EFFECT OF THE SPEED OF TAEKWONDO KICK EXECUTION ON THE MUSCULAR FORCE PRODUCTION, OBTAINED BY BIOMECHANICAL MODELING.

Pedro Vieira Sarmet Moreira, **LAMFE-PEB/COPPE (UFRJ),** **sarmet_treinamento@hotmail.com**
Kristy Alejandra Godoy James, **LAMFE-PEB/COPPE (UFRJ),** **krstygodoy@gmail.com**
Luciano Luporini Menegaldo, **LAMFE-PEB/COPPE (UFRJ),** **lmeneg@peb.ufrj.br**

Abstract. Slow movements are frequently used in sports' training for motor learning or skills perfecting, but there are some critical points about the practice of slow training, aiming to learn/improve, fast techniques that lead us to hypothesize that slow motion has poor specificity with the real fast technique that overcomes the obvious difference in speed. For this we analyzed an experienced taekwondo practitioner (former athlete) with kinematic analysis and biomechanical modeling for calculating forces of 48 muscles during the slow and fast Round-House Kick. We found many differences in range of motion, angular velocities and muscle force production, meaning that more than a technical variation, the slow motion can be considered another technique by the motor control point of view. It implies that the slow motion should not replace the traditional fast training, but instead, to be used as a complementary method training for balance and for recruiting CORE stabilizer and hamstring muscles in a similar (but not equal) technique.

Key-words: *Inverse Dynamics, Static Optimization, Round-House Kick*

1. INTRODUCTION

Slow movements are frequently used in the sports training for motor learning or skills perfecting. Reducing the speed, the central nervous system becomes able to take time to correct technical noises by means of simultaneous visual feedbacks, specially through Basal Ganglia (Delong & Stick, 1975) and Cerebellum (Jueptner, N., Weiller, 1998) corrections. During slow movements, brain areas dedicated to online motor control can use delayed sensory feedbacks, and executive areas can consciously regulate the motor performance, unlike fast movements which require an anticipatory and more automated regulation (Sauvage 2013; Salimi-Badr, 2017). Additionally, many brain areas used to control the slow movement are different from the fast movement (Sauvage et al., 2013). For example, Sauvage et al. (2013) found that slow foot movements specifically recruited frontopolar and right dorsomedian prefrontal areas bilaterally, during its execution, whereas fast movements strongly activated the sensorimotor cerebral cortex. They also noted that anterior vermis, lobules VI/VII and VIII of the cerebellum were specifically activated during fast movements, concluding that the selection of the neural networks underlying voluntary movement of the foot is depending on the speed strategy. However, the slow motion may not be the same mechanical movement as would be an artificially decelerated fast movement, i.e. various dynamic pathway of movement, like the proximal-distal momentum transmission, the inertia and the range of motion should be different when the speed is switched from fast to slow. This possibility, associated with the different demand for angular and linear acceleration of body segments should imply in a so big difference on the characteristics of the muscle contraction and demanded muscle force production that if it is the case, the efficacy of the slow motion methods of training transfer for the real fast speed needs to be questioned.

Taekwondo is a Korean combat sport in which the speed of kick is the main motor quality to be sought by athletes (Moreira et al., 2016). This speed is dependent on the force production by the muscles (Moreira et al., 2015; 2016). Then, if to lower the speed of movement can facilitate the neural feedback, it's necessary to analyze if the slow movements has some similar kinematic characteristics of movement and a significant muscle load demand to cause positive learning transfer or specific strengthening effect of some muscles. Thus, the goal of the present study is to analyze the effect of the speed of taekwondo kick execution on the muscular force production, calculated through biomechanical modeling.

2. METHODS

A black belt taekwondo practitioner (35 years, 72Kg, 1.77cm, experience: 24 years of training) performed three slow Bandal Chagui kicks and three fast kick to a vertical tower (Boomboxe®) of combat training, with 18 reflexive markers (Hellen Hayes simplified protocol), collected through a Smart Capture kinematic system (BTS®), composed by 7 cameras (BTS®) sampled at 250Hz. The kicks were executed from the static starting fight position, with each foot on a different force plate (model: B600, BTS®) sampled at 1000 Hz, synchronized with the kinematic system. The raw kinematic and force data were reconstructed through the Smart Tracker Software (BTS®), interpolated and filtered by a Low Pass Butherworth zero-lag 4^{th} order filter at 10 Hz through the Smart Analyzer (BTS®) software, and imported to the open-source software system (OpenSim) for the Inverse Kinematic (IK), Reduce Residuals Algorithm (RRA) and Static Optimization (SO) processing, to obtain reconstructed 3D data of bone rigid bodies and muscle representation with their respective estimated forces.

The resultant data vectors of muscle forces, angular position and angular velocities were post processed through MATLAB software (Mathworks®, 2016a) for generating the final graphics and to extract the peak force values of 48 muscles during the kick. This movement was divided in two phases: 1) Impulse Phase – from the resultant ground reaction force (GRFres) onset (threshould: when GRFres>102.5% the basal force) to its next offset (GRFres<1% of basal value); 2) The aerial kick phase – from the GRF offset to the contact with the target. The aerial phase was subdivided in 2 phases: a) knee flexion and b) knee extension, with basis on the peak of knee flexion angle.

3. RESULTS

The graphics containing the results of angular position and velocity of the fast kick are demonstrated in figs. 1 and 2, in which the peaks of angular position and angular velocity for each joint in the slow and fast kicks are demonstrated in the table 1. The muscular force curves of the fast kick, calculated through static optimization, are demonstrated in fig. 3 and the data for comparison of the peak values of estimated forces between the fast and slow kick are demonstrated in the table 3. The ratios of "aerial time"/"impulse time" were 1.22 and 0.54, for the slow and fast kick, respectively. Table 2 demonstrates the meaning of the used muscle tendon actuators abbreviation.

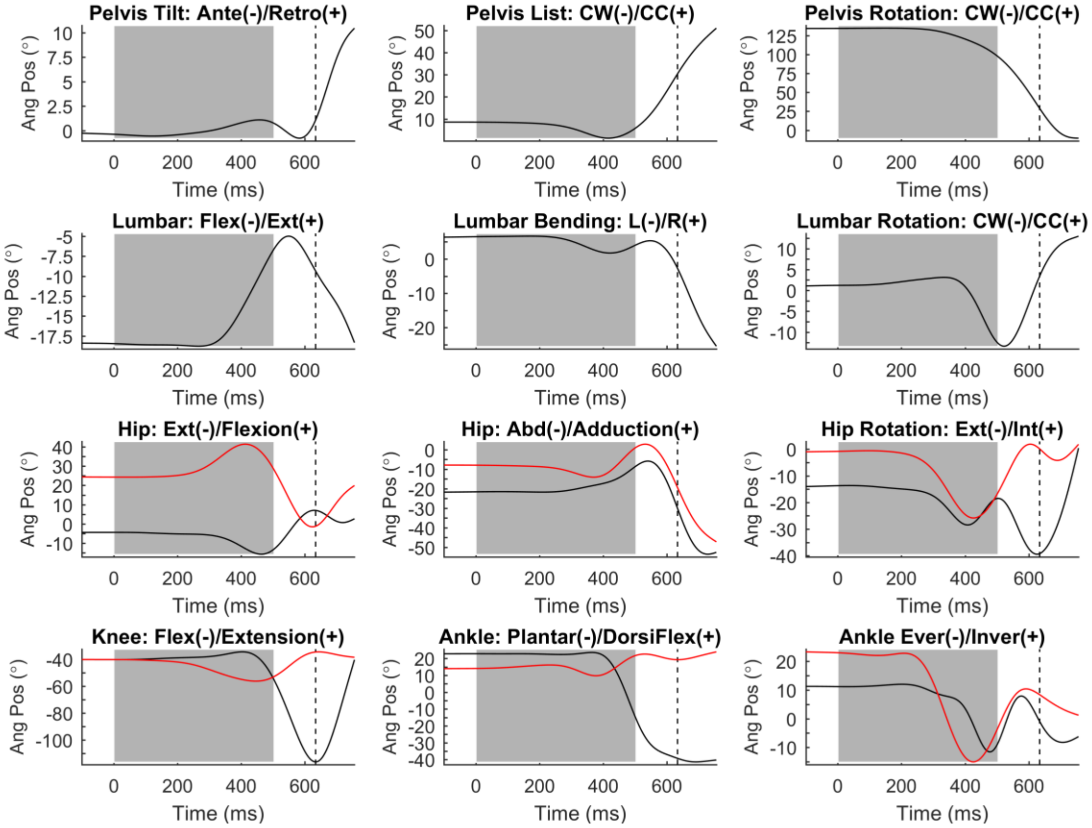

Figure 1. Angular Position of spine, hip and leg joints obtained during the fast kick.

The gray area represents the "Impulse Phase", the gray vertical trace, represent the moment of peak of knee flexion angle. The black line represents the left (dominant) leg angles while the red line represents the right leg. **Ante**: Anteversion; **Retro:** Retroversion; **CW:** Clock Wise; **CC:** Counter Clock Wise; **Flex:** Flexion; **Ext:** Extension; **Abd:** Abduction; In rotation, **Ext:** External; **Int:** Internal; **Plantar**: Plantar-flexion; **DorsiFlex**: Dorsiflexion; **Ever:** Eversion; **Inver:** Inversion;

4. DISCUSSION

Although the fast and slow kicks have an apparent very similar motor pathway from the qualitative analysis of the reconstructed 3D movement, the graphical analysis showed a large number of differences in the range of motion, velocities and in the ratio of aerial time/impulse time. This ratio was visible lower in the fast kick. It was caused by the increased need for impulse time to accelerate forward the foot and center of gravity and for a decreased necessary time to perform the aerial phase. These kinematic differences influence the produced forces by various muscles as well as they are influenced by the intentional more explosive contraction of these muscles on the fast movement.

Despite the majority of muscles developed higher forces during the fast kick, it's interesting to note that some muscles performed similar or even higher forces during the slow kick, particularly on the left internal oblique, right external oblique and on the erector spinae of both sides. Some knee flexors (semimembranosus and biceps-short head) also produced higher forces during the slow controlled movement, when compared with the ballistic kick. It probably occurred due to the lower angular momentum generated by the contractions performed in the impulse phase, forcing thus, the hamstrings to apply more force to flex the knee. The lower momentum of the kicking leg and trunk associated with the higher time of contraction it's a reasonable explanation for the higher activation of some stabilizing CORE muscles (obliques and erectors spinae). This high activation, associated with a great time of contraction should imply in a greater physiological work, contractile impulse and fatigue, when executing controlled slow kicks.

Liu et al. (2008) studied the speed effect on kinematic pathway and muscle force during a fundamental motor ability of walking and they found a similar macrostructure of the kinematic pathway during the slow walking when compared with the fast walking. But, the analysis of some details of the movement reveled that a) there are walking speed dependent differences in the angular position during the pelvis obliquity trajectory and in the first peak of knee flexion; b) there are speed dependent differences in the modeled force peaks or timing of occurrence of these peaks for the tibialis anterior, soleus, hamstring and quadriceps muscles. The speed dependent differences in the present study were more accentuated, probably due the fact that the taekwondo kick is not a natural movement as the walking is, but a sport specific movement culturally determined, acquired and perfected through many hours of training.

In conclusion when a natural ballistic kick is performed in slow motion, it turns into another technique, but with some similarities with the natural form. The theoretical basis lead us to infer that the higher time of execution offers opportunities to use simultaneous feedback for noise correction but the majority of muscles sub activate carrying to an insufficient physiological intensity to train force, speed and coordination, the higher threshold fibers necessary to perform correctly the real movement. On the other hand, the apparent lower proximal-distal transmission of momentum generates opportunity to work specific muscles of CORE and Hamstrings with significative intensity. Based on these achievements, the slow motion can be recommended as a complementary training method, but not as a substitute method over the traditional training for the motor learning and performance development. However, applied research needs to be performed to confirm or refute this point of view.

Table 1. Angular kinematic results. Deg.: degree; **CW:** Clock Wise; **CC:** Counter Clock Wise; **Impulse:** Impulse Phase; **Aerial:** Aerial Phase.

		ANGULAR POSITION (deg)				ANGULAR VELOCITY (deg/s)			
		Speed of Execution				Speed of Execution			
		Slow		Fast		Slow		Fast	
Joint	Variable	Impulse	Aerial	Impulse	Aerial	Impulse	Aerial	Impulse	Aerial
Pelvis	Peak of Retroversion	4.6	3.4	10.5	1.1	8.5	5.3	9.3	103.8
	Peak of Anteversion	3.0	-18.4	-0.8	-0.5	-23.0	-58.1	-11.5	-24.9
	Peak of CC List	7.3	50.2	51.1	8.6	51.7	129.4	89.8	233.3
	Peak of CW List	-1.0	2.5	4.9	1.3	-38.8	35.9	-51.2	89.8
	Peak of CC Rotation	133.6	85.4	101.3	134.9	1.1	-29.4	2.4	-8.5
	Peak of CW Rotation	85.4	4.9	-10.5	101.3	-261.9	-269.2	-303.3	-632.8
Lumbar	Peak of Extension	-4.4	-3.7	-5.0	-7.4	43.4	45.4	77.1	70.4
	Peak of Flexion	-12.5	-11.0	-18.3	-18.8	-28.0	-35.6	-2.4	-102.7
	Peak of Right Bending	5.4	3.3	5.3	6.7	14.4	23.8	44.3	44.5
	Peak of Left Bending	2.0	-12.2	-25.4	1.7	-19.8	-66.9	-38.4	-221.5
	Peak of CC Rotation	-3.9	21.7	13.0	3.1	60.5	94.0	10.1	204.2
	Peak of CW Rotation	-6.2	-4.9	-13.4	-11.5	-34.4	-16.9	-160.3	-111.3
Hip	Peak of Flexion	2.7	37.7	-4.4	7.0	152.8	205.6	92.7	220.6
	Peak of Extension	-7.1	2.7	-15.8	-14.5	-44.8	-172.5	-94.8	-111.4
	Peak of Adduction	-17.6	-17.5	-9.9	-5.9	25.2	22.1	121.5	121.3
	Peak of Abduction	-21.2	-51.2	-21.7	-53.5	-17.5	-156.7	-2.8	-434.3
	Peak of Int. Rotation	-9.2	-14.1	-13.7	0.4	126.9	87.1	163.9	509.5
	Peak of Ext. Rotation	-23.9	-23.5	-28.5	-39.4	-105.7	-108.3	-137.5	-276.5
Knee	Peak of Extension	-25.9	-22.1	-40.4	-34.5	18.8	355.0	45.5	827.4
	Peak of Flexion	-67.5	-105.2	-116.2	-49.9	-346.6	-337.2	-398.6	-602.6
Ankle	Peak of Dorsiflexion	19.4	-12.9	-9.9	23.6	2.6	64.6	21.3	21.4
	Peak of PlantarFlexion	-16.7	-32.1	-41.3	-9.9	-268.1	-107.9	-486.0	-479.0
Subtalar	Peak of Invertion	1.3	8.8	7.9	12.0	254.1	247.7	130.0	315.7
	Peak of Evertion	-10.0	-9.9	-10.7	-11.6	-107.7	-111.8	-261.9	-211.2

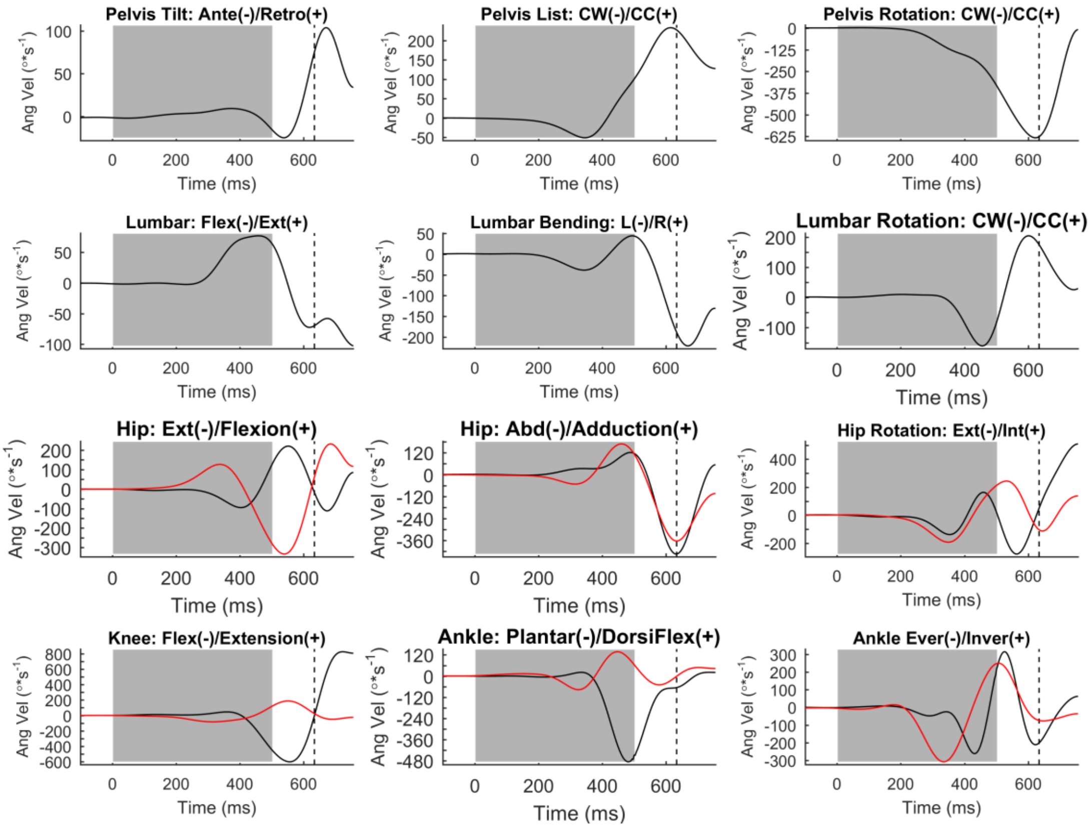

Figure 2. Angular Velocity of spine, hip and leg joints obtained during the fast kick.

The gray area represents the "Impulse Phase", the gray vertical trace, represent the moment of peak of knee flexion angle. The black line represent the left (dominant)leg angles while the red line represent the right leg. **Ante**: Anteversion; **Retro:** Retroversion; **CW:** Clock Wise; **CC:** Counter Clock Wise; **Flex:** Flexion; **Ext:** Extension; **Abd:** Abduction; In rotation, **Ext:** External; **Int:** Internal; **Plantar**: Plantar-flexion; **DorsiFlex**: Dorsiflexion; **Ever:** Eversion; **Inver:** Inversion;

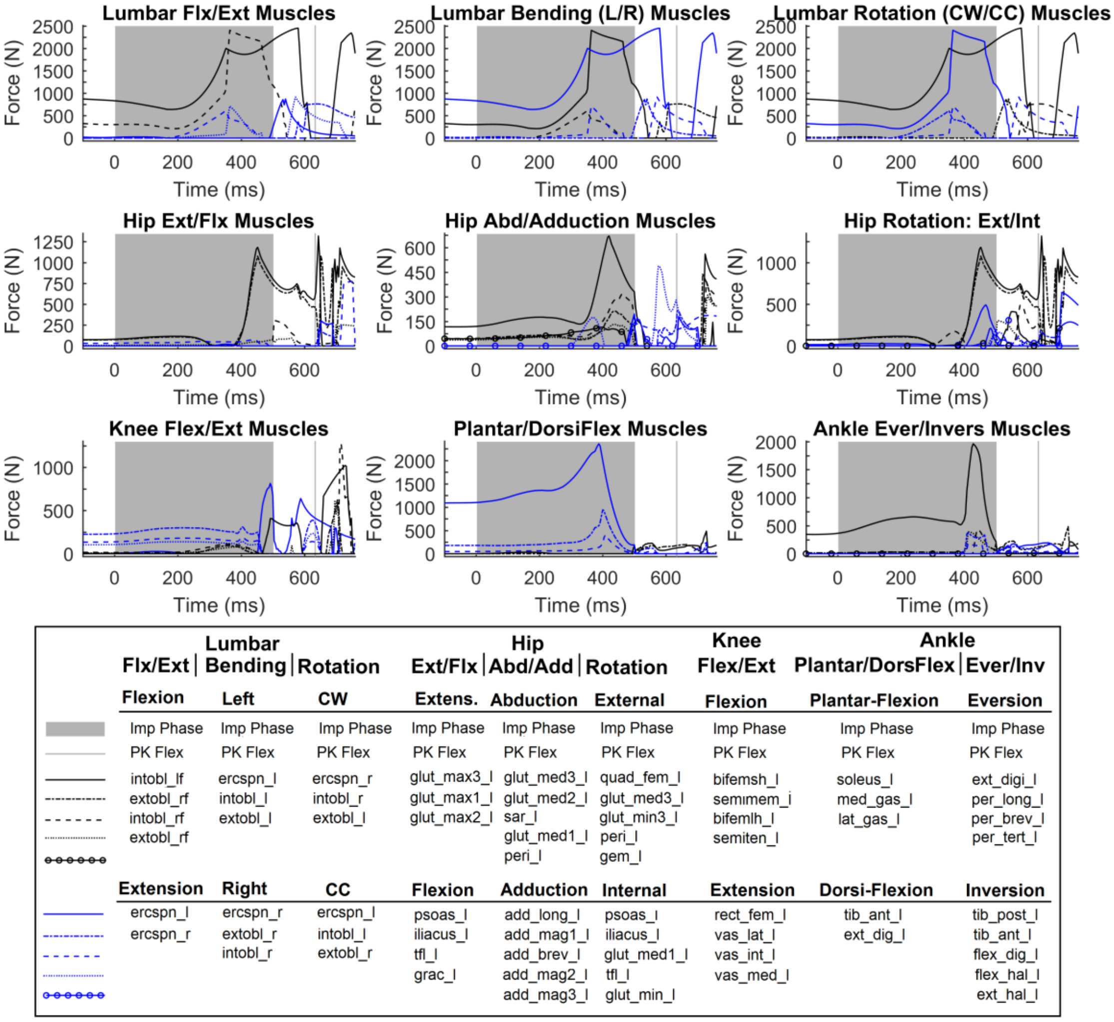

Figure 3. Muscular forces acting during the kick determinate through static optimization. **Imp Phase:** Impulse Phase"; **PK Flex:** Instant of peak of knee flexion angle. Black and blue colors represent antagonist muscle groups. Meaning of muscle abbreviation is showed in the table 1.

Table 2. Meaning of muscle tendon actuators abbreviation of OpenSim model gait2392.

Muscle actuator	Abbrevation		Muscle actuator	Abbrevation	
	right	left		right	left
Gluteus Medius 1	glut_med1_r	glut_med1_l	Psoas Major	psoas_r	psoas_l
Gluteus Medius 2	glut_med2_r	glut_med2_l	Quadratus Femoris	quad_fem_r	quad_fem_l
Gluteus Medius 3	glut_med3_r	glut_med3_l	Gemellus	gem_r	gem_l
Gluteus Minimus 1	glut_min1_r	glut_min1_l	Piriformis	peri_r	peri_l
Gluteus Minimus 2	glut_min2_r	glut_min2_l	Rectus Femoris	rect_fem_r	rect_fem_l
Gluteus Minimus 3	glut_min3_r	glut_min3_l	Vastus Medialis	vas_med_r	vas_med_l
Semimembranosus	semimem_r	semimem_l	Vastus Intermedius	vas_int_r	vas_int_l
Semitendinosus	semiten_r	semiten_l	Vastus Lateralis	vas_lat_r	vas_lat_l
Biceps Femoris Long Head	bifemlh_r	bifemlh_l	Medial Gastrocnemius	med_gas_r	med_gas_l
Biceps Femoris Short Head	bifemsh_r	bifemsh_l	Lateral Gastrocnemius	lat_gas_r	lat_gas_l
Sartorius	sar_r	sar_l	Soleus	soleus_r	soleus_l
Adductor Longus	add_long_r	add_long_l	Tibialis Posterior	tib_post_r	tib_post_l
Adductor Brevis	add_brev_r	add_brev_l	Flexor Digitorum Longus	flex_dig_r	flex_dig_l
Adductor Magnus 1	add_mag1_r	add_mag1_l	Flexor Hallucis Longus	flex_hal_r	flex_hal_l
Adductor Magnus 2	add_mag2_r	add_mag2_l	Tbibialis Anterior	tib_ant_r	tib_ant_l
Adductor Magnus 3	add_mag3_r	add_mag3_l	Peroneus Brevis	per_brev_r	per_brev_l
Tensor Fasciae Latae	tfl_r	tfl_l	Peroneus Longus	per_long_r	per_long_l
Pectineus	pect_r	pect_l	Peroneus Tertius	per_tert_r	per_tert_l
Gracilis	grac_r	grac_l	Extensor Digitorum Longus	ext_dig_r	ext_dig_l
Gluteus Maximus 1	glut_max1_r	glut_max1_l	Extensor Hallucis Longus	ext_hal_r	ext_hal_l
Gluteus Maximus 2	glut_max2_r	glut_max2_l	Erector Spinae	ercspn_r	ercspn_l
Gluteus Maximus 3	glut_max3_r	glut_max3_l	Internal Oblique	intobl_r	intobl_l
Iliacus	iliacus_r	iliacus_l	External Oblique	extobl_r	extobl_l

Table 3. Modeled muscle force (in Newton), calculated through Static Optimization.

Muscles	Knee Flexion Phase		Knee Extension Phase	
	Fast Kick	Slow Kick	Fast Kick	Slow Kick
glut_med3_l	81	171	179	150
glut_min1_l	412	38	88	10
glut_min2_l	438	83	63	11
glut_min3_l	125	125	18	6
semimem_l	0	264	622	273
semiten_l	92	0	607	1
bifemlh_l	0	0	1272	3
bifemsh_l	385	541	1021	474
sar_l	138	103	186	116
add_long_l	238	87	561	0
add_brev_l	0	9	392	0
add_mag1_l	0	16	438	0
add_mag2_l	0	0	310	0
add_mag3_l	0	0	145	0
tfl_l	302	53	46	138
pect_l	138	16	331	0
grac_l	94	16	253	7
glut_max1_l	0	0	202	53
glut_max2_l	0	0	304	330
glut_max3_l	0	0	774	0
iliacus_l	721	348	1075	7
psoas_l	784	414	1318	22
quad_fem_l	115	140	642	129
gem_l	18	12	287	57

Muscles	Knee Flexion Phase		Knee Extension Phase	
	Fast Kick	Slow Kick	Fast Kick	Slow Kick
peri_l	168	64	0	1
rect_fem_l	639	307	406	404
vas_med_l	234	0	199	0
vas_int_l	142	0	122	0
vas_lat_l	387	0	334	0
med_gas_l	119	284	187	208
lat_gas_l	50	57	239	47
soleus_l	2	0	0	0
tib_post_l	3	0	213	84
flex_dig_l	1	0	7	4
flex_hal_l	1	0	5	2
tib_ant_l	225	330	485	209
per_brev_l	43	45	43	27
per_long_l	128	146	166	88
per_tert_l	23	18	19	11
ext_dig_l	178	166	196	102
ext_hal_l	13	13	14	8
ercspn_r	1143	731	719	1476
ercspn_l	2454	2421	2347	2376
intobl_r	0	0	0	0
intobl_l	873	512	123	890
extobl_r	762	868	762	889
extobl_l	917	0	468	0

5. REFERENCES

DELONG, M. R., STRICK, P.L. Relation of basal ganglia, cerebellum, and motor cortex units to ramp and ballistic limb movements. **Brain Research**, v. 71: p. 327-335, 1975.

SALIMI-BADR, Armin; EBADZADEH, Mohammad Mehdi; DARLOT, Christian. Fuzzy neuronal model of motor control inspired by cerebellar pathways to online and gradually learn inverse biomechanical functions in the presence of delay. **Biological cybernetics**, v. 111, n. 5-6, p. 421-438, 2017.

JUEPTNER, N., WEILLER, C. A review of differences between basal ganglia and cerebellar control of movements as revealed by functional imaging studies**. Brain**,. v. 121, p. 1437-1449, 1998.

LIU, M. Q., ANDERSON, F. C., SCHWARTZ, M. H., & DELP, S. L. Muscle contributions to support and progression over a range of walking speeds. **Journal of biomechanics**, v. 41, n. 15, p. 3243-3252, 2008.

MOREIRA, P. V. S., GOETHEL, M. F. & GONÇALVES, M. Neuromuscular performance of Bandal Chagui: Comparison of subelite and elite taekwondo athletes. **Journal of Electromyography and Kinesiology,** v. 30, p. 55-65, 2016. Available in: https://doi.org/10.1016/j.jelekin.2016.06.001

MOREIRA, P. V. S., PAULA, L. V., & VELOSO, A. P. Segmental kick velocity is correlated with kick specific and nonspecific strength performance in a proximodistal sequence. **Arch. Budo**, v. 11, p. 271-276, 2015.

SAUVAGE, C., JISSENDI, P., SEIGNAN, S., MANTO, M., & HABAS, C. (2013). Brain areas involved in the control of speed during a motor sequence of the foot: real movement versus mental imagery. **Journal of neuroradiology**, v. 40, n. 4, p. 267-280, 2013.

6. ACKNOWLEDGEMENTS

This work was suported by CAPES with a PNPD Post Doctoral grant.

7. RESPONSABILITY FOR THE INFORMATIONS

The authors are the only responsible for the included information in this work.