, and during rest. The maximum isometric voluntary contraction was executed on the horizontal plane with 45° shoulder planar flexion and 90° elbow flexion in the upper extremities.

The sanding activity was performed 3 times; 1 time dealt with translations to upward and downward directions. We instructed the subjects that these translations were performed in 1 second according to beats of a metronome with 60 Hz. The sanding activities were set at 6 conditions with 3 incline boards and 2 weight loads. The incline boards were set at 0°, 25°, and 45°, the weight loads at 2 and 4 kg. The order of sanding conditions was executed first at the incline board at 0° →25° →90° with a load of 2 kg and then at 0° →25° →90° with a load of 4 kg.

4. Analysis

After sanding motions were recorded, all signals were digitally full-wave rectified, then filtered at 5 Hz by using a 4th -order Butterworth low-pass filter. The EMG activities in sanding motions were normalized by those of the maximum isometric voluntary contractions, as follows:

$$\%EMG = \frac{EMG_{act} - EMG_{base}}{EMG_{mivc} - EMG_{base}} \quad (1)$$

where *%EMG* denotes normalized EMG activities shown by percentage. EMG_{act}, EMG_{base}, and EMG_{mivc} denote EMG activity during sanding motions, during rest, and during maximum isometric voluntary contractions, respectively.

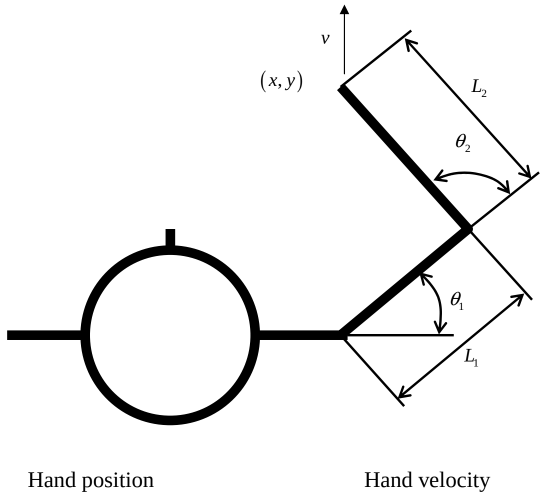
Among applications of sanding motions, we analyzed the second one. The data of this application were selected from changes of velocity at the hand position. From joint angle data from the shoulder and elbow's electrogoniometers, the hand position was calculated by the following equations:

$$\begin{aligned} x &= L_1 \cos\theta_1 + L_2 \cos\theta\,(\theta_1 + \theta_2) \\ y &= L_1 \sin\theta_1 + L_2 \sin\theta\,(\theta_1 + \theta_2) \end{aligned} \quad (2)$$

where x and y are the hand positions to the sagittal and frontal directions, respectively. L_1 and L_2 are the lengths of the upper and lower arm measured from each subject, respectively. θ_1 and θ_2 are the angles of the shoulder horizontal flexion and elbow flexion, respectively, during sanding motions. From the differentiation of equation (2), the hand velocity was found by the following equation,

$$v = \sqrt{\left(\frac{d}{dt}x\right)^2 + \left(\frac{d}{dt}y\right)^2} \quad (3)$$

From the above equation, we found approximately 0 m/s velocity at which sanding motions is stopped, and we selected the data in the interval. Figure 1 shows a schematic diagram of the hand position and hand velocity. As an example of the waveform



$$\begin{aligned} x &= L_1 \cos\theta_1 + L_2 \cos(\theta_1 + \theta_2) \\ y &= L_1 \sin\theta_1 + L_2 \sin(\theta_1 + \theta_2) \end{aligned} \qquad v = \sqrt{\left(\frac{d}{dt}x\right)^2 + \left(\frac{d}{dt}y\right)^2}$$

Figure 1. Schematic diagram of hand position and hand velocity. L_1 and L_2 denote the length of the upper and lower arms, respectively. θ_1 and θ_2 denote the joint angles of the shoulder and elbow, respectively.

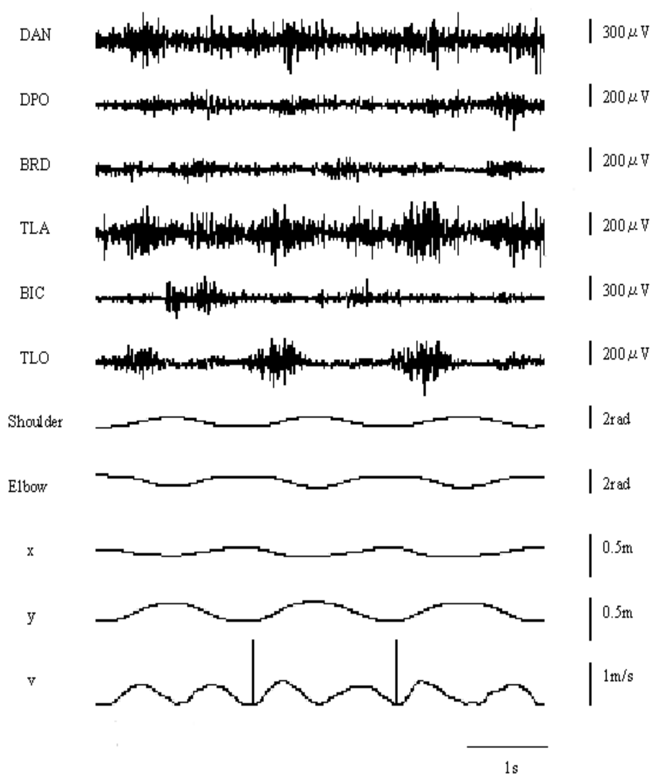


Figure 2. EMG activity and kinematic records during 3 repeatable sanding motions at a 45° incline board and a 4 kg weight load in 1 subject. Abbreviations from DAN to TLO denote EMG activities, Shoulder and Elbow denote joint angles, x and y denote hand positions, and v denotes hand velocity. Two horizontal bars in the hand velocity indicate the approximate 0m/s velocity point for selecting data.

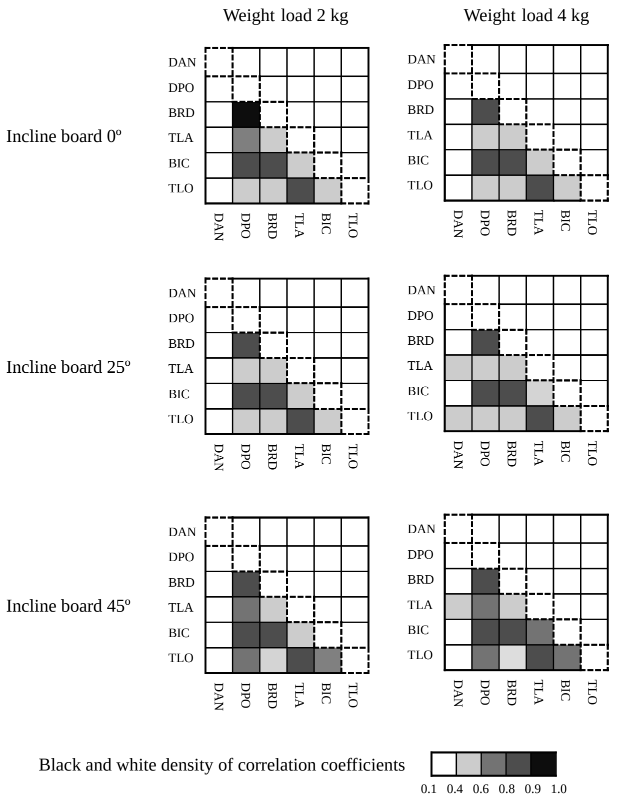


Figure 3. Correlation coefficients of muscle activities. The black and white density in each square denotes the correlation coefficient (r) for the relations between the muscle activities. The correlation coefficients were shown by averaged values for all subjects. Entries below the diagonal denote positive values, whereas entries above it denote negative values.

for selecting, Fig. 2 shows EMG activities and kinematic records in sanding motions.

5. Statistics

Derrick et al.[8] have evaluated time-series data sets by using Pearson's product-moment correlation coefficient, and they have reported that the correlation coefficient is a valid and reliable indicator of temporal similarity. Thus we calculated the correlation coefficient between the EMG activities of 2 muscles to investigate the temporal similarities between muscle activities by the Pearson product-moment correlation coefficient. From combinations for 2 muscle activities among 6, that is, ${}_6C_2$, we obtained a combination of 15 ways. We calculated the correlation coefficient r of 15 ways for each subject's data in the following equation,

$$r=\frac{\sum_{i=1}^{N}(m_{1i}-\overline{m_1})(m_{2i}-\overline{m_2})}{\sqrt{\sum_{i=1}^{N}(m_{1i}-\overline{m_1})^2}\sqrt{\sum_{i=1}^{N}(m_{2i}-\overline{m_2})^2}} \quad (4)$$

where m_1 and m_2 are the muscle activities of muscle 1 and muscle 2 from the combinations of 2 muscle activities, and $\overline{m_1}$ and $\overline{m_2}$ are the mean muscle activities between intervals. N denotes the number of data. After calculating each subject's correlation coefficient, we averaged the correlation coefficient as that of all the subjects. We decided a degree of the correlation from the value of the correlation coefficient as follows: $0.1 \leq r < 0.4$ no correlation, $0.4 \leq r < 0.6$ a moderate degree of correlation, $0.6 \leq r < 0.8$ a marked degree of correlation, $0.8 \leq r < 0.9$ high correlation, and $0.9 \leq r < 1.0$ extremely high correlation.

Results

Figure 3 shows the correlation coefficients of muscle activities at 6 conditions. The black and white density in each square denotes the coefficient (r) for the relations between muscle activities. The coefficients were shown by averaged values for all subjects. Entries below the diagonal denote positive values, whereas entries above it denote negative values. Relations for the values of r are indicated by black and white densities.

As commonly observed features in all conditions, no negative correlations were shown in all combinations for all EMG activities, and correlation coefficients over positive 0.4 were shown in all conditions of BRD vs. DPO, TLA vs. DPO and BRD, BIC vs. DPO, BRD and TLA, TLO vs. DPO, BRD, TLA and BIC. From the view of differences according to each incline board, there is a different correlation coefficient between weight loads of 2 and 4 kg in BRD vs. DPO, and TLA vs. DPO at an incline board of 0°. An extremely high correlation coefficient was shown in a weight load of 2 kg in BRD vs. DPO, and a high correlation coefficient was shown in a weight load of 2 kg in TLA vs. DPO. At an incline board of 25°, there are different correlation coefficients between weight loads 2 kg and 4 kg in TLA vs. DAN, and TLO vs. DAN, and a

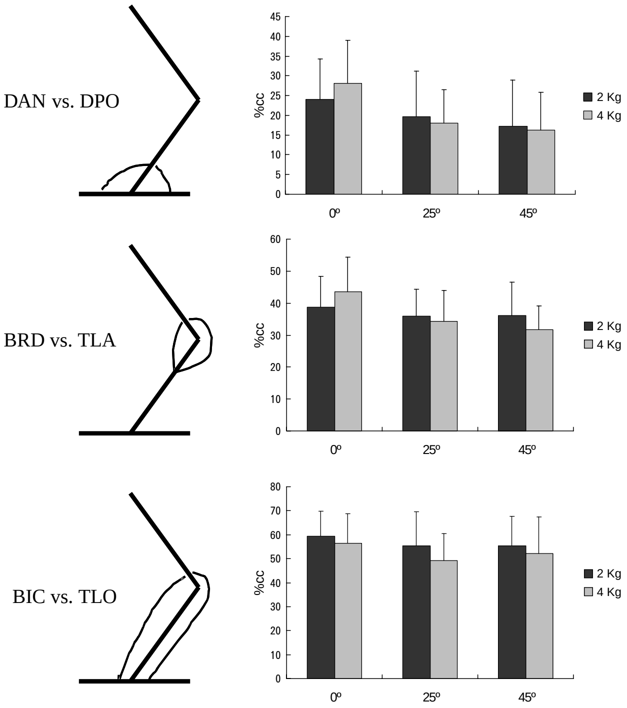


Figure 4. Percentage of cocontraction of muscle activity between agonist and antagonist muscles. Left figures indicate musclo-skeletal drawing of agonist and antagonist pair muscles, and right figures indicate %cc graphed by averaged values and standard deviations.

moderate degree of positive correlation was shown in the weight load of 4 kg. At an incline board of 45°, there are different correlation coefficients between weight loads 2 kg and 4 kg in TLA vs. DAN, and BIC vs. TLA. A moderate degree of positive correlation was shown in the weight load of 4 kg in TLA vs. DAN, and a marked degree of positive correlation was shown in the weight load of 4 kg in BIC vs. TLA.

From the above correlation coefficient, we are able to understand muscle coordination as the temporal similarities in the muscle activity. However, the correlation coefficient might become high, even if the amplitude of the muscle activity is different. Gribble and Ostry[9] have investigated muscle coactivation in point-to-point arm movements and concluded that it may reflect a simple strategy to compensate for forces introduced by multijoint limb dynamics. So to investigate coactivation as limb dynamics in sanding motions, we calculated percentage of cocontraction (%cc) between agonist and antagonist muscles in reference to Winter's equation[10], as follows:

$$\%cc = 2 \times \frac{\int \%EMG_{ago} \cup \int \%EMG_{ant}}{\int \%EMG_{ago} + \int \%EMG_{ant}} \times 100 \qquad (5)$$

where *%EMG* denotes normalized EMG activities calculated by equation 1, and subscripts of *ago* and *ant* denote agonist antagonist muscle. We calculated %cc with regard to DAN vs. DPO, BRD vs. TLA, and BIC vs. TLO. Figure 4 shows percentage of cocontraction of muscle activity between agonist and antagonist muscles of the above muscle combination. In Fig 4, left figures indicate musclo-skeletal drawing of agonist and antagonist muscles, and right figure indicate %cc graphed by average value and standard deviation. Contrasting it with correlation coefficients, at incline board 0°, the %cc became larger in 4 kg weight load than in 2 kg weight load, except BIC vs. TLO. At incline board 25°, %cc became larger in weight load 2 kg than in weight load 4 kg. At incline board 45°, the %cc became larger in weight load 2 kg than in 4 kg. However, no significant differences were shown in each condition for pair muscles by using ANOVA.

Discussion

We analyzed muscle coordination in sanding motions using the coefficient correlation between two muscle activities. According to Derrick et al.[8], the coefficient correlation can be used to evaluate the entire curve as opposed to discrete data points, and high correlation is always indicative of temporal similarity. Therefore we hypothesized that if a correlation coefficient is a high positive value, two muscle activities are in the in-phase mode, and if a correlation coefficient is a low negative value, two muscle activities are in the antiphase mode.

As shown in Fig. 3, the correlation coefficients of BRD, BIC, TLA, and TLO were generally high as a result of this experiment. As for this, we thought that BRD vs. BIC were activated as the elbow joint flexor, and TLA vs. TLO were activated as the elbow joint extensor. Moreover, the combinations of DPO vs. BRD, DPO vs. TLA, DPO vs. BIC, DPO vs. TLO, BRD vs. TLA, BRD vs. BIC, BRD vs. TLO, TLA vs. BIC, TLA vs. TLO, and BIC vs. TLO showed over a moderate degree of correlation for each condition. From this result, we can state that the muscle coordination as in the in-phase mode is necessary for these muscle combinations in sanding motions, regardless of any conditions. In contrast, a negative correlation was not seen in any muscle combination. Thus we clarified that there was no muscle coordination in the antiphase mode, a quite opposite action. In a summary of the results in Fig. 3, there was a tendency in a horizontal plane for high muscle coordination to impose performance with a small weight load. When the incline board was elevated, there was a tendency for high muscle coordination to impose performance with a heavy weight load.

In the previous research of muscle activity in sanding, there were several qualitative studies that investigated only the differences of the waveform in each condition, as reported by Spaulding and Robinson[4]. Although Endoh[5] investigated muscular work, using EMG as the quantitative study, unfortunately only two muscles were examined in the sanding activity, and it cannot be considered as a source for enough information in an EMG study. In this study, we were able to examine muscle coordination by using the correlation coefficient, and we were also able to understand the changes of muscle coordination at different incline boards and weight loads in the sanding activity. Li and Caldwell[6] also have examined muscle coordination using the correlation coefficient during cycling, and they have obtained a quantitative indication of similarity in muscle activity patterns between the conditions.

The correlation coefficient indicates a temporal similarity of waveform in this study to muscle coordination. However, it is impossible to clarify the relationship between agonist and antagonist because of the inefficiency of human movement[10]. Kellis et al.[11] examined the coactivation of the rectus femoris and biceps femoris during drop jumping and assessed an improvement of stability around the knee. Moreover, muscle coactivation can be used to indicate the achievement of a motor skill with a progressive inhibition of muscular activity[12], or it can be used to investigate a simple strategy to compensate for forces introduced by multijoint limb dynamics[9]. Thus we also calculated cocontraction to investigate the strategy of muscle activities or limb dynamics. With the correlation coefficient compared to the percentage of cocontraction, reversal effects were indicated between the correlation coefficient and the percentage of cocontraction in each condition, as shown in Fig 3 and Fig. 4. In a horizontal plane as an incline board of 0°, there are smoothness effects of movement with high muscle coordination and with low coactivation under a condition at small weight loads, except bi-articular pair muscle in BIC vs. TLO. When the sanding board was applied with the inclination, there were smoothness effects of movement with high muscle coordination and with low coactivation under a condition at heavy weight loads. According to Rohrer et al.[2], they have stated that the movement of stroke patients seems to grow smoother with recovery. In conjunction with the results of Fig. 3 and Fig. 4, we are able to understand a smoothness effect of muscle activity in sanding motions. Therefore we consider the results of this study to be important information for selecting the conditions of sanding on a treatment process of voluntary movement recoveries in the sanding activity.

Acknowledgments

The authors express gratitude to the occupational therapists at Kanazawa Nishi Hospital for the use of their desktop-type sanding board.

References

1) Brunnstrom S: Movement therapy in hemiplegia: a neurophysiological approach. Harper & Row, New York, 1970

2) Rohrer B, Fasoli S, Krebs HI, et al: Movement smoothness changes during stroke recovery. J Neurosci 22: 8297-8304, 2002

3) d' Avella A, Saltiel P, Bizzi E: Combinations of muscle synergies in the construction of a natural motor behavior. Nature Neurosci 6: 300-308, 2003

4) Spaulding SJ, Robinson KL: Electromyographic study of the upper extremity during bilateral sanding: Unresisted and resisted conditions. Am J Occup Ther 38: 258-262, 1984

5) Endoh T: An electromyographic study of the upper

extremity during unilateral sanding activities of stroke patients with hemiplegia: effect of slope of sanding board, activity posture, sanding block shape, and block weight. JTHS 3: 191–198, 2000
6) Li L, Caldwell GE: Muscle coordination in cycling: effect of surface incline and posture. J Appl Physiol 85: 927–934, 1998
7) Perotto A: Anatomical guide for the electromyographer : The limbs and trunk. 3rd ed. Charles C. Thomas, Springfield, 1994
8) Derrick TR, Bates BT, Dufek JS: Evaluation of time-series data sets using the Pearson product-moment correlation coefficient. Med Sci Sports Exerc 26: 919–928, 1994
9) Gribble PL, Ostry DJ: Independant coactivation of shoulder and elbow muscles. Exp Brain Res 123: 355–360, 1998
10) Winter DA: Biomechanics and motor control of human movement. John Wiley and Sons, New York, 1990
11) Kellis E, Arabatzi F, Papadopoulos C: Muscle co-activation around the knee in drop jumping using the co-contraction index. J Electromyogr Kinesiol 13: 229–238, 2003
12) Basmajian J: Motor learning and control: a working hypothesis. Arch Phys Med Rehabil 58: 38–41, 1977

サンディング動作における上肢の筋協調

犬丸敏康，甲斐寛子*，生田宗博，柴田克之，西村誠次，小島久典**

要　　旨

作業療法において、サンディングは上肢筋の筋力や随意収縮の改善などで頻繁に用いられる作業種目の一つである。しかしながら、サンディング動作における筋活動の研究は定性的に捉えたものが多く、定量的な評価が少ない。さらに、サンディング動作中の筋の協調性について検討された研究はほとんどない。そこで本研究ではサンディング動作中の筋電図から波形の類似性を相関係数により調査し、サンディング動作における上肢の筋の協調性を定量的に検討した。

健常男性9名を被験者として、サンディング動作中の上肢の6筋から表面電極にて筋活動を計測した。関節角度から求めた手先速度の変化からサンディング動作の開始と終了を決定し、その区間における2筋の組み合わせの筋電図波形から相関係数を計算した。サンディング作業の条件として、傾斜角と重量負荷を変化させた。

相関係数が高いほど協調性が高いと捉えると、水平面では重量負荷が小さい方で協調性があり、傾斜角が上がることによって重量負荷が重い方で協調性が高くなるという傾向があった。

本研究の結果から、我々はサンディング作業の随意運動回復の過程においてサンディングの条件の選択における重要な情報を提示することができた。