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Original Article

Effects of trunk anterior tilt and knee joint flexion angle changes on muscle activity in the lower limb muscles

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Abstract. [Purpose] We examined the effects of trunk anterior tilt angle (TA) and knee flexion angle (KA) on lower limb muscle activity. [Participants and Methods] Twenty-eight healthy male participants (age, 24.7 ± 4.7 years) performed nine standing tasks with different TA and KA. The participants were instructed to remain still during each task. The nine standing tasks were randomly performed while measurements of muscle activity were obtained for seven muscles: gluteus maximus (GMAX), medial hamstrings (MH), lateral hamstrings (LH), rectus femoris (RF), vastus lateralis (VL), medial gastrocnemius (MG), and soleus (SOL). The activities of these muscles were normalized using isometric grade 3 of the manual muscle testing (isoMMT3). The intra-rater reliability for the mean values of the muscle activities measured with the isoMMT3 (intra-class correlation coefficient with 95% confidence interval) was confirmed using equation ICC (1,3). [Results] GMAX, MH, LH, RF, and MG were affected by both TA and KA, whereas VL was affected by KA, and SOL was affected by TA. [Conclusion] Our findings may facilitate a better understanding of the changes in muscle activity of the lower limb muscles due to differences in TA and KA.

Key words: Electromyography, Muscle activation, Standing position

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INTRODUCTION

Strength training (ST) is frequently performed in a clinical setting[1, 2)]. ST typically combines closed- and open-kinetic-chain exercises to improve overall strength[3)]. The usefulness of closed kinetic-chain exercises (CKCEs) to overcome muscle weakness has been reported in many previous studies[4–6)].

In order to consider a patient's abnormality in CKCEs, it is essential to understand the muscle activity of the lower limb in healthy people. Marchetti et al.[7)] reported the muscle activation of the gluteus maximus (GMAX), vastus lateralis (VL), rectus femoris (RF), vastus medialis, biceps femoris, and semitendinosus muscles during back squats and showed that the muscle activity in GMAX and quadriceps varied with knee position. Caterisano et al.[8)] reported the muscle activity of GMAX, VL, and vastus medialis during three types of squats of different depths (partial squat, parallel squat, and full squat) and described the muscle activity in GMAX, which become progressively more active as squatting depth increased from partial to full. These previous studies showed that changes in lower limb posture alter muscle activity in the lower limb. However, no previous studies have defined both the trunk anterior tilt angle (TA) and knee flexion angles (KA) or examined the muscle activity of lower limb muscles due to changes in these angles in the standing position. These angles may interrelate and affect muscle activation in the lower limb.

When examining muscle activity, it is common to determine the amplitude normalization of muscle activity with a maxi-

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*Corresponding author. Hideaki Muraoka (E-mail: h.muraoka@gmail.com) mal voluntary contraction (MVC)[9–12]. However, it is often challenging to measure MVC due to pain in clinical practice, and MVC might be affected by other factors, such as motivation[13]. A previous study also showed that although normalization to an MVC is commonly used, this is not always possible and may not be the best method for some analyses[14]. A recent study showed that a normalization method inspired by the isometric grade 3 of manual muscle testing (isoMMT3), which is the ability of a muscle to maintain a position against gravity, could be an interesting, feasible, and reliable method that requires no special equipment. We think that the normalization of lower limb muscle activation during isoMMT3 could be useful for pathological populations. Therefore, the purpose of this study was to examine the effect of two factors, TA and KA, on muscle activity in the lower limbs of healthy subjects using isoMMT3.

PARTICIPANTS AND METHODS

In this study, the G*power 3.1 (effect size, 0.25; Power, 0.95) was used to find the sample size and showed that 28 participants were necessary. The participants were 28 healthy males with no orthopedic problems (age, 24.7 ± 4.7 years; height, 171.4 ± 4.8 cm; mass, 60.7 ± 5.41 kg). They had no prior surgery or disease. All participants agreed to refrain from alcohol and resistance training of the legs in the 72 h prior to performing the tasks. They were informed verbally and in writing about the procedures and provided written consent before participating in the study. The study conformed to the Declaration of Helsinki principles, and all appropriate written consent under the law was obtained before beginning this study. The study received approval from the Ethics Committee of Kansai University of Health Sciences, Japan (approval number 18-43).

Before EMG measurements, each participant's skin was prepared by shaving the body hair and cleaning the skin with alcohol to reduce impedance. Following preparation of the skin, disposable Ag/AgCl surface electrodes (Lec Trode NP, Sekisui Kasei Tenri Co. Ltd.) were placed at an inter-electrode distance of 20 mm, parallel to the following muscles on the left leg, and muscle activity data for each of the following muscles were recorded according to SENIAM recommendation as follows[16]: GMAX (the electrodes were placed at locations 50% along the line between the second sacral vertebrae and the greater trochanter); medial hamstring (MH, the electrode was placed at the midpoint on the line between the sciatic tuberosity and the medial epicondyle of the tibia); lateral hamstrings (LH, the electrode was placed at the midpoint on the line between the sciatic tuberosity and the lateral epicondyle of the tibia); RF (the electrode was placed at midpoint on the line from the anterior superior iliac spine to the superior part of the patella); VL (the electrode was placed at a point two-thirds distal on the line from the anterior superior iliac spine to the lateral side of the patella); medial gastrocnemius (MG, the electrode was placed at the point below the knee joint and 2 cm inside the midline of the lower limb); and soleus (SOL, the electrode was placed at a point two-thirds distal on the line between the medial condyle of the femur to the medial malleolus). The shape of the electrodes was rectangular, with a height and width of 18 and 38 mm. In the area surrounding these electrode attachment positions, the muscle belly was confirmed by palpation. The electrode cables were secured to the skin using tape to minimize the stretching of the electrode cables. After attaching the electrodes, it was confirmed that no noise occurred during joint movement. The EMG waveform of each muscle was recorded by a bipolar derivation method using a telemetry EMG device (MQ-8, Kissei Comtech Co.) at a sampling frequency of 1,000 Hz and band-pass filtered at 10–500 Hz. In this study, we used the SENIAM-recommended clinical examination of each muscle to see whether the activity of each muscle was correctly recorded.

The methods to calculate isoMMT3 were similar to those described by Daniels for manual muscle testing. For GMAX, the participants laid prone with the hip joint placed in an extension position, and the knee flexed at 90°. For MH and LH, the participants stood on one leg with hands on a table, with the knee of the tested leg fixed at 90° and hip extended at 0°. For RF and VL, the participants sat on a chair/table with the knee joint placed in an extension position. For MG, the participants stood on one leg and balanced while touching a handrail with two fingers with the ankle joint placed in a plantarflexion position and the knee joint placed in an extension position. For SOL, the participants stood on one leg and balanced while touching the handrail with two fingers with the ankle joint placed in a plantarflexion position and the knee joint flexed at 30°. During isoMMT3, the participants were verbally instructed to hold the test limb with minimal force in order to stabilize the muscle activity.

After that, participants performed the standing task for a total of nine conditions: TA0°-KA0°, TA0°-KA30°, TA0°-KA60°, TA30°-KA0°, TA30°-KA30°, TA30°-KA60°, TA60°-KA0°, TA60°-KA30°, and TA60°-KA60°. To measure TA and KA before performing the nine standing tasks, 8-mm diameter markers were placed on the participant's acromion, the midpoint of the straight line connecting the superior anterior iliac spine to the superior posterior iliac spine (pelvis), the greater trochanter, the lateral epicondyle of the femur, and the lateral malleolus. TA and KA were measured using a goniometer based on the markers as follows: TA was the angle between the line connecting the acromion to the pelvis and the perpendicular line to the floor passing through the pelvis: KA was the angle between the line connecting the greater trochanter to the lateral epicondyle of the femur and the line connecting the lateral epicondyle of the femur to the lateral malleolus. TA and KA were both set to 0° when the two lines were in a straight (Fig. 1). To keep KA constant, the height from the floor to the greater trochanter was measured when the knee joint was flexed to 30° and 60° with the toes aligned before starting the tests. The KA angle was kept as constant as possible using a measuring device created to hold the greater trochanter in a stable position during the three repetitions of the tasks. When the KA was 30° and 60° during these tasks, the ratio of the posterior tilt angle of the thigh in the sagittal axis and the anterior tilt angle of the lower leg was set to be as small as possible. The stipulations

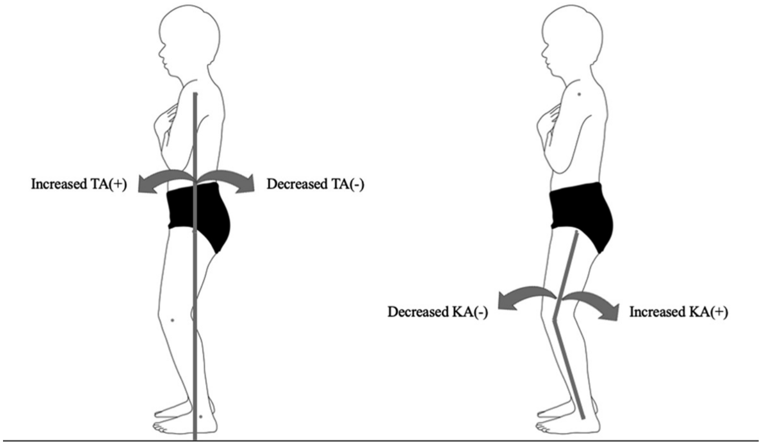

Fig. 1. Definition of TA and KA.
An increase in TA indicates an increase in joint angle, while a decrease in TA indicates a decrease in joint angle. An increase in KA indicates an increase in joint angle, while a decrease in KA indicates a decrease in joint angle.

for the performance of the standing tasks were that both upper limbs should be located in front of the chest; the trunk should always be in an extended position; no trunk or pelvic rotation or internal or external motion of the knee joint should occur; the foot should be placed at 0° with the foot angle in such a position that the long axis of both lower legs is perpendicular to the floor in the frontal plane, and the soles of both feet should be thoroughly grounded on the floor. The participants were visually checked for adherence to these stipulations during the implementation of the nine standing tasks. The order in which tasks were performed was randomized, given that the order of execution would affect subsequent operations. For the isoMMT3 and nine standing tasks, the electromyography (EMG) measurement time was set to 5 s, and the integrated electromyographic values (IEMG) were calculated from the middle 3 s of the stable EMG waveform. Each task was conducted three times, and the mean of the three values was used as the data for each individual. Participants took a 10-s rest between the same muscle test and a 3-min rest between different muscle tests to allow participants to recover from any tiredness. The IEMG of all muscles in nine standing tasks was divided by the IEMG of isoMMT3 and normalized. The means (SD) and 95% confidence intervals (95%CI) of IEMG in all muscles were calculated for the nine standing tasks.

To calculate each joint angle, videos were taken from the side using a digital SLR camera (EOS M6, Canon) during the standing tasks. The video editing app Free Video to JPG Converter was used to convert the measured 5-s video images into 500 still images (every 0.01 s) for each standing task, and any one of the 500 still images could be extracted at will. Then, using the extracted still images, TA and KA were calculated using image processing software (ImageJ Ver. K1.45, Spartan-Coders). During each standing task, it was confirmed that the participants were otherwise stationary. The distance between a participant and the camera during video recording was 500 cm. The participant was positioned at the center of the screen, and the image was taken with the as high optical zoom as possible.

For the statistical analyses, the Shapiro-Wilk test was conducted on all data before testing, and the assumption of normality was confirmed. Because normality was observed in all data, a two-way repeated ANOVA was applied to show the effect of the two factors, TA and KA, on the muscle activity of each muscle. When TA, KA, and interaction were significant, followed by multiple comparison. If one factor and interaction were significant, one-way repeated ANOVA was performed, followed by multiple comparisons for differences between levels of significance were performed. We used Tukey's honestly significant difference test for the multiple-comparison procedure. In addition, an intra-rater reliability of EMG value of each muscle activity measured with isoMMT3, using an intra-class correlation coefficient (ICC) with 95% confidence interval (95%CI), was confirmed using equation ICC (1,3). The reliability ICC was defined as excellent for ICC above 0.75, acceptable for 0.74 >ICC>0.40, and poor for ICC less than 0.39[17]. All significance levels were set at p=0.05, and all analyses were performed using SPSS Statistics Ver. 19 (International Business Machines Co.).

RESULTS

The means (SD) and 95%CI of IEMG for the seven muscles during nine standing tasks are shown in Table 1. In all muscles, the maximum 95%CI for IEMG of each muscle was below 1 for all nine tasks. The mean values of TA and KA in the nine tasks are shown in Table 2. IEMG of isoMMT3, using an intra-class correlation coefficient (ICC) with 95% confidence interval (95%CI), are shown in Table 3. There were excellent reliabilities of IEMG of isoMMT3 in all tested muscles.

Because the two factors TA and KA and their interactions were significant for the IEMG of GMAX, MH, LH, RF, and MG, multiple comparisons were conducted to confirm the changes in muscle activity of each muscle for each TA and KA.

Table 1. Changes in IEMG of seven muscles
The means (SD) and 95%CI of IEMG for seven muscles during nine standing tasks are shown.

A) Changes in I-GM

Task	Mean (SD)	95%CI
TA0°-KA0°	0.072 ± 0.060	0.049;0.096
TA0°-KA30°	0.071 ± 0.040	0.056;0.087
TA0°-KA60°	0.102 ± 0.067	0.076;0.128
TA30°-KA0°	0.098 ± 0.067	0.072;0.124
TA30°-KA30°	0.142 ± 0.761	0.112;0.171
TA30°-KA60°	0.170 ± 0.782	0.139;0.200
TA60°-KA0°	0.096 ± 0.057	0.074;0.118
TA60°-KA30°	0.140 ± 0.074	0.111;0.169
TA60°-KA60°	0.222 ± 0.092	0.186;0.257

B) Changes in I-MH

Task	Mean (SD)	95%CI
TA0°-KA0°	0.112 ± 0.090	0.078;0.147
TA0°-KA30°	0.071 ± 0.040	0.056;0.087
TA0°-KA60°	0.091 ± 0.071	0.064;0.118
TA30°-KA0°	0.417 ± 0.200	0.340;0.495
TA30°-KA30°	0.251 ± 0.149	0.193;0.309
TA30°-KA60°	0.097 ± 0.048	0.079;0.116
TA60°-KA0°	0.454 ± 0.198	0.378;0.531
TA60°-KA30°	0.329 ± 0.154	0.269;0.388
TA60°-KA60°	0.211 ± 0.116	0.166;0.256

C) Changes in I-LH

Task	Mean (SD)	95%CI
TA0°-KA0°	0.087 ± 0.056	0.066;0.109
TA0°-KA30°	0.096 ± 0.081	0.064;0.127
TA0°-KA60°	0.111 ± 0.072	0.083;0.139
TA30°-KA0°	0.309 ± 0.118	0.263;0.354
TA30°-KA30°	0.154 ± 0.126	0.105;0.202
TA30°-KA60°	0.101 ± 0.060	0.078;0.124
TA60°-KA0°	0.377 ± 0.172	0.311;0.444
TA60°-KA30°	0.247 ± 0.176	0.179;0.315
TA60°-KA60°	0.128 ± 0.078	0.097;0.158

D) Changes in I-RF

Task	Mean (SD)	95%CI
TA0°-KA0°	0.082 ± 0.053	0.061;0.103
TA0°-KA30°	0.157 ± 0.064	0.133;0.182
TA0°-KA60°	0.424 ± 0.153	0.364;0.483
TA30°-KA0°	0.060 ± 0.030	0.048;0.072
TA30°-KA30°	0.103 ± 0.039	0.088;0.118
TA30°-KA60°	0.272 ± 0.108	0.230;0.314
TA60°-KA0°	0.056 ± 0.023	0.047;0.065
TA60°-KA30°	0.090 ± 0.038	0.075;0.104
TA60°-KA60°	0.222 ± 0.080	0.191;0.253

E) Changes in I-VL

Task	Mean (SD)	95%CI
TA0°-KA0°	0.044 ± 0.020	0.036;0.052
TA0°-KA30°	0.287 ± 0.146	0.230;0.343
TA0°-KA60°	0.550 ± 0.206	0.470;0.630
TA30°-KA0°	0.041 ± 0.016	0.035;0.048
TA30°-KA30°	0.192 ± 0.098	0.154;0.230
TA30°-KA60°	0.471 ± 0.155	0.411;0.531
TA60°-KA0°	0.040 ± 0.013	0.035;0.045
TA60°-KA30°	0.167 ± 0.118	0.122;0.213
TA60°-KA60°	0.450 ± 0.148	0.393;0.508

F) Changes in I-MG

Task	Mean (SD)	95%CI
TA0°-KA0°	0.093 ± 0.060	0.070;0.116
TA0°-KA30°	0.039 ± 0.012	0.035;0.044
TA0°-KA60°	0.046 ± 0.015	0.041;0.052
TA30°-KA0°	0.280 ± 0.168	0.215;0.345
TA30°-KA30°	0.069 ± 0.053	0.048;0.089
TA30°-KA60°	0.049 ± 0.021	0.040;0.057
TA60°-KA0°	0.423 ± 0.193	0.348;0.498
TA60°-KA30°	0.117 ± 0.089	0.083;0.152
TA60°-KA60°	0.058 ± 0.026	0.048;0.068

G) Changes in I-SOL

Task	Mean (SD)	95%CI
TA0°-KA0°	0.179 ± 0.072	0.150;0.208
TA0°-KA30°	0.175 ± 0.072	0.148;0.204
TA0°-KA60°	0.166 ± 0.111	0.123;0.209
TA30°-KA0°	0.245 ± 0.121	0.199;0.292
TA30°-KA30°	0.295 ± 0.148	0.237;0.352
TA30°-KA60°	0.261 ± 0.146	0.204;0.318
TA60°-KA0°	0.252 ± 0.129	0.202;0.302
TA60°-KA30°	0.301 ± 0.140	0.250;0.352
TA60°-KA60°	0.311 ± 0.173	0.245;0.376

Table 2. The mean value of TA and KA during nine standing tasks

Task	TA (°)	KA (°)
TA0°-KA0°	1.461 ± 0.857	−1.210 ± 2.096
TA0°-KA30°	0.659 ± 1.722	31.066 ± 2.082
TA0°-KA60°	1.270 ± 1.078	58.756 ± 1.677
TA30°-KA0°	29.746 ± 1.160	−1.806 ± 1.543
TA30°-KA30°	31.621 ± 1.822	31.334 ± 2.317
TA30°-KA60°	32.135 ± 1.822	57.994 ± 1.731
TA60°-KA0°	61.113 ± 2.391	−2.904 ± 1.502
TA60°-KA30°	58.908 ± 1.932	30.465 ± 1.718
TA60°-KA60°	58.689 ± 1.964	58.942 ± 1.967

The TA and KA in each task are shown.

Table 3. ICC (95%CI) of IEMG measured with isoMMT3

Muscle	ICC (95%CI)
GM	0.977 (0.958;0.988)
MH	0.959 (0.925;0.979)
LH	0.972 (0.948;0.986)
RF	0.946 (0.903;0.973)
VL	0.961 (0.929;0.980)
MG	0.946 (0.907;0.974)
SOL	0.917 (0.853;0.958)

GMAX activity was not significantly different between different KAs in TA0° condition, but increased at KA60° compared to KA0° in TA30° condition, and increased at KA60° compared to KA0° and KA30° in TA60° condition (Fig. 2, A1). GMAX activity was not significantly different between TA in KA0° condition, but increased at TA30° and TA60° compared to TA0° in KA30° condition, and increased at TA60° compared to TA0° in KA60° condition (Fig. 2, B1).

MH activity was not significantly different between different KAs in TA0° condition, but increased at KA60° compared to KA0° and KA30°, and at KA60° compared to KA30° in TA30° condition, and increased at KA60° compared to KA0° in TA60° condition (Fig. 2, A2). MH activity increased at TA30° and TA60° compared to TA0° in KA0° condition, and at TA30° and TA60° compared to TA0° in KA30° condition, and at TA60° compared to TA0° and TA30° in KA60° condition (Fig. 2, B2).

LH activity was not significantly different between different KAs in TA0° condition, but increased at KA30° and KA60° compared to KA0° in TA30° condition, and increased at KA60° compared to KA0° and KA30°, and at KA30° compared to KA0° in TA60° condition (Fig. 2, A3). LH activity increased at TA30° and TA60° compared to TA0° in KA0° condition, and at TA60° compared to TA0° in KA30° condition, but was not significantly different between different TAs in KA60° condition (Fig. 2, B3).

RF activity increased at TA30° and 60° than at KA0°, and at KA30° than at KA0° in all TA0, 30, and 60° conditions (Fig. 2, A4). RF activity was not significantly different between TA in KA0° condition, increased at TA30° and 60° than at TA0° in KA30° condition, and increased at TA30° and TA60° than at TA0° in KA60° condition (Fig. 2, B4).

MG activity increased at KA30° and KA60° compared to KA0° in TA0° condition, and at KA30° and KA60° compared to KA0° in TA30° condition, and at KA60° compared to KA0° and KA30°, and at KA30° compared to KA0° in TA60° condition (Fig. 2, A5). MG activity increased at TA60° compared to TA0° and TA30° in KA0° condition, and at TA30° and TA60° compared to TA0° in KA30° condition, but was not significantly different between different TAs in KA60° condition (Fig. 2, B5).

VL activity was unaffected by changes in TA, but it increased at KA60° compared to KA0° and KA30°, and at KA30° compared to KA0° (Fig. 3).

SOL activity was unaffected by changes in KA, but it increased at KA30° and KA60° compared to KA0° (Fig. 4).

DISCUSSION

In this study, we normalized the muscle activation of GMAX, MH, LH, RF, MG, VL, and SOL using isoMMT3. We then examined the effects of TA and KA on the activation of each muscle in nine standing tasks with different TAs and KAs. Previous studies have reported no difference in within-day reliability between MVC and subMVIC normalization methods for triceps brachii[18)] and back and abdominal muscles[19)]; the gluteus medius, RF, semitendinosus, and tibialis anterior muscle demonstrated an excellent intra-rater reliability within-and between-day reliability of normalization methods for both isoMMT3[15)]. In this study, there was excellent reliability of IEMG of isoMMT3 in all tested muscles.

In nine standing tasks, the muscle activations of GMAX, MH, LH, RF, and MG were altered by TA and KA, but VL and SOL were not affected by TA or KA, respectively. A previous study reported that GMAX rather than the biceps femoris appeared to become progressively more active as squatting depth increased from partial to full[8)]. As expected, the muscle activity of GMAX, MH, and LH varied with knee joint flexion angle. In KA0°, the muscle activity of MH and LH increased with increasing TA, whereas the muscle activity of GMAX did not increase with increasing TA. This result may have been influenced by the anatomical differences between GMAX and hamstrings. A previous study showed that the GMAX underwent a decrease in the hip extension moment arm with increasing hip flexion angle, while the hamstrings experienced an increase in the moment arm, from 0° to 35° of hip flexion[20)]. MH and LH may have more suitable anatomical features for maintaining hip flexion compared to GMAX. Based on the anatomical differences, MH and LH may be more actively

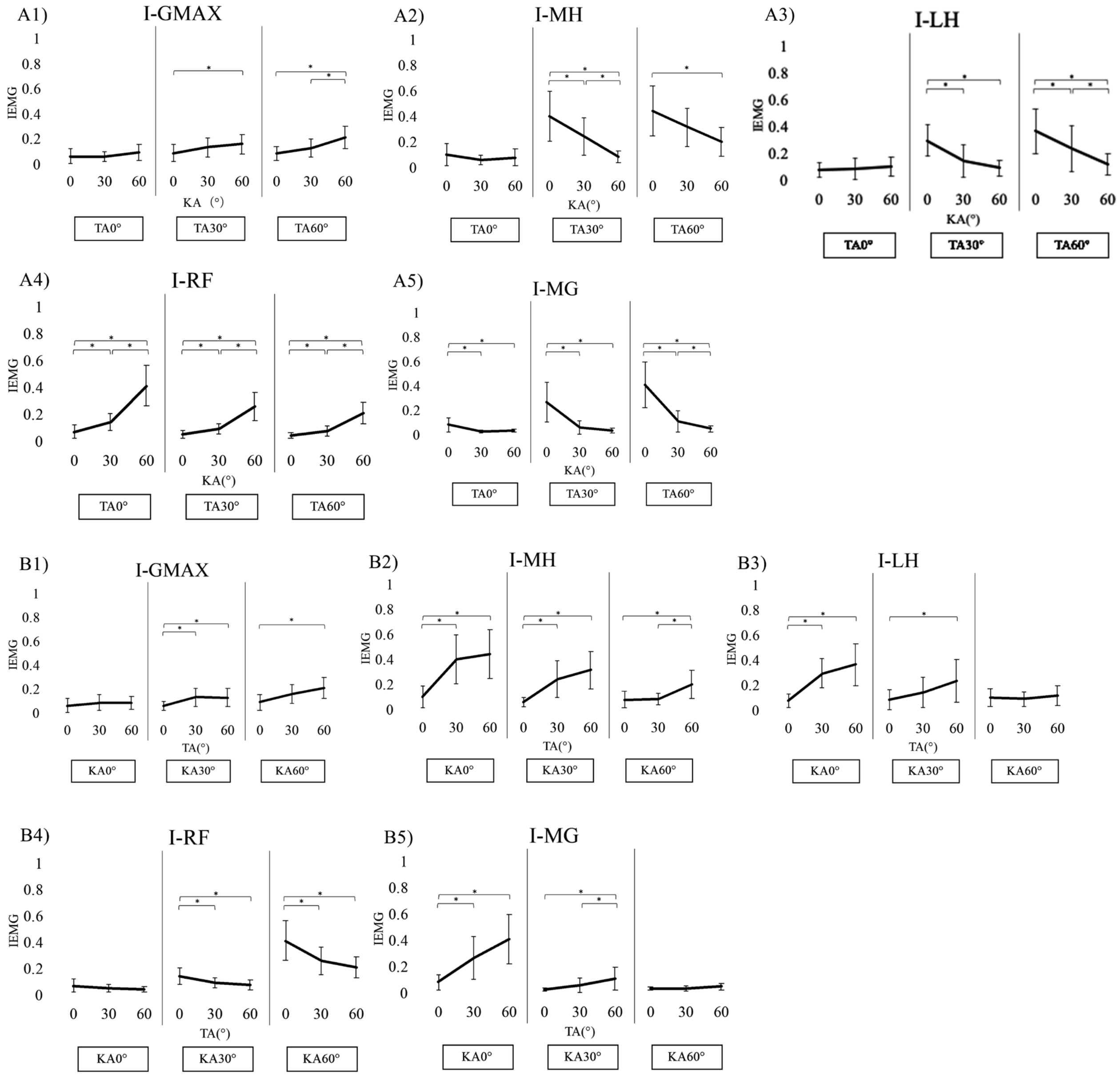

Fig. 2. Changes in muscle activity of each muscle due to differences in anterior trunk tilt and knee joint flexion.
A) Effect of KA change for each TA condition The vertical axis indicates the IEMG of each muscle. The horizontal axis indicates the KA. (*p=0.05)
A1) Changes in I-GMAX
A2) Changes in MH muscle activity
A3) Changes in LH muscle activity
A4) Changes in RF muscle activity
A5) Changes in MG muscle activity
B) Effect of TA change for each KA condition. The vertical axis indicates the IEMG of each muscle. The horizontal axis indicates the TA. (*p=0.05)
B1) Changes in GM muscle activity
B2) Changes in MH muscle activity
B3) Changes in LH muscle activity
B4) Changes in RF muscle activity
B5) Changes in MG muscle activity

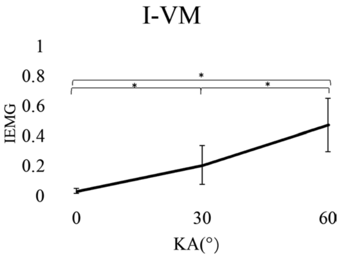

Fig. 3. Changes in VM muscle activity due to differences in KA.

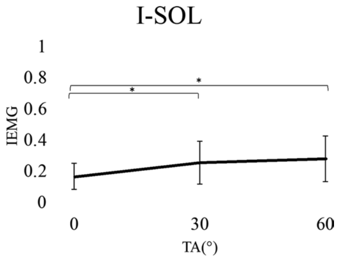

Fig. 4. Changes in SM muscle activity due to differences in TA.

involved than GMAX in keeping the TA. However, MH and LH showed decreased muscle activity with increasing KA at the same TA. These results may have been influenced by the fact that MH and LH have knee flexion actions. We thought that increased MH and LH muscle activity at KA30° and KA60° were inefficient for maintaining the KA and that increased KA reduced the muscle activity. Although the GMAX did not show any increase in muscle activity with increasing TA in the KA0°, GMAX muscle activity increased with increasing TA in KA30° and KA60°. We thought that the hamstrings had difficulty applying the trunk anterior tilt brake in the knee flexion position, which may have led to a compensatory increase in muscle activity in the GMAX. In this study, lumbar flexion was visually checked to ensure it did not occur, although the pelvic tilt angle was not calculated. However, slight differences in pelvic tilt angle may cause differences in the results for the same TA, and care must be taken when applying these findings to clinical practice.

A previous study reported the RF and VL muscle activity in males performing isometric back squats at three KAs (20°, 90°, and 140°). The muscle activity of VL, a mono-articular muscle, showed no difference between 20° and 90°, whereas RF, a bi-articular muscle, was reported to differ between 20° and 90°[7)]. In the present study, both RF and VL activity increased with the increase in KA. In the previous study, weights were used, which may have caused differences in the results from this study. In addition to KA, this present study revealed the effect of both TA and KA on RF and VL: (1) both VL and RF muscle activities increased with increasing KA, and (2) VL muscle activity did not change with increasing TA, whereas RF muscle activity decreased. The previous study showed that biarticular muscles have intermediate activation when the muscles have an agonistic action at one joint and antagonistic action at the other joint[7)]. In clinical practice, we often experience a predominance of muscle activity in RF, a bi-articular muscle, as opposed to in mono-articular muscles. Increasing TA in the knee flexion position may inhibit RF, but although this difference is statistically significant, it cannot be concluded to be of clinical importance.

To the best of our knowledge, there have been no previous reports that defined TA or KA in detail and reported the muscle activity of ankle muscles. In this study, we revealed differences of muscle activity in MG and SOL due to differences in TA and KA. The knee flexion position requires exertion of the knee joint extension muscle. Therefore, the MG with knee joint flexion action may show decreased muscle activity with increasing KA. Besides, the MG exhibited increased muscle activity with increasing TA. As TA increases, the body's center of gravity shifts forward, which may lead to increased muscle activity of the ankle flexor muscle to maintain the ankle position. In the future, to prove this hypothesis, it will be necessary to simultaneously measure the external moments acting on the ankle joint, for example by using three-dimensional motion analysis.

SOL showed no change in muscle activity due to differences in KA. This study confirmed no visually noticeable difference between the posterior tilt of the thigh and the anterior tilt of the lower leg. As a result of the lack of differences between the posterior tilt angle of the thigh and the anterior tilt angle of the lower leg, along with a minimal shift in the body's center of gravity, increased knee flexion angle may not have increased SOL muscle activity. Slight differences in the posterior tilt angle of the thigh and the anterior tilt angle of the lower leg may cause differences in the results of SOL. In the future, the posterior thigh tilt and anterior lower leg tilt angle should be defined in detail and examined using three-dimensional motion analysis and plantar pressure analysis.

There were several limitations to this study. In this study, the intra-rater reliability of isoMMT3 was calculated by normalizing the muscle activity of each muscle, but the inter-rater reliability could not be examined because there was only one person measuring the muscle activity. When measuring KA in this study, the angle of inclination between the thigh and lower leg was checked to ensure that there was as little difference as possible, but an accurate angle was not calculated. In addition, we defined the angle of trunk forward tilt, but did not define the pelvic tilt angle at that time. Although it was visually confirmed that the hips were not bent, a slight difference in pelvic tilt angle may have occurred under the same TA conditions. We cannot deny the possibility that a slight postural change affected the muscle activity. Previous studies have described the potential difficulty of recording consistent muscle activity due to electrode movement on the skin during tasks, as well as the potential for noise to occur as a result of electrode movement[21, 22)]. In addition, muscle activity is affected by joint angle[23)] and contraction speed[24)]. Therefore, in this study, muscle activity was measured at a constant joint angle, but the joint angle change might have affected the muscle activity of the targeted muscles. In addition, during isometric contraction, the position of the muscle fibers remains relatively constant, but may move slightly relative to the electrode due to the elasticity of the tendon[14]. Although there were some limitations, the results of this study showed that TA and KA in the standing position affected changes in muscle activity of the lower limb muscles. In future studies, it may be useful to consider changes in muscle activity of lower limb muscles in the standing position in patients with similar attributes, where measurement of MVC is difficult.

Funding and Conflict of interest

We declare that there is no conflict of interest.

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