Electromyographic analysis of selected muscles in healthy participants wearing knee braces during activities of daily living

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Research Article

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Abstract

<u>Objective:</u>

To investigate the effect of different adjustments of the unloader brace on muscle activity for the vastus medial, biceps femoris, gastrocnemius medialis, and anterior tibialis in the same leg during daily life activity.

Methods:

Twenty-five healthy participants wearing unloaded OA braces (valgus, varus) performed the activity of daily living (ADL) which include 10 meters walking test (10MWT) and stair climbing (STC). Electromyography and anatomic angle data were recorded by the Noraxon system. Seven trials were performed (1) without the brace, (2) with a valgus brace without adjustment (Lv0), (3) with a valgus brace with level 1 adjustment (Lv1), (4) with a valgus brace with level 2 adjustment (Lv2), and the same last 3 measurements for varus adjustments.

<u>Results:</u>

No significant differences were found between the different adjustments in both tests, except in the biceps femoris during the swing phase in the case of stair climbing.

<u>Conclusion:</u>

Knee braces are recommended use for patients who suffer from osteoarthritis (OA), to support their knees. The brace adjustments don't have any effect on muscle activity or knee flexion in case the patient was asked to increase the level of the brace.

1. Introduction

Knee osteoarthritis (OA) is a common degenerative joint disease that leads to loss of function in the knee joint associated with pain and disability (1). The changes in cartilage structure and the narrowing of the joint space cause pain and stiffness for the patients (1). With knee OA the activities of daily living can be affected due to pain and limitations joint limitations. The level of pain increases in the stance phase, while the knee is extended. Knee OA for adults over 55 years of age have been shown to develop knee OA with almost 10% (1–3), almost 90% of these cases are in the medial compartment. This high percentage is due to the fact, that approximately 60% of the total load passes through the medial compartment of healthy knees. As a result of knee OA, the mechanical load will pass medially through the knee more than normal, which will increase the degeneration of the joint. (1, 2, 4). Furthermore, OA was predicted to be one of the leading causes of disability by the year 2020 (5).

Total knee arthroplasty (TKA) is the most common treatment for knee OA. However, this treatment is generally suitable for those with severe OA due to the invasiveness of the procedure, cost, and risk of complications (6, 7). On the other hand, TKA is not always the optimal solution, particularly in young patients. TKA is an unfavorable treatment for active young patients because it increases the risk of surgery revision by two-three times (8, 9). Hence, the importance of non-operative intervention methods increases for patients with knee OA to alleviate pain and improve knee function. At the same time, these methods can postpone TKA. These methods are commonly used by healthcare professionals including intra-articular injections, activity modification, nonsteroidal anti-inflammatory drugs (NSAIDs), wedged insoles, physical therapy, and knee bracing (10, 11).

Various types of knee braces are often prescribed as a non-operative intervention for patients with knee OA. To lessen symptoms and possibly slow disease progression, some braces are designed to reduce forces in either the medial or lateral compartments. The main purpose of these braces is to increase the joint space, which will decrease the load on the affected compartment, which and help to decrease the symptoms (12–14). Numerous studies investigated these knee braces (1, 15–22). The studies investigated the effect of the brace on healthy (17) and patients (16). Also, compared between the brace and wedged insoles (1, 23) or between brace adjustments (adjusted and unadjusted) (20). Furthermore, the studies considered different parameters to evaluate the braces during the trials like joint forces (22), moments (23), range of motion (ROM) (24, 11), pain severity (15), and walking speed (25). One of the interesting parameters in brace studies is muscle activity, which indicates the level of muscle activation during movement with or without a brace. For instance, Ebert et al. (17), used healthy subjects with normal alignment to examine the effect of varus and valgus adjustments of a knee brace (unloaded) on the knee muscle activity and tibiofemoral joint loading. The study reported that there were no differences in kinetic or muscle activity parameters between the braced and no braced conditions. Another study by Ramsey et al. (26) investigated the effect of an unloader knee brace with valgus adjustment on muscle co-contraction and joint instability during gait. As a result of bracing, the study reported that there was a significant reduction in the muscle co-contraction between vastus lateralis-biceps femoris and vastus medialis-semimembranosus. A greater decrease in vastus lateralis-lateral hamstrings co-contraction was been found in participants with greater varus alignment.

Moreover, knee flexion is one of the parameters which can be measured to demonstrate the effect of the brace on the knee joint. A couple of studies had measured the brace's influence on knee flexion. In Lamberg et al (27), the aim was to find out whether a valgus knee brace would change the load in the medial compartment of the OA knee after 2 and 8 weeks of use. The study reported that by wearing the brace the peak knee extension was decreased ($p = 0.006$) during the stance phase. On the other hand, the peak knee flexion ($p = 0.11$) didn’t change during the swing phase. Implementing a knee brace didn’t affect the knee motion. Furthermore, Orshimo et al (28), the study aimed to use an unloader brace with valgus adjustment with patients undergoing cartilage restoration process to reduce the loading on the medial compartment, which can be another solution for these patients instead of non-weight bearing post-operative protocols. The result showed at heel strike the knee flexion wasn’t affected by the brace. On the other hand, in the early stance phase, the peak flexion angle was significantly decreased in the braced condition (28). Three studies out of four investigated the same type of brace (valgus) (28, 27, 26), and the fourth study investigated varus and valgus braces (17). Moreover, all the studies shared the same type of brace 3-point leverage system.

To investigate the effect of different adjustments of the unloader brace on muscle activity for the vastus medial, biceps femoris, gastrocnemius medialis, and anterior tibialis in the same leg during daily life activity. Our hypothesis was that valgus and varus adjustments in an unloaded knee brace will decrease muscle activation and knee flexion.

2. Material And Methods

Subjects:

Twenty-five young healthy participants (14 males, 11 females), adults aged from (20 to 35) years old, without any pathology were included in the study. The mean age of the patients was 26.7 ± 3.4 years, the mean body height was 175.8 ± 9.4 cm and the mean body weight was 74.4 ± 11.2 kg. The mean body mass index (BMI) was 24 ± 2.7 kg/m^2. The following exclusion criteria were established: no previous history of either orthopedic or neurological ailments, such as a recent injury or surgery, which could affect their walking pattern. Furthermore, the right leg has to be the dominant leg.

Measurement setup:

To measure muscle activity and knee flexion, 8 sensors for surface electromyography (sEMG) and 7 inertial measurement units (IMUs) from the MyoMuscle and MyoMotion system (Noraxon U.S.A. Inc., Scottsdale, USA) were used. Four muscles from the right leg were analyzed the knee extensor (vastus medialis), the knee flexor (biceps femoris), the plantar flexor (gastrocnemius medialis), and the dorsiflexor (anterior tibialis). Before the electrodes and corresponding sensors were attached, hair was shaved, and skin was disinfected. The EMG electrodes (Noraxon´s disposable self-adhesive dual Ag/AgCl electrodes) were positioned according to the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) recommendations (Fig. 1), longitudinally over the muscle bellies of the muscles outlined above [28]. The seven inertial sensors were attached to the body with elastic straps or tape based on the guideline instructions, the reference sensor was attached to the sacrum (pelvis). The thigh sensors were attached with elastic straps or tape on the middle of the thigh, the same methods were used with the shank sensors which were attached slightly to the medial side of the tibia, Furthermore, the feet sensors were attached by a clip in the top of the shoes (Fig. 1). The aim of using the IMU system was to measure knee flexion during the different trials.

Figure 1: *EMG and IMU sensors position with the brace*

All participants wore the same knee osteoarthritis brace (Valgus and varus) M.4s OA 3-points pressure valgus - varus osteoarthritis knee brace and the 4-points principle of stabilization (Medi GmbH & Co. KG, Bayreuth, Germany) (Fig. 2). All kinematic measurements were recorded with a sampling frequency of 100 Hz [29].

Figure 2: *The M.4s OA comfort. The brace can be Adjusted in case of Osteoarthritis*

Test procedure:

The measurements took place in the RWTH Aachen University Hospital, Germany. Each measurement lasted approximately one hour and a half. Before starting with the measurements, the participants were asked to perform the calibration procedure for the IMU sensor system, where the participants had to hold a static standing in the upright position (neutral zero joint position). After calibration, the participants were asked to perform the two following tests: 10-meter walking test (10MWT), and stair climbing (STC). To minimize the number of external influences and boundary conditions participants were asked to maintain their walking speed instead of a default speed. Hence, the only difference in the next step was the addition of the brace. The 10MWT was conducted in a hallway in the hospital. Regarding the STC, the participants performed on seven stairs with dimensions of 26 x 84 x 19 cm. The study analyzed the stance and swing phases in 10MWT and STC. Each test was performed with 7 trails with different levels: without the brace (WOB), valgus brace without adjustment (Lv.0), valgus brace with adjustment level 1 (LV.1), valgus brace with adjustment level 2 (Lv.2), and the same order for varus adjustments. The two levels were identified with the rotation of the hinges above and below the knee joints in the braces; level one was identified with ¾ of the rotation and level 2 was identified with a full rotation of the hinges on both braces (29). To avoid bias in repeated measurements, with each participant the sequence of the trails was changed.

Data processing:

The measured data were systematically processed, and relevant parameters were extracted. The MyoMuscle (Clinical DTS version) measure with an initial sampling rate of 3000Hz transmits pre-processed smoothed and rectified EMG data (100ms RMS), shown as a unipolar positive signal (30). A bandpass filter was used (10-500Hz) with a 100Hz wireless update rate to the receiver. For this data, we used the Peak value (1000ms) for amplitude normalization to be able to compare the measurements with different levels and on both sides (31). By using peak value, the EMG data (measured in μV) were normalized to % of the mean muscle activity.

The MyoResearch Software (version MR 3.12, Noraxon U.S.A. Inc., Scottsdale, USA) provides the “Contact Mode” option, which can automatically detect the initial and terminal contact of each foot based on the acceleration data of the IMUs placed on the feet during walking and stair climbing (32). The muscle activity and anatomical angles regarding the gait cycle can be analyzed from this option. The continuously measured data (normalized muscle activity and anatomic angle) were split into strides, and for each stride, the x-axis (time-axis) was normalized to the gait cycle (in percent). The data of each gait cycle were interpolated to 100 points and the mean over 2 strides was calculated for all measured variables. The mean muscle activities and joint angles over the gait cycle of all participants for the different test conditions were presented with the help of MATLAB (MathWorks R2019a, MathWorks, Natick, MA, USA).

Statistical analysis:

Statistical analyses were performed using the software IBM® SPSS Statistics (IBM® SPSS Statistics v. 25, IBM Cooperation). The normal distribution of the dependent variables was examined using the Shapiro-Wilks test and was not confirmed for most variables. Therefore, nonparametric tests were used. To evaluate the effect of wearing the brace, the Wilcoxon test was used to compare results between WOB and LV0 measurements. The effect size r is equal to (Eq. 1)

$$r = \frac{z}{\sqrt{N}} \qquad \textit{Equation 1}$$

(with z-value from the associated Wilcoxon test and N as the number of pairs). It is presented as the coefficient of determination r^2, explaining the collective variance of the analyzed variables. To compare the different levels of the brace, the Friedman test was calculated with pairwise Post Hoc analysis and the brace adjustments as the independent variables. There were three groups: Lv0, Lv1, and Lv2 brace adjustment. The pairwise comparison was prepared only in case of significant results. Statistically significant differences were set at $p < 0.05$.

3. Results

Appendix 1 and 2 demonstrate the descriptive statistics of the minimum, maximum, mean, and standard deviation of muscle activation of (vastus medialis, biceps femoris, gastrocnemius medialis, anterior tibialis) and angles of the knee flexion during walking (10MWT) and stair climbing (STC) while wearing valgus and varus braces.

The brace and the changes it causes

In Table 1, the statistical comparison (Wilcoxon test) showed significant differences between Lv0 of both braces and the WOB in many parameters. The valgus brace had a significant reduction which was in the swing phase while walking test in the knee flexion and the stance phase while stair climbing in vastus medialis. Furthermore, the significant increase was in the swing phase while stair climbing in vastus medialis and anterior tibialis. On the other hand, the varus brace had a significant reduction during walking, which was in the stance phase on two occasions, the first was in vastus medialis, and the second was in knee flexion. Moreover, a significant reduction was in walking during the swing phase in knee flexion. In the stair-climbing test, a significant increase was in vastus medialis during the stance phase. In contrast, a significant reduction was in the biceps femoris during the stance phase.

Table 1
Statistic results of the Wilcoxon test used to compare between the measurements taken without a brace and the brace in an Lv0 position of both braces

Parameter / Level			N	Median%		z	P-Value significance (2-tailed)	Effect size r^2 in %
				Without	**With**			
Sagittal plane	**Valgus Walking**	Vastus. Medialis (Stance)	25	81.2	77.5	-1.870	0.061	37.4
		Vastus. Medialis (Swing)	25	52.7	54.7	-0.955	0.339	19.1
		Biceps. Femoris (Stance)	25	60.9	67.4	-0.390	0.696	7.8
		Biceps. Femoris (Swing)	25	67.2	70.2	-0.498	0.619	7.0
		Gastrocnemius. Med (Stance)	25	90.4	82.7	-0.848	0.148	17.0
		Gastrocnemius. Med (Swing)	25	35.9	45.7	-1.171	0.241	23.4
		Anterior. Tibialis (Stance)	25	70.3	68.1	-1.224	0.221	24.5
		Anterior. Tibialis (Swing)	25	71.3	69.1	-0.309	0.757	6.1
		Knee flexion (Stance)	25	11.0	10.1	-1.305	0.192	26.1
		Knee flexion (Swing)	25	44.3	43.3	-2.112	0.035	42.2
	Valgus STC	Vastus. Medialis (Stance)	25	94.5	81.4	-2.408	0.016	48.2
		Vastus. Medialis (Swing)	25	24.5	35.3	-2.960	0.003	59.2
		Biceps. Femoris (Stance)	25	59.6	61.1	-1.682	0.093	33.6
		Biceps. Femoris (Swing)	25	78.1	74.2	-0.229	0.819	4.6
		Gastrocnemius. Med (Stance)	25	91.5	80.2	-0.686	0.493	13.7
		Gastrocnemius. Med (Swing)	25	39.7	41.0	-0.700	0.484	14.0
		Anterior. Tibialis (Stance)	25	54.4	50.7	-1.413	0.158	28.3

	Anterior. Tibialis (Swing)	25	91.8	97.5	-2.112	0.035	42.2
	Knee flexion (Stance)	25	40.7	38.8	-0.458	0.647	9.2
	Knee flexion (Swing)	25	73.3	86.0	-1.117	0.264	22.3
Varus Walking	Vastus. Medialis (Stance)	25	81.2	64.9	-2.462	0.014	49.2
	Vastus. Medialis (Swing)	25	52.7	61.2	-1.117	0.264	22.3
	Biceps. Femoris (Stance)	25	60.9	60.7	-0.807	0.420	16.1
	Biceps. Femoris (Swing)	25	67.2	73.0	-0.013	0.989	0.3
	Gastrocnemius. Med (Stance)	25	90.7	80.1	-0.148	0.882	3.0
	Gastrocnemius. Med (Swing)	25	35.9	37.1	-0.498	0.619	9.9
	Anterior. Tibialis (Stance)	25	70.3	63.9	-1.197	0.231	23.9
	Anterior. Tibialis (Swing)	25	71.3	76.7	-0.296	0.767	5.9
	Knee flexion (Stance)	25	11.0	10.7	-1.965	0.049	39.3
	Knee flexion (Swing)	25	44.3	42.1	-2.288	0.022	45.8
Varus STC	Vastus. Medialis (Stance)	25	94.5	87.6	-1.574	0.115	31.5
	Vastus. Medialis (Swing)	25	24.5	34.8	-3.135	0.002	62.7
	Biceps. Femoris (Stance)	25	59.6	65.6	-2.153	0.031	43.1
	Biceps. Femoris (Swing)	25	78.1	83.6	-1.520	0.128	30.4
	Gastrocnemius. Med (Stance)	25	91.5	87.4	-0.013	0.989	0.3
	Gastrocnemius. Med (Swing)	25	39.7	40.7	-1.682	0.093	33.6
	Anterior. Tibialis	25	54.4	49.2	-0.928	0.353	18.6

	(Stance)						
	Anterior. Tibialis (Swing)	25	91.8	96.6	-1.345	0.178	26.9
	Knee flexion (Stance)	25	40.7	40.6	-0.619	0.536	12.4
	Knee flexion (Swing)	25	73.3	70.2	-1.170	0.242	23.4

Table 1: *Statistic results of the Wilcoxon test used to compare between the measurements taken without a brace and the brace in an Lv0 position of both braces.*

The effect of the brace adjustments

To show the effect of different brace adjustments in the sagittal plane, the brace was tuned to (Lv1) and (Lv2) valgus or varus. This demonstration shows the pattern of the mean curves of muscle activity (vastus medialis, biceps femoris, gastrocnemius medialis, anterior tibialis) and knee flexion during walking (Fig. 3) and stair climbing (Fig. 4) for the right leg over one gait cycle while wearing the brace with different levels.

Figure 3:*The pattern of the mean curves of the muscle activities for the four muscles vastus medialis (A), biceps femoris (B), gastrocnemius medialis (C), anterior tibialis (D), and the knee flexion (E) for the right leg during walking.*

Figure 4: *The pattern of the mean curves of the muscle activities for the four muscles vastus medialis (F), biceps femoris (G), gastrocnemius medialis (H), anterior tibialis (I), and the knee flexion (J) for the right leg during stair climbing*

Returning to the muscle activation during the gait cycle in Figs. 3 and 4, the muscle activation pattern of the vastus medialis in walking and stair climbing showed a reduction in all adjustments during the stance phase in comparison with WOB. In contrast, the figures showed an increase during the swing phase in both tests. For the biceps femoris, the figures showed that there is an increase in the muscle activation pattern for all adjustments in comparison with WOB. For gastrocnemius medialis during walking, all the adjustments showed slightly lower values in comparison with WOB in the stance phase, in the swing phase the pattern of it showed higher values. The same situation with stair climbing. For anterior tibialis, in both tests, the pattern for all adjustments was slightly higher than the WOB during the stance phase and lower in the swing phase. The knee flexion in both tests during stance and swing phases were almost equal.

We were able to analyze the effect of the different levels of the brace adjustments on one gait cycle, by comparing the obtained measurements for the adjustments Lv0, Lv1, and Lv2 in valgus and varus. In valgus adjustments, no significant effect was found for the brace on the mean of the parameters in the sagittal plane during walking and stair climbing in both phases. On the contrary, the varus adjustments led to one significant change in biceps femoris activity (Table 2). A significant decrease in the muscle activity while performing with the brace Lv2 in comparison with Lv0 in the swing phase during stair climbing $p = 0.022$.

Table 2
Statistic results of the Friedmann-Test of analyzing the effect of the varus brace on biceps femoris

Brace adjustment	**Trail**	**Parameter**		**N**	**Chi-Square**	**Sig.**	**Post hoc pairwise comparison: Sig**		
							Lv0 VS Lv1	**Lv0 VS Lv2**	**Lv1 VS Lv2**
Varus	Stair climbing	Swing phase	Biceps femoris	25	7.280	0.026	0.774	0.022	0.359

Table 2: *Statistic results of the Friedmann-Test of analyzing the effect of the varus brace on biceps femoris.*

4. Discussion

Unloader knee braces have been recommended as a treatment guideline for all knee OA (15, 33, 34). This study provides information about muscle activity for the lower extremity while wearing a knee brace during walking and stair climbing. Our hypothesis contradicted the results that the brace adjustments decrease muscle activity.

The results showed that wearing a knee brace has a significant reduction in the biceps femoris in the swing phase during stair climbing between varus adjustments Lv0 and Lv2. This result could be related to the varus brace structure, which applies an adduction pressure on the knee, this will decrease the muscle activity on the lateral side of the leg during the swing phase while stair climbing. This reduction in muscle activity could lead by time to muscle weakness because the muscle doesn’t function naturally as it has to be (35).

No other significant values were found between the brace adjustments whether in valgus or varus. Our results corresponded with (17, 20). At Ebert et al. (17), participants with normal knee alignment were recruited, the investigation was on the effectiveness of valgus-varus unloader knee brace adjustments on knee muscles activation and tibiofemoral loading. The result showed that in kinetic and muscle activity parameters, there were no differences between the braced and no braced conditions. On the other hand, Hart et al. (20) the immediate effects of a varus unloader knee brace on lower limb electromyographic activity was investigated in subjects with valgus malalignment and lateral knee OA and after anterior cruciate ligament reconstruction. Also, the results showed that there were no significant differences in muscle co-contraction between the three test conditions. Our results contradicted with study results of

Ramsey et al. (26). the aim was to investigate the level of control joint instability and muscle co-contraction influence of valgus knee brace during gait. The results showed that there was a significant reduction in the co-contraction muscles between vastus lateralis-Biceps femoris and between vastus medialis-semitendinosus. Participants with higher varus alignment showed higher decreases in vastus lateralis-biceps femoris co-contraction.

In previous studies, we found that they investigated knee flexion (18, 36). Our results also contradicted the results of Hart et al, and Ota et al. Ota et al (36) investigated the effect of the custom-made brace compared to the hinged brace. The study reported there were significantly large peak knee flexion angles during the swing phase with custom-made knee brace more than the hinged knee brace. The study of Hart et al [18], aimed to determine the immediate effects of a varus unloader knee brace on gait biomechanics in people with lateral knee OA and valgus malalignment after anterior cruciate ligament reconstruction (ACLR). The study reported that there was a significant increase in the peak knee flexion angle in the adjusted brace in comparison with no brace.

There exist some limitations in our study. Contrary to previous studies, we included healthy participants to analyze instead of patients. Therefore, we were able to analyze the effect of the brace and different brace adjustments on muscle activity. Furthermore, the signal recording wasn't optimal in a couple of trials, especially the ankle records due to the surrounding environment in the hallway in the University Hospital (cables underground, neon lights, metal, and wifi signal. Moreover, we had to take out one of the frontal straps, which was located over the knee since we couldn't attach the EMG sensors and the electrodes for the vastus medialis. The plan is to work on patients suffering from OA.

5. Conclusion

Knee braces are recommended use for patients who suffer from OA, to support their knees. The brace adjustments don't have any effect on muscle activity or knee flexion in case the patient was asked to increase the level of the brace. Also, based on the results and as a precautionary measure its recommended to add strength exercises for the patients to prevent any muscle weakness that could happen due to the brace in the future.

Abbreviations

ADL
activity of daily living
10MWT
10 meters walking test
STC
stair climbing
WOB
without the brace

Lv0
with a brace without adjustment
Lv1
with a brace with level 1 adjustment
Lv2
with a brace with level 2 adjustment
OA
osteoarthritis
TKA
total knee arthroplasty
NSAIDs
nonsteroidal anti-inflammatory drugs
ROM
range of motion
BMI
body mass index
sEMG
surface electromyography
IMUs
inertial measurement units
ACLR
anterior cruciate ligament reconstruction.

Declarations

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Author's contributions

Conception and design: Alrawashdeh.

Acquisition of data: Alrawashdeh, Siebers

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The authors read and approved the final manuscript.

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Availability of data and materials

The data that support the findings of this study are available from RWTH University Hospital, Aachen. But restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of Waleed Alrawashdeh.

Ethics approval and consent to participate

The study measurements were carried out based on RWTH university hospital regulations and guidelines. Moreover, this study was approved by the Medical Ethical Committee (Ref. No. EK 121/17) of the University Hospital RWTH Aachen, and a signed informed consent form was obtained from each subject.

Consent for publication

Not applicable.

Conflict of interest

There is no conflict of interest between the authors

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Figures

Figure 1

EMG and IMU sensors position with the brace

Figure 2

The M.4s OA comfort. The brace can be Adjusted in case of Osteoarthritis

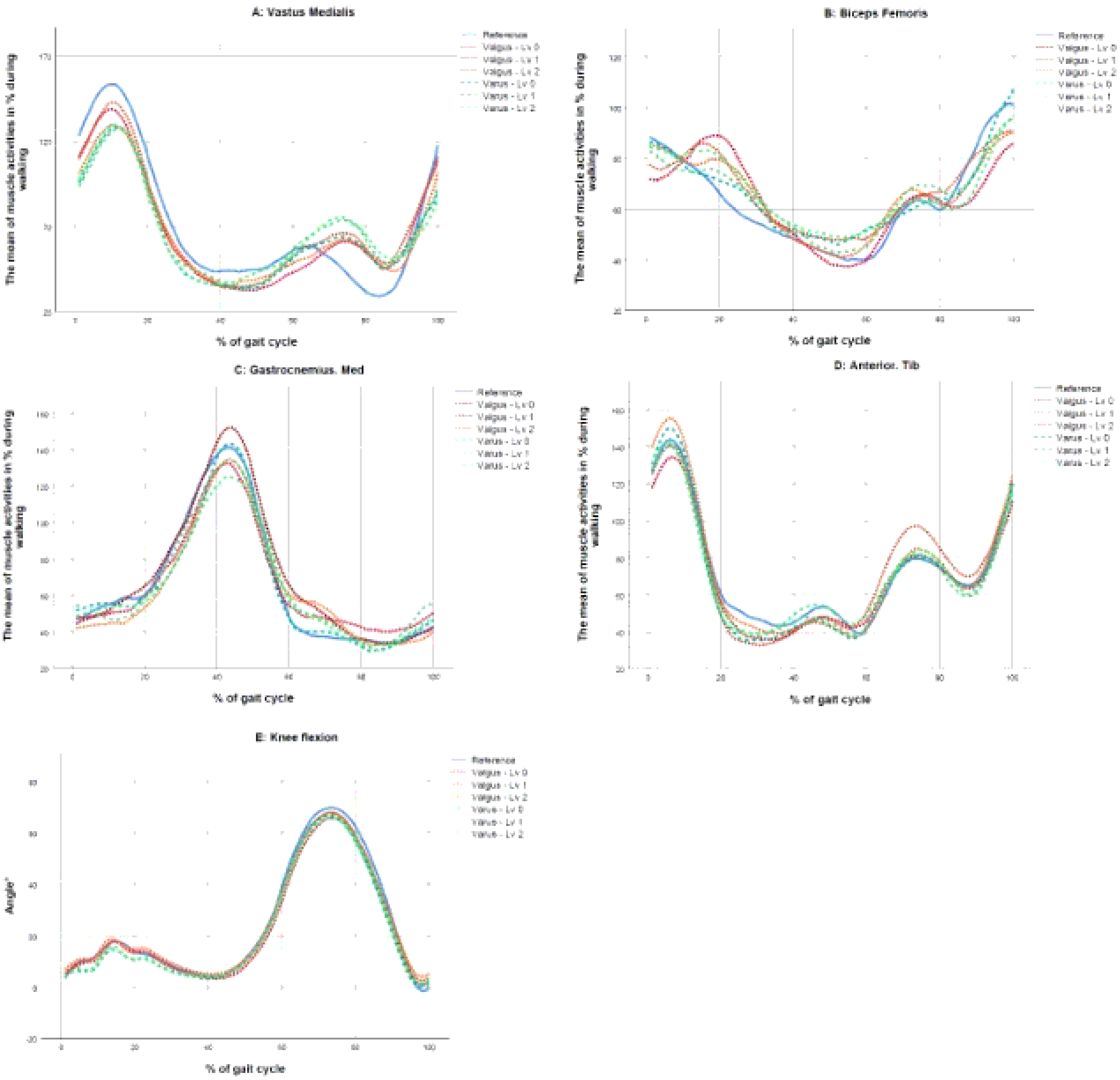

Figure 3

The pattern of the mean curves of the muscle activities for the four muscles vastus medialis (A), biceps femoris (B), gastrocnemius medialis (C), anterior tibialis (D), and the knee flexion (E) for the right leg during walking.

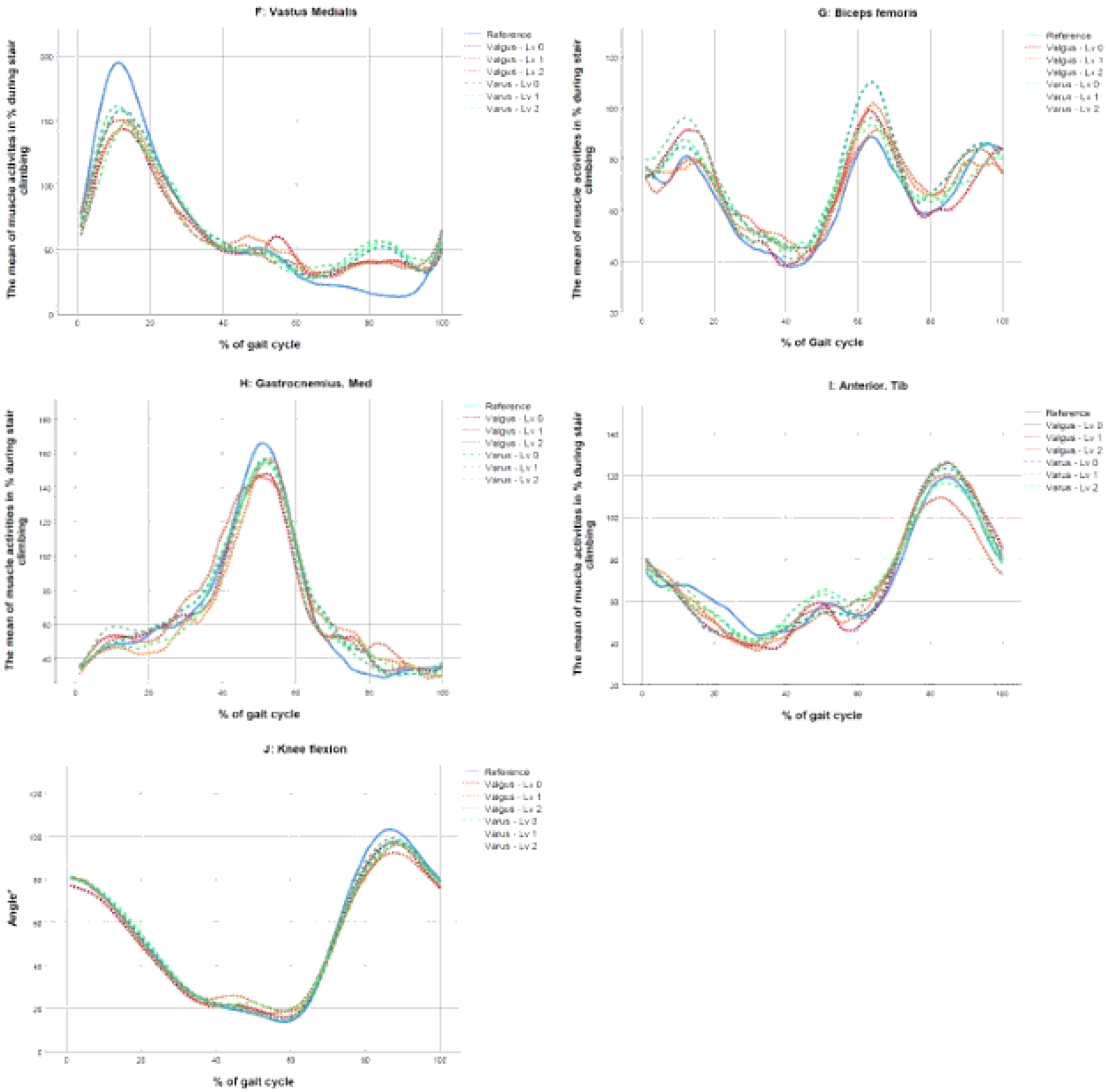

Figure 4

The pattern of the mean curves of the muscle activities for the four muscles vastus medialis (F), biceps femoris (G), gastrocnemius medialis (H), anterior tibialis (I), and the knee flexion (J) for the right leg during stair climbing

Supplementary Files

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- Appendix.docx