Muscle Synergy Network during Nursing Care Robot-Assisted Sit-to-Stand Transition

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***Abstract*—This study aims to reveal the muscle synergy-based network when sit-to-stand (STS) was performed with and without nursing care robot assistance. Six subjects participated in the experiment. They performed the STS transition by themselves and with robot assistance. Eight muscular activities were measured. Muscle synergy was extracted using non-negative matrix factorization. An extended Bayesian Information Criterion graphical lasso network was constructed and analyzed. As a result, a different network of muscle synergy during STS transition was observed.**

***Index Terms*—Sit-To-Stand Transition, Nursing Care Robot, Muscle Synergy, Network Analysis**

I. Introduction

Sit-to-stand (STS) transition is an important movement in our daily life and is identified as the most difficult and mechanically demanding activity. However, due to various physical disabilities, people who need support with the STS are increasing. Thus, various STS assistance robots were designed to solve this problem [1].

Because when STS is assisted by a nursing care robot, the robot directly interacts with its users, whether the robot could meet the need depends on the user's performance. The evaluation of the STS robot's effect on humans from a different viewpoint is necessary. In our previous study, the STS nursing robot was evaluated from the center of press, center of mass, motion coordination, and muscle synergy [2]–[5].

Considering that the STS-related muscles do not work independently, and there are different types of muscle synergy during the robot-assisted STS, it is hypothesized that there exists a particular network between different muscle synergy pattern. As a consequence, this study aimed to reveal the muscle synergy-based network when STS was assisted by a nursing care robot. Findings from this study can be expected to provide deeper insight into human-robot interaction for nursing robotics.

II. Methods

Six healthy young volunteers (age: 25.8 ± 2.5 y.o., height: 1.78 ± 0.02 m, body mass: 72.0 ± 8.4 kg) participated in the experiment. None of them reported lower limb pathology, neurological disease, low back pain, or use of medication that may influence motor ability. This study was approved by the Ethics Committee on the Division of Health Science, Graduate School of Medicine, Osaka University (No. 305, 20140821).

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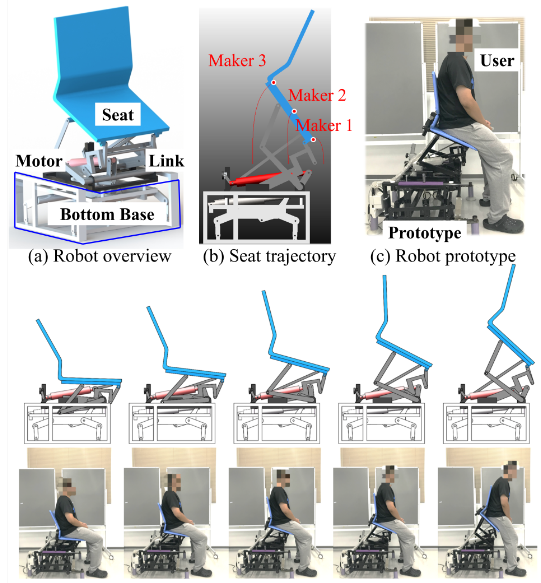

(a) Robot overview (b) Seat trajectory (c) Robot prototype

(d) Robot supported Sit-to-Stand movement

Fig. 1. Overview of nursing care robot for STS assistance.

Fig. 1 (a) illustrates the overview of a STS nursing care robot. This robot mainly consisted of four parts: a seat, four-bar links, a motor, and a bottom base [5]. STS can be supported by the robot seat's vertical and rotation movement. Trajectories of three markers on the robot seat are plotted in Fig. 1 (b). Fig. 1 (c) and (d) depict the prototype of the robot and one example of STS supported by the robot.

Fig. 2 depicts the experiment and measured muscles. To compare the muscle synergy of STS with and without robot support, two experimental conditions were set. We asked all volunteers to sit on the robot with a 43 cm seat height of 80° between crus and feet and performed STS without robot support (Self-STS) and with robot support (Robot-STS) for

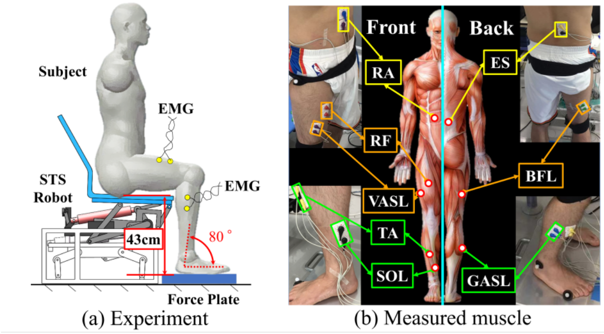

Fig. 2. STS experiment overview.

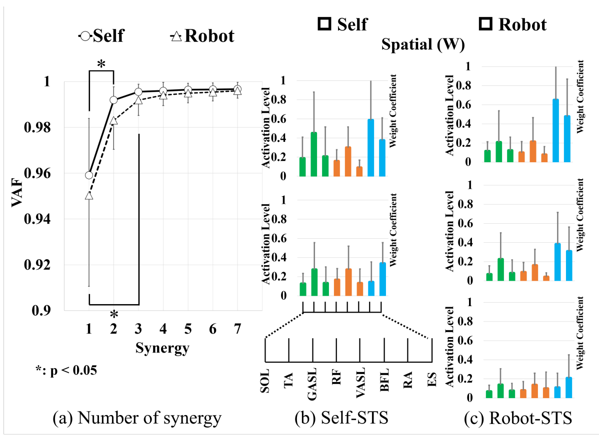

Fig. 3. Results of muscle synergy.

both five times.

Eight muscular activities at RA (upper rectus abdominis), ES (erector spinae), RF (rectus femoris), VASL (vastus lateralis), BFL (biceps femoris long head), TA (tibialis anterior), SOL (soleus), GASL (gastrocnemius lateral head) were measured through surface electromyogram (sEMG). Muscle synergy was extracted from the sEMG using non-negative matrix factorization. Variance accounted for (VAF) was calculated to determine the number of synergies. The spatial pattern of muscle synergy was later used for network analysis.

To reveal the network between muscle synergy, an extended Bayesian information criterion graphical lasso network analysis with 200 non-parametric bootstraps was performed. The tuning parameter λ was set at 0.5. In the network, the spatial synergy pattern was presented by nodes, which were connected by edges that indicate the association between each node.

Difference among spatial pattern of muscle synergy, and the VAF was analyzed using JASP (version 0.16.0.0). Nonparametric one-way and two-way ANOVA were used to ascertain the presence of a significant difference in VAF and muscle synergy. Dun's post hoc comparison was tested. The significant level was defined to be 5%. Network modeling and analysis were performed using JASP network analysis.

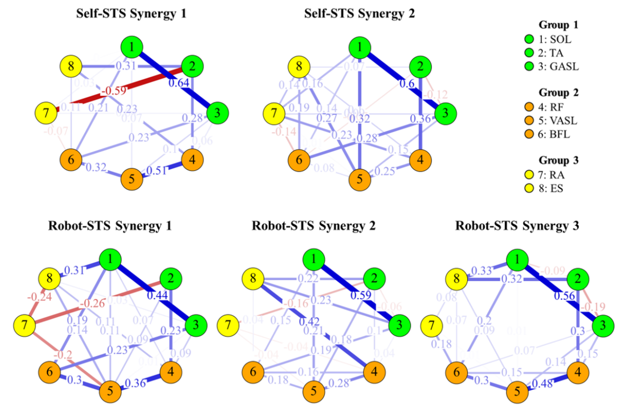

Fig. 4. Results of muscle synergy network.

III. Results and Discussion

Fig. 3 depicts the results of muscle synergy. There were two synergies for self-STS and three synergies for Robot-STS. The spatial muscle synergy showed a significant difference between Self- and Robot-STSs, expected for GASL and ES.

Fig. 4 depicts the muscle synergy network results. For both Self-STS and Robot-STS, network weight between SOL and GASL had the highest value, which indicates nodes 1 and 3 hold the strongest positive correlation (blue and thick lines). TA muscle at Self-STS synergy one and two Robot-STS synergies showed the highest negative correlation between RA (red and thick lines).

The experimental results verified our hypothesis: STS-related muscles worked with coordination and there were particular networks among those muscles. This is the first study that focused on the muscle synergy network during nursing care robot-assisted STS. There are still some limitations in this study. We did not take temporal muscle coordination into consideration, and we did not test the nursing care robot on the older citizens or any patients. Further analysis of the network, e.g. the centrality and similarity are necessary.

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