Effect of Tilted Ground on Muscle Activity in Human Sit-to-Stand Motion: Preliminary Result

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Abstract. In this paper, the aim is to clarify the mechanism of generating muscle activity for sit-to-stand motion by analyzing the relationship between muscle activity and sitting and standing posture. For efficient prevention and rehabilitation of disability in sit-to-stand movement, it is important to understand the control mechanism involved in the movement. To clarify the mechanism, it was hypothesized that the muscle activity involved in sit-to-stand movement is generated using sitting and standing posture as input, and the aim is to define the relationship between posture and muscle activity in sit-to-stand motion. Sit-to-stand motion in flat condition was compared with that in tilted ground condition. Through an experiment for one subject, the muscle activity contributing towards raising the hip and pushing the body forward was higher in the tilted condition than in the normal condition. This implies that human standing posture could be recognized based on the feet.

Keywords: Sit-to-Stand, Muscle Synergy, Posture

1 Introduction

Sit-to-stand motion is an important daily activity as our daily life begins from seated to standing position. However, older people tend to have difficulty in various motions including sit-to-stand [1] motion. To maintain quality of life, it is important to develop methods of prevention or rehabilitation of the disability based on the mechanism of human motion, *i.e.*, when the prevention or rehabilitation assists the human's original bodily function, the prevention or rehabilitation should be effective. Therefore, it is important to clarify the mechanism of sit-to-stand motion.

Sit-to-stand motion is generated by four muscle groups [2] called muscle synergy [3]. The four muscle synergies contribute towards bending the body, raising the hip, extending the body, and stabilizing it. Changing parameters of these four muscle synergies drives various sit-to-stand motion [4]. However, making the adjustment of muscle synergies in sit-to-stand motion is unclear.

Various motions are analyzed based on muscle synergy hypothesis [3]. In muscle synergy hypothesis, humans do not control each muscle from the central nervous system, but rather control muscle groups called muscle synergy. As humans have more joints and muscles to control each joint, it seems to be difficult to control all muscles using the central nervous system. To solve this difficulty, in muscle synergy hypothesis, there would be groups of muscles called muscle synergy. In muscle synergy, muscles in a synergy are controlled by the same motor command from the brain. Using muscle synergy, the central nervous system could easily control many muscles just by controlling small numbers of muscle synergies. Based on this hypothesis, a research to clarify the relationship between visual and vestibular input and muscle synergy in sit-to-stand motion was conducted previously and it was clarified that the visual and vestibular input affect the synergies contributing towards extending and stabilizing the body [5].

Humans also adjust their muscle activity in stabilizing posture or walking. To realize walking in various environments, humans design their muscle activity to control their body based on the environment, their posture, and the direction of gravity [6]. Walking is generated by five muscle synergies [7] and that is adjusted based on the timing of foot contact [8]. Muscle activity in walking is also adjusted by muscle reflex of lower limbs, when the ground is tilted by 2° [9, 10]. The adjustment based on foot contact enable walking in an environment where the ground changes from horizontal to tilt. Stabilizing posture is also enabled by adjusting many muscles based on various sensors such as visual, vestibular, and somatosensory input [11].

In general, muscle activity generation is achieved using two control methods: Feedforward control and feedback control [12]. In the feedforward control method, humans design and adjust their muscle activity before a movement starts. In feedback control, the human adjusts their muscle activity during a movement based on the sensory input. In walking, the five muscle synergies are considered as feedforward control, and the adjustment based on foot contact or the adjustment by muscle reflex is considered as feedback control. In feedback control, for movements mainly using lower limbs such as walking, stabilizing posture, or sit-to-stand motion, humans utilize visual, vestibular, and somatosensory input to achieve the movement [13]. However, feedback control has time delay because of the latency of the nervous system [14]. Therefore, though humans can easily adjust with tiny environmental changes such as when the ground was tilted by 2° [10], they cannot adjust with large environmental changes, without making large movements, for instance when the ground suddenly moves when standing [15]. As sit-to-stand motion ends in approximately one second, the feedforward control should have significant responsibility.

For feedforward control in sit-to-stand motion, available information before starting the motion, to generate muscle activity, is the posture in sitting and imagined posture in standing (Fig. 1). This implies that the muscle activity should be generated based on the postures and other information, such as pos-

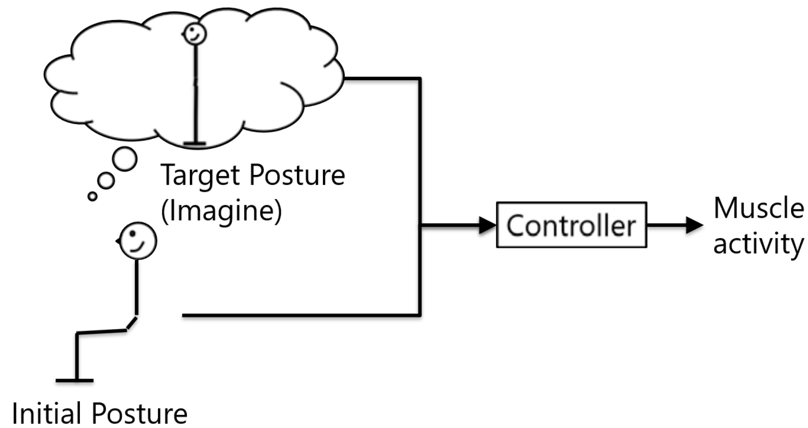

Fig. 1. Hypothesis of feedforward control in sit-to-stand motion. For a feedforward control in sit-to-stand motion, available information before starting the movement, should be posture in sitting and imagined posture in standing. This implies that the muscle activity should be generated based on the postures.

ture between sitting and standing, should not be related to muscle activity in sit-to-stand motion. Based on this hypothesis, this research aims to define the relationship between sitting and standing posture and muscle activity during sit-to-stand motion and uses this to clarify the mechanism of generating muscle activity in sit-to-stand motion. This is achieved by analyzing muscle activity during sit-to-stand motion, when the sitting and standing posture changes. When the sitting and standing posture is changed, the input of the feedforward controller changes. This change should cause a change in the muscle activity. By analyzing the change in muscle activity, changes in the controller or generation of muscle activity, based on sitting and standing posture, can be clarified.

2 Method

2.1 Approach

To define the relationship between sitting and standing postures and muscle activity during sit-to-stand motion, the muscle activity during sit-to-stand motion in normal conditions and the condition with change in posture is compared. As the posture changes, the condition for a subject to perform sit-to-stand motion on tilted ground (Fig. 2) is prepared. The degree of tilt was set at 10°, which was large enough compared to the degree at which humans could adjust using only muscle reflex [10]. As the mechanism of feedforward control in sit-to-stand motion is clarified in this research, the motion in the experiment should not be adjustable by feedback control. Therefore, the feedback control is adjusted by selecting an extremely large degree is selected. Moreover, the subject should be

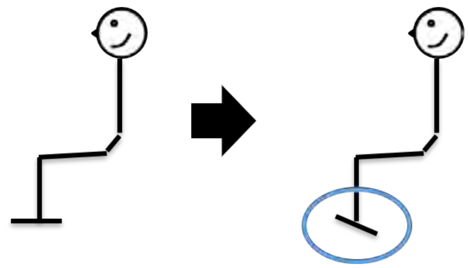

Fig. 2. Sit-to-stand motion in tilt condition. As the condition where sitting and standing postures were changed, tilt condition where the ground was tilted was prepared.

aware of the existence of a tilt. In this tilt condition, a measurement experiment is executed.

2.2 Experimental Procedure

To compare muscle activity in normal and tilt condition, a measurement experiment (Fig. 3) was conducted. The subject moved from a sitting to standing posture using momentum. Muscle activity in the right side of lower limb and body, namely trapezius (TRAP), rectus abdominis (RA), elector spine (ES), external oblique (EO), gluteus maximus (GMAX), gluteus medius (GMED), rectus femoris (RF), vastus medialis (VM), vastus lateralis (VL), biceps femoris long head (BFL), semitendinosus (SEMI), tibias anterior (TA), gastrocnemius medius (GASM), gastrocnemius lateralis (GASL), peroneus longus (PER), and soleus (SOL) was measured. In the experiment, the muscle activity in sit-to-stand was measured motion using surface electromyography (Delsys Trigno System, Delsys Inc.) at 2 kHz. Kinematics data was measured using motion capture system (MAC3D, MotionAnalysis Corp.) and Helen Hayes marker set [16] at 100 Hz, and reaction force data of hip and foot was measured using force plate at 2 kHz (TF3040, TechGihan Corp.). This measurement was conducted for one healthy subject whose age was 20–30.

After measurement, the signals were analyzed according to previous studies [5]. Initially, the period of movement was eliminated using kinematic data. The start of the movement was defined as the time when body started to bend. This was judged by the forward acceleration of the right shoulder marker. The end time was defined as the time when the standing posture was stabilized. This was assessed as the time at which the height of the right shoulder marker reached the top. Then the muscle activity was extracted from surface electromyography data. Initially, the surface electromyography data was filtered through a band pass filter (fourth-order Butterworth filter) between 20 Hz to 500 Hz. Following this, the data was rectified and filtered using a second-order Butterworth filter with a cut-off frequency of 5.3 Hz [17]. Individual muscle activation was normalized based on the maximum activation of all trials under all the conditions. Muscle synergy was then extracted from muscle activity during the entire sit-to-

Fig. 3. Experiment. In this experiment, foot angle is tilted at 10°.

stand movement, using non-negative matrix factorization [18]. Muscle synergies were extracted by determining the number of synergies as four, because previous studies used four muscle synergies to analyze sit-to-stand motion [2, 4].

To compare between the conditions, muscle synergies in the normal and tilted ground conditions were averaged. The timing of each movement based on the hip rise timing was adjusted using force plate data, to average the muscle synergy in each condition.

Finally, to compare between horizontal and tilted grounds, an analytical test was conducted. For spatial patterns, the contribution of muscle activity towards ankle dorsiflexion might be larger in tilted condition because the posture became dorsiflexed. To test this, each activity in each synergy was compared in t test. For temporal patterns, the activity of synergies to push the body forward or backward could be changed in the tilted condition because in this condition, the human body was tilted forward, based on the foot angle. To test this, the highest value of each temporal pattern was compared with the amplitude of the activity. Moreover, in temporal patterns, the timing could change in tilted condition to realize sit-to-stand motion more stably in an unfamiliar environment. If the motion became more stable, the timing and duration of the synergies would change. This was tested by comparing the time when the synergy achieved the highest value, start time, and end time of the synergy. The start and end time were defined as the time when the activity reached or fell by 50 % of the highest value.

3 Result

The extracted muscle synergies are depicted in Fig. 4. The left side depicts spatial patterns showing which muscles were activated in each muscle synergy, the horizontal axis shows the muscles, and the vertical axis shows the activity levels. The right side depicts temporal patterns, activation time of each muscle

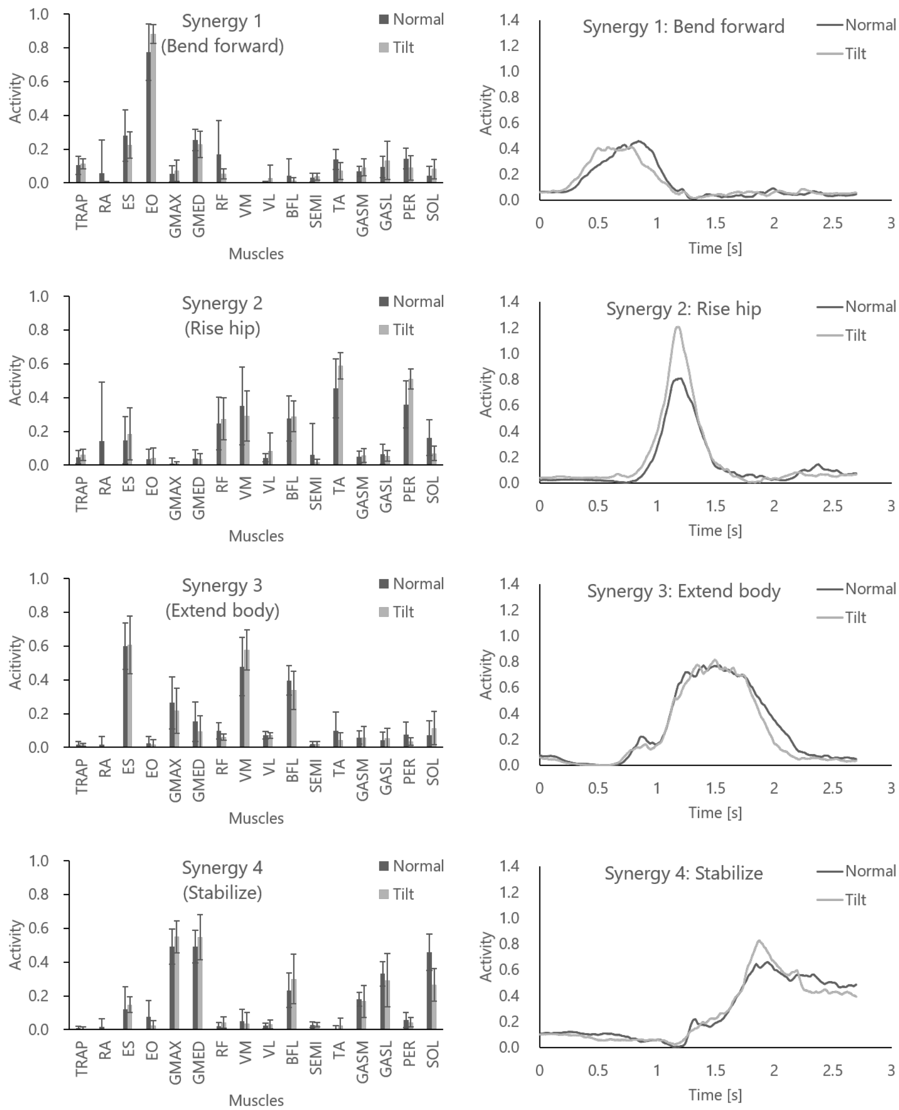

Fig. 4. Extracted muscle synergy. Left side depicts spatial patterns outlining the muscles that are activated in each muscle synergy, and the right side depicts temporal patterns showing the activation time of each muscle synergy. From the top to the bottom, each line raising the shows the contribution of muscle synergy towards bending the body, rise hip, extending the body, and stabilizing. The black line represents normal condition and gray line represents tilted condition.

synergy, the horizontal axis shows the time in seconds, and the vertical axis shows activity levels. From the top to the bottom, each line shows the contribution of muscle synergy towards bending the body, raising the hip, extending the body, and stabilizing. The Black line represents normal condition and gray line shows tilted condition. As the muscle activity was normalized based on the maximum activity of each muscle in all conditions and trials and the muscle synergies were normalized to make the norm of each spatial pattern to be one, the temporal patterns were roughly lower than one.

By the spatial patterns of the extracted synergies, it was revealed that each synergy had their own function, like previous studies [2, 4, 5]. Synergy 1 was responsible for bending forward because external oblique (EO), flexor of lumbar, was mainly activated. Synergy 2 was responsible for raising the hip because tibias anterior (TA), dorsal flexor of ankle, and rectus femoris (RF) and vastus medialis (VM), extensor of knee, were primarily activated. Synergy 3 was responsible for extending the body because the elector spine (ES), extensor of lumbar, and vastus medialis (VM), extensor of knee, were mainly activated. Synergy 4 was responsible for stabilization because gluteus maximus (GMAX) and medius (GMED), extensor of hip, biceps femoris long head (BFL), flexor of knee, and gastrocnemius medius (GASM) and lateralis (GASL) and soleus (SOL), planter flexor of ankle, were activated.

Upon comparison of the muscle activity between normal and tilted conditions, the spatial pattern had no difference. In temporal patterns, the timing of the highest value, start, and end also had no difference. On the other hand, during the highest activity of raising the hip, the muscle synergy was larger in tilted condition than the normal condition. In other synergies, there were no differences in the highest value.

4 Discussion

Through this experiment comparing sit-to-stand motion on horizontal and tilted grounds, it was established that the activity of muscle synergy that contributed towards raising the hip became larger when the subject had to stand on tilted ground than horizontal ground. The synergy that contributed towards raising the hip had the function to move the body forward to raise the hip. This implied that the subject designed the activity of muscle synergy to push his body forward, *i.e.*, in tilted condition, a person might consider the target posture to be pushed forward. Therefore, the posture while standing might be considered based on the foot (Fig. 5).

However, this result was only from one subject, so this result must be deeply analyzed and verified with more subjects. In tilted condition, in addition to the change in posture, other changes appeared causing the area supporting the body to decrease in tilted condition. When the area supporting the body decreases, it would become hard to stabilize the body. This would cause some differences, such as the stability of the center of the mass of the body. However, this was not

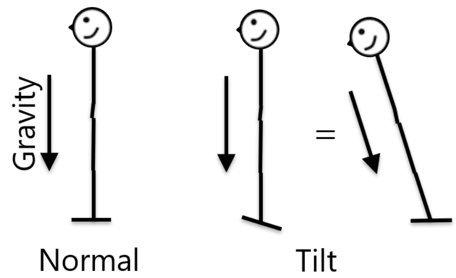

Fig. 5. How human considers the standing posture. The fact that the activity of muscle synergy that contributes to push a body forward becomes larger might suggests that human might consider the standing posture based on foot.

observed. This difference could be observed when the experiment is conducted in more subjects.

Also, this discussion could not completely cover the reasoning of the result in neuroscience aspects. In this research, the sitting and standing postures, which were available information to generate feedforward signal for sit-to-stand motion, were changed before starting the motion. The change of the posture was set at a tilt angle of 10° to avoid observing the feedback mechanism, such as muscle reflex. The tilt of 10° was larger than the degree at which humans could balance, only using muscle reflex [10], which is a feedback mechanism. However, feedback mechanism should always be activated, both in reflex mechanism and central nervous system. Further research to fully understand feedforward and feedback mechanisms are required in the future.

There were some difficulties conducting the experiment based on the ability of subjects. Comparing to the sit-to-stand motion in normal ground against the tilted ground, the result would be affected if a subject were used to standing on tilted ground, for instance, such if the subject often goes to mountains. If a subject were used to being on tilted ground, the subject would already have some ability to control muscles to adapt to a tilted ground. In this case, there might be small differences between the conditions compared to normal subjects. Because of this issue, it may have to be considered that the angle of the tilt was changed for each subject.

5 Conclusion

To clarify the mechanism of generating muscle activity in sit-to-stand motion, the feedforward mechanism of sit-to-stand motion was outlined and compared with sit-to-stand motion on normal and tilted ground, with when the posture was different. As a result, during the activity of raising the hip the muscle synergy became larger in the tilted condition. The synergy also contributed towards pushing the body forward, which might be because the person imagined the standing posture based on the position of the foot. The standing posture on tilted ground becomes forward compared to the posture on normal ground. This result would be verified in more subjects and the effect of skills possessed by the subjects and the tilt angle need to be considered. Moreover, the relationship between kinematics, muscle synergy, and conditions would also have to be discussed.

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