Muscle Synergy Analysis in Human Standing-up Motion Using Different Strategies

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Abstract—**Standing-up motion is an important activity which affects people's daily lives. It is necessary to understand the mechanism of standing-up motion to improve physical ability of the elderly. Muscle synergy theory was employed to clarify how humans coordinated muscles to achieve different kinds of standing-up motion. Muscle synergy model was developed to represent muscle activation that generates standing-up motion. The results showed that start time, peak time and amplitude were significantly different among the temporal patterns of the two strategies. These characteristics could be used in explaining how humans generate different standing-up motion.**

I. Introduction

Standing-up motion is an important daily activity. It is necessary to understand the mechanism of different kinds of standing-up motion movements to improve physical ability of the elderly. Hughes and his colleagues defined three strategies used in the standing-up motion: momentum, stabilization and hybrid [1]. This study especially focuses on momentum and stabilization strategies. To clarify the standing-up motion based on muscle activities, the muscle synergy theory [2] is employed. Our previous forward dynamic simulation [3] showed different coordinative structure could generate the three strategies defined by Hughes, but it was not confirmed in real human standing-up motion. Therefore the objective of this study is to verify the characteristics of muscle synergy structure of different strategies of human standing-up motion.

II. Method

In this study, muscle activation can be expressed as a linear summation of spatial pattern and temporal pattern, as in Eq. (1).

$$\mathbf{M} = \mathbf{WC}, \tag{1}$$

where matrices **M**, **W**, and **C** indicate muscle activation, spatial pattern and temporal pattern respectively. Spatial pattern **W** is used to represent the relative activation level of muscle, and temporal pattern **C** is used to indicate the weighting coefficient of muscle synergy. To calculate elements of matrices **W** and **C**, non-negative matrix factorization algorithm [4] is used. Muscle activation matrix is obtained from measurement experiment described in the next section.

III. Experiment

A. Experimental Setting

In this experiment, five healthy male subjects (25.4±2.5 years old) were asked to do standing-up motion using two strategies. A motion capture system (Motion Analysis) with eight infrared cameras was used to get kinematics data of the subject. Surface EMG device (DL-141, S&ME) was used to measure muscle activities. Ten muscles which contribute most in standing-up motion were measured and spatial pattern of muscle synergy is different from muscle activation level. Two force plates (Tec Gihan) were used to obtain the reaction force data.

B. Result

In this study, the coefficient of determination of the two strategies of four muscle synergies were more than 90%. This showed that four muscle synergies could present the muscle activation in standing-up motion.

The results showed that spatial patterns of two strategies were similar. For muscle synergy 1, rectus abdominis was mostly activated to generate momentum for motion. Muscle synergy 2 mainly activated tibialis anterior, which contributed to dorsiflex ankle joint to move forward. Muscle synergy 3 activated erector spine to extend the body and move upward. Muscle synergy 4 mainly activated gastrocnemius and soleus to decelerate movement.

However, parameters of temporal patterns such as start time, peak time and amplitude were different between the two strategies. The start time and peak time were earlier when using momentum strategy. The amplitude of stabilization strategy was larger than that of momentum strategy. These characteristics could be used in explaining how humans generated different kinds of standing-up motions.

IV. Conclusion

This study employed muscle synergy model to analyze how humans generated different kinds of the standing-up motion. The results showed that four muscle synergies could represent muscle activation successfully. In addition, results showed that different strategies had different start time, peak time and amplitudes of temporal patterns.

References

[1] Hughes M. A., Weiner D. K., Schenkman M. L., Long R. M. and Studenski S.A., "Chair rise strategies in the Elderly",Clinical Biomechanics, vol. 9, pp. 187-192, 1994.

[2] Bernstein N., The coordination and regulation of movement, Pergamon, Oxford, 1967.

[3] An Q., Ishikawa Y., Aoi S., Funato T., Oka H., Yamakawa H., Yamashita A. and Asama H., "Analysis of Muscle Synergy Contribution on Human Standing-up Motion Using Human Neuro-Musculoskeletal Model", Proceedings of the 2015 IEEE International Conference on Robotics and Automation (ICRA2015), pp.5885-5890, Seattle (USA), May 2015.

[4] Lee D. D. and Seung H. S., "Learning the parts of objects by non-negative matrix factorization", Nature, vol. 401, pp. 788-791.

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