LOWER BODY KINEMATICS AND MUSCLE ACTIVITY DURING EXERCICES IN 3D MOTORIZED ROTATING PLATFORM. IN-VIVO STUDY AND MODEL

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The purpose of this study was to characterize muscle solicitations implied by the movement of a motorized rotating platform (MRP). Subjects performed five classical exercises on a MRP as part of lower limbs rehabilitation programs. EMG signals were recorded to quantify level and duration of activation of seven lower limbs muscles. Subject-specific musculoskeletal models were built and animated from kinematic recordings to estimate muscle lengths evolution. Results show that unipodal stance exercise was more demanding compared to bipodal ones. The characterization of solicitations imposed by MRP exercises could be useful for physiotherapists in order to help them to better select and configure exercises regarding to subject specificities, pathology and rehabilitation evolution.

KEY WORDS: Motorized rotating platform, musculoskeletal model, rehabilitation.

INTRODUCTION: Since ten years, balanced exercises on motorized rotating platforms (MRP) have been integrated in training and rehabilitation programs. Studies have reported that balance training had a positive impact in both injured and healthy subjects (Galozzi & Faina 2008, Fabri *et al.* 2008, Couillandre *et al.* 2008). Couillandre *et al.* (2008) showed that proprioception and force were improved after a training program on a MRP. Furthermore, Kim *et al*. (2013) found that knee push-up plus exercise performed on a MRP activated the serratus anterior more than the same exercise on static stable and static unstable surfaces. However, the benefits of unstable surfaces are conflicting in the literature and cannot be generalized. Nevertheless, as human movement for normal daily activities occurs in multi-dimensions, the importance of exercises in multi-dimensions or on unstable surfaces has been emphasized (Kim *et al.*, 2013).
While benefits of MRP have been investigate, less is known about the solicitation and the kinematics imposed by this device. However, understanding the way musculoskeletal system is working during an exercise on a MRP could help physiotherapists and coaches to improve training or rehabilitation settings.
Therefore, the aim of this study was to characterize muscle solicitations implied by the movement of a MRP. More specifically, we aimed to estimate lower limbs muscle activities by the use of electromyographic (EMG) acquisition. We also built subject-specific musculoskeletal models to assess the variation of muscle-tendon complex (MTC) lengths during the movement.

METHODS: Seven healthy men (27 ± 5 years old) volunteered to participate to this study. They were all physically active with no concern of specific pain.
3D motion kinematics of the platform and subject lower parts was assessed using optoelectronic system (VICON Peak, Oxford, United Kingdom). A specific kinematic model

was used to be compatible with the animation of EOS geometries. This model is composed of additional markers to facilitate the link between kinematic data and bone reconstructions.
Surface EMG (Trigno, Delsys, Boston, US) of leg muscles was collected with disposable electrodes and pre-amplified in site by a sixteen-channel electromyography recorder. Sampling rate was 1000 Hz in on-line recording per channel. Electrodes were applied with a following skin shaved and prepared with alcohol so that the skin-electrode interface impedance was below 10 kΩ. The electrodes were placed bilaterally according to SENIAM recommendations (Hermens, *et al.*, 2000). The sites for electrode pairs were located by muscle palpation during activation augmented by a structural marking procedure for both sides over the gastrocnemius lateralis (GL) and medialis (GM), the soleus (SOL), the tibialis anterior (TA), the peroneus longus (PER), the vastus lateralis (VL) and the biceps femoris (BF). EMG and kinematics acquisition were synchronized.
To build subject-specific musculoskeletal models, subjects were scanned with the EOS system. EOS is a low dose stereoradiographic device which take two simultaneous radiographies (one in the frontal plan and one in the sagittal plan). From these radiographies, the skeletal geometry of the subject was reconstructed following the method described by Assi (2013). Then, the localization of muscular insertions on the bone geometry was obtained using the study of Hausselle (2014). The present study focuses on the muscular activity of lower limbs, so the pelvis, the femurs, the tibias and the fibulas were reconstructed. To allow the animation of the model from the kinematic data, each subject was scanned with optoelectronic markers on the skin.
After appropriate warm-up, subjects were asked to perform a set of 5 balanced exercises (figure 1) on a MRP (Imoove, Allcare Innovation, France). Exercises had been selected among classic rehabilitation programs. Those exercises were:

- Bipodal stance with flexed knees, in the center of the platform (BSF)
- Bipodal stance with straight legs, in the center of the platform (BSS)
- Right lunge (RL)
- Left lunge (LL)
- Unipodal stance on the take-off foot (US)

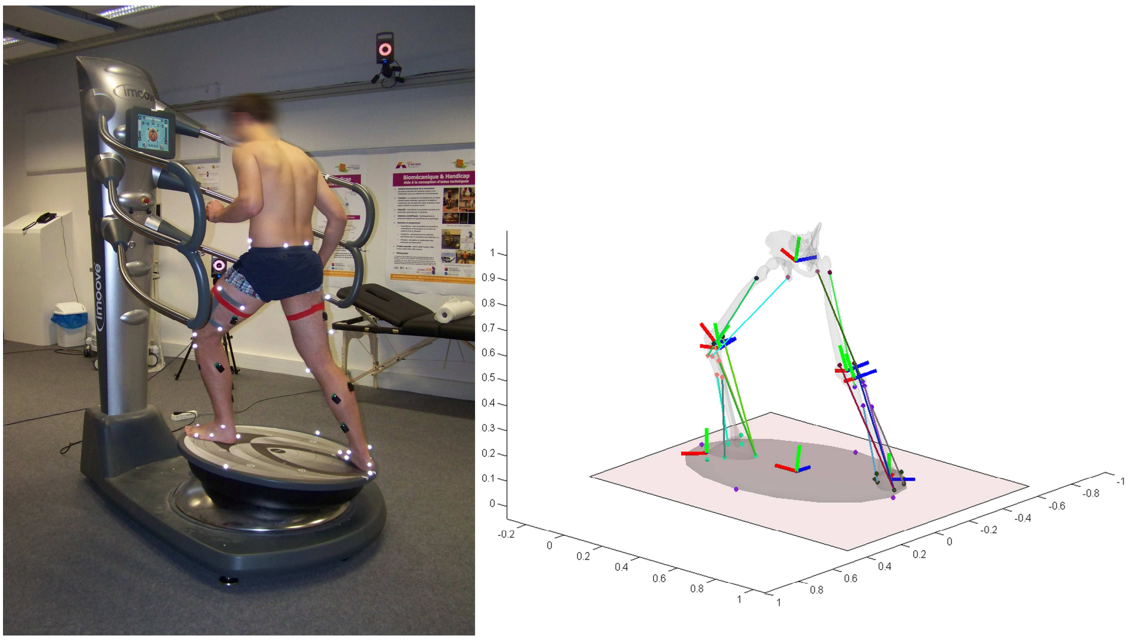

Figure 1: Experimentation (left), subject-specific musculoskeletal model, animated from kinematics acquisition (right)

Maximum voluntary contractions (MVC) performed against manual resistance were assessed at the end of each session in order to normalize EMG activity as a percentage of maximal value (%MVC).
For each exercise, EMG onset / offset latency was quantified (>15%MVC during at least 500ms). Using this information, the mean duration of contraction was calculated and expressed as a percentage of the total exercise period. Then, the mean EMG amplitude (RMS-EMG) was calculated over each contraction phase. Considering all the contractions, the mean level of activation during each exercise on the MRP was obtained.
The localization of muscular insertions over the duration of an exercise was obtained by animating the subject specific musculoskeletal model from the recorded kinematics. Assuming that length of the MTC is the direct distance between its proximal and distal insertions, the evolution of musculotendinous lengths during each MRP exercise was calculated. So we estimated both the duration of contraction with a decrease of the MTC length and the duration of contraction with an increase of the MTC length. From these values, we obtained the repartition of both types of contraction (% total duration of contraction) for each muscle during each exercise.

RESULTS: The tables below represent the three calculations described previously (average over the seven subjects of the study). We also calculated the standard deviation to characterize the reproducibility of the values over the participants. There is no data for left muscles during unipodal stance exercise because subjects were all right-footed.

Table 1
Mean duration of contraction (% total exercise period), for each muscle and each exercise

	R-VL	L-VL	R-BF	L-BF	R-GM	L-GM	R-GL	L-GL	R-SOL	L-SOL	R-TA	L-TA	R-PER	L-PER
BSF	88 +/- 13	80 +/- 19	2 +/- 4	2 +/- 3	11 +/- 12	17 +/- 19	24 +/- 28	14 +/- 17	71 +/- 17	64 +/- 23	20 +/- 15	26 +/- 15	15 +/- 9	21 +/- 18
BSS	37 +/- 29	36 +/- 22	8 +/- 11	13 +/- 19	49 +/- 15	42 +/- 23	35 +/- 38	20 +/- 20	69 +/- 20	63 +/- 23	18 +/- 21	14 +/- 19	20 +/- 20	11 +/- 12
US	89 +/- 15		0 +/- 0		65 +/- 34		68 +/- 34		99 +/- 1		63 +/- 23		87 +/- 13	
RL	91 +/- 13	86 +/- 15	1 +/- 2	2 +/- 3	40 +/- 14	30 +/- 19	30 +/- 25	24 +/- 24	80 +/- 16	67 +/- 21	28 +/- 21	49 +/- 17	64 +/- 17	28 +/- 17
LL	75 +/- 25	96 +/- 5	3 +/- 4	4 +/- 6	39 +/- 15	49 +/- 22	37 +/- 33	26 +/- 23	69 +/- 17	77 +/- 13	47 +/- 14	23 +/- 12	21 +/- 20	44 +/- 20

Table 2
Mean level of activation (% MVC), for each muscle and each exercise

	R-VL	L-VL	R-BF	L-BF	R-GM	L-GM	R-GL	L-GL	R-SOL	L-SOL	R-TA	L-TA	R-PER	L-PER
BSF	29 +/- 9	24 +/- 6	0 +/- 1	1 +/- 2	10 +/-10	12 +/- 10	15 +/- 9	12 +/- 9	35 +/- 11	31 +/- 10	22 +/- 10	25 +/- 8	18 +/- 6	24 +/- 9
BSS	18 +/- 7	19 +/- 8	0 +/- 1	4 +/- 4	29 +/- 9	29 +/- 7	18 +/- 10	12 +/- 12	29 +/- 8	24 +/- 6	14 +/- 9	9 +/- 6	21 +/- 7	12 +/- 8
US	34 +/- 22		2 +/- 2		35 +/- 12		21 +/- 10		55 +/- 22		34 +/- 9		41 +/- 13	
RL	34 +/- 12	26 +/- 8	2 +/- 3	7 +/- 9	19 +/- 9	26 +/- 8	18 +/- 9	13 +/- 11	39 +/- 9	34 +/- 12	21 +/- 10	35 +/- 7	34 +/- 11	26 +/- 9
LL	28 +/- 16	29 +/- 8	2 +/- 3	2 +/- 4	19 +/- 10	22 +/- 6	16 +/- 13	13 +/- 11	40 +/- 16	35 +/- 11	33 +/- 12	20 +/- 7	20 +/- 4	34 +/- 8

Table 3
Repartition of contractions with a decrease *vs.* an increase of the MTC length (% total duration of contraction), for each muscle and each exercise

	R-VL	L-VL	R-BF	L-BF	R-GM	L-GM	R-GL	L-GL	R-SOL	L-SOL	R-TA	L-TA	R-PER	L-PER
BSF	51 / 49	45 / 55	48 / 52	51 / 45	47 / 53	43 / 56	61 / 38	61 / 38	58 / 41	63 / 36	62 / 37	71 / 28	29 / 70	34 / 65
BSS	49 / 49	42 / 57	71 / 28	55 / 45	56 / 44	56 / 43	56 / 44	54 / 46	61 / 39	63 / 37	49 / 49	64 / 35	48 / 52	63 / 37
US	50 / 49		54 / 45		47 / 52		49 / 50		50 / 50		55 / 44		49 / 50	
RL	50 / 50	45 / 55	62 / 37	57 / 42	52 / 48	49 / 50	61 / 38	67 / 32	52 / 47	57 / 42	65 / 34	55 / 45	47 / 53	41 / 58
LL	44 / 55	50 / 50	43 / 56	51 / 47	46 / 53	49 / 50	56 / 44	47 / 52	57 / 42	57 / 43	54 / 45	57 / 42	47 / 52	43 / 56

Results show that the vastus lateralis and the soleus are the most demanding muscles in term of muscle activity during MRP exercises. In fact their level of activation were around 30%-40% (table 2) during 80%-70% of the exercises duration (table 1). On the contrary, biceps femoris was less activated during exercises (<5%MVC during less than 10% of the exercises duration).

Regarding the differences between each exercise, results show that unipodal stance was more demanding compared to bipodal ones. In this case, all muscles were activated at a higher level than during all other exercises.
Table 3 shows that exercises on the MRP were globally performed with as much contraction with shortening MTC as contraction with lengthening MTC. There is one exception for the peroneus longus which worked mainly during increasing of MTC length, during bipodal stance (with flexed knees).

DISCUSSION: This study characterized muscle contractions and kinematics of lower limbs during classic rehabilitation exercises on a MRP. The knowledge of duration of muscle activation, mean level of activation and MTC length evolution of the main lower limbs muscles during classic rehabilitation exercises on a MRP could be useful for physiotherapists. Taking our results into account, they will be able to efficiently select the type and level of exercises regarding to subject specificities, pathology and rehabilitation evolution.
In this first version of the musculoskeletal model, MTC length was considered as the direct distance between its proximal and distal insertions. This simplification is quite compatible with some muscles like gastrocnemius and soleus. However, there are some bent shape muscles which should require the consideration of via-points in the model. For example, the patella could be introduced on a next version of the model and used to better define the trajectory of the quadriceps muscles for instance.

CONCLUSION: The characterization of muscle demands during exercises performed on a MRP is an important prerequisite to draw effective training or rehabilitation programs. This study aims to help physiotherapists to achieve their goals.

REFERENCES:
Assi, A., Chaibi, Y., Presedo, A., Dubousset, J., Ghanem, I., & Skalli, W. (2013). Three-dimensional reconstructions for asymptomatic and cerebral palsy children's lower limbs using a biplanar X-ray system: A feasibility study. *European Journal of Radiology*, *82*(12), 2359–2364.
Couillandre, A., Duque Ribeiro, M.-J., Thoumie, P., & Portero, P. (2008). Changes in balance and strength parameters induced by training on a motorised rotating platform: A study on healthy subjects. *Annales de Réadaptation et de Médecine Physique*, *51*(2), 59–66.
Fabri, S., Lacaze, F., Marc, T., Roussenque, A., & Constantinides, A. (2008). Rééducation des entorses du genou : traitement fonctionnel. *EMC - Kinésithérapie - Médecine Physique - Réadaptation*, *4*(2), 1–21.
Galozzi, R., & Faina, M. (2005). HUBER® platform: an innovative methodology for postural re-education techniques. Presented at the 15th World Congress of Aesthetic Medicine, Rome.
Hausselle, J., Assi, A., El Helou, A., Jolivet, E., Pillet, H., Dion, E., Skalli, W. (2014). Subject-specific musculoskeletal model of the lower limb in a lying and standing position. *Computer Methods in Biomechanics and Biomedical Engineering*, *17*(5), 480–487.
Hermens, H. J., Freriks, B., Disselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography and Kinesiology*, *10*(5), 361–374.
Kim, S., Kwon, O., Kim, S., Park, K., Choung, S., & Weon, J. (2014). Serratus anterior muscle activation during knee push-up plus exercise performed on static stable, static unstable, and oscillating unstable surfaces in healthy subjects. *Physical Therapy in Sport*, *15*(1), 20–25.