BIOMECHANICAL ANALYSIS TO DETERMINE MUSCLE INTERVENTION IN BALLISTIC STRETCHING

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Joint mobility is an advantage to sport technique optimization. The aim of this work was to examine the relationships between hip angular velocity and angular acceleration and the tension level of Rectus Femoris (RF), Vastus Medialis (VM) and Biceps Femoris (BF) muscles during execution of a ballistic stretching exercise. Measurements of body segments' kinematics were made using a motion capture system (Xsens) synchronized with an EMG capture system (Delsys). Obtained results have shown that a reliable methodology has been developed that allows studying physiologic and functional behavior of biokinematics unity.

KEYWORDS: biomechanical analysis, muscle intervention, ballistic stretching

INTRODUCTION: Mobility is a fundamental requirement to execute properly movements in terms of quantity and quality. It development affects in a very positive form to physical development of performance factors and sport capabilities. Mechanics restrictions that confine this mobility are: nerve restraints, muscle tissue restrictions, joint restrictions, skin restrictions, subcutaneous connective tissue and friction resistance (Gianikellis, Gazapo, García, & Cruz, 2003). Muscular resistance to stretching results from (a) neural factors (incomplete muscle relaxation, action of stretch reflexes) and (b) muscle mechanical properties (Zatsiorsky & Prilutsky, 2012). Mobility can be classified in active and passive. Passive mobility is maximum segment amplitude reached by the athlete thanks to the intervention of external forces and extension or relaxation of antagonist muscles. On the other hand, active mobility is understood as maximal movement amplitude reached by the athlete joint thanks to agonist muscles contraction and antagonist extension. Passive mobility is always greater than active mobility. Stretching techniques considered are: a) ballistic stretching, consisting of quick movements inside of ends of functional range of movement of implied joints, b) static stretching, where joints adopt an extreme posture from which its begin to stretch. Stretching is passively induced both gravity force in anatomic involved segments, as manual manipulation passively applied, or through force application to increase stretching quantity, and c) proprioceptive neuromuscular facilitation (pnf), that involves a pre contraction until muscle groups maximal level until muscle elongation occurs. Ballistic stretching disadvantages are widely known, but there is short information with respect its principal advantage that consist in agonist muscles strengthening through an active contraction. But, according to the existing bibliography, as the review done by Opplert and Babault (2018), there is no consensus on how to execute a ballistic stretch, even confusing the terms – which are not generally defined. It is believed that ballistic (also called dynamic) stretching consist in a contraction of the agonist muscles and antagonist muscles relax (Sumakawa et al., 2011). Due to this, the aim of this work has been to find cause-effect relationships between angular velocity and angular acceleration of hip joint, and the tension level of Rectus Femoris (RF), Vastus Medialis (VM) and Biceps Femoris (BF) muscles during a ballistic stretching exercise.

METHODS: Twenty participants in this study were active (at least 3 days of training at week) with a body mass of 71.44 ± 11.59 kg, height of 1.72 ± 0.07 m., hip height of 1.01 ± 0.05 m. and 23.3 ± 1.73 years old. Each participant performed a protocol of hip flexion stretching based on ballistic method (Gianikellis et al., 2003). Protocol consisted of a warm-up phase with a duration of 5 minutes, where participant have an initial contact with the exercise. Once finished the warm up phase, 6 repetitions of hip flexion-extension in standing pose were performed.

The XSens MVN BIOMECH system (Enchende, The Netherlands) was used to obtain body segments' kinematics from inertial units. Kinematic data were stored as .MVNX file and were postprocessed with the Visual3D software (C-motion, Inc., Germantown, MD, USA). The defined segments' local reference systems (LRS) axes X-Y-Z corresponding to mediolateral-anteroposterior- longitudinal directions, respectively. The Y-X-Z Euler sequence of rotation was used, allowing the analysis of hip kinematics. Hip angle (pelvis with respect the femur segment), angular velocity and angular acceleration with respect anteroposterior axe (Y axe, flexo-extension movement) were calculated. "Data smoothing" (was carried out by generalized cross-validation using quintic splines.

Muscle electromyography (EMG) of left and right Rectus femoris (RF), Vastus Medialis (VM) and Biceps femoris (BF) were recorded using a Delsys Trigno Wireless EMG system, pre-amplified (909 V/Vgain, CMRR> 80 dB), digitized at 2KHz and synchronized with the Xsens system. Electrodes location was performed following Seniam.org (1999) recommendations. Electrodes were attached to skin (cleaned with 70 % isopropyl alcohol) using adhesive strips. MATLAB software was used to display EMG and Kinematics parameters obtained, as shown in Figure1. Each flexion-extention repetition was divided into 4 phases: 1st phase: acceleration of flexion. 2nd phase: deceleration of flexion. 3rd phase: acceleration of extension. 4th phase: deceleration of extension.

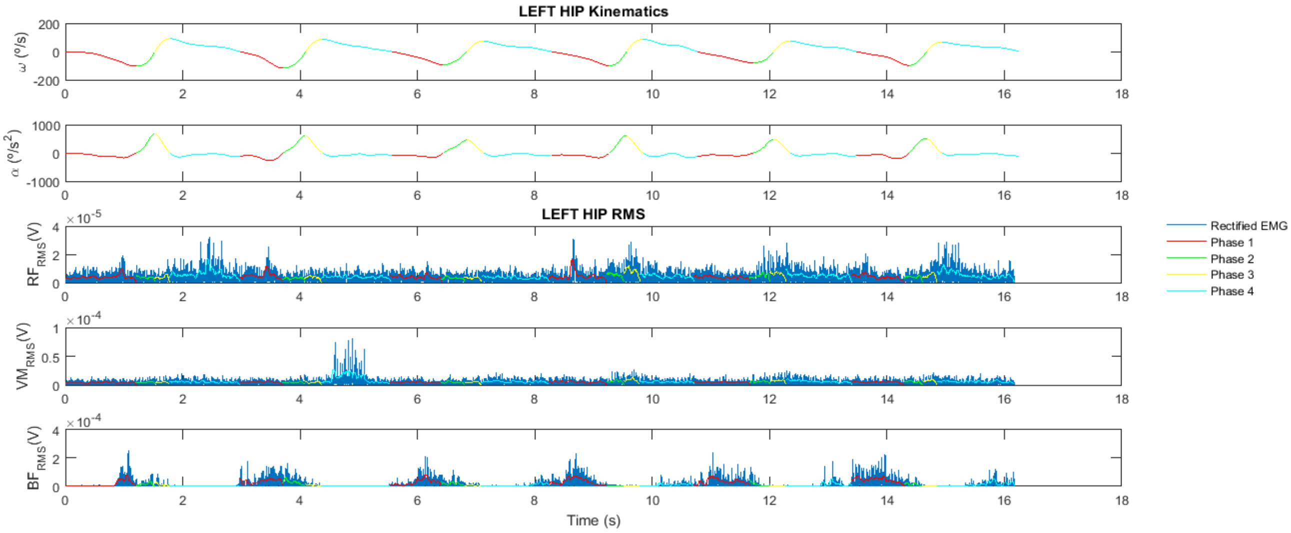

Figure 1. Example of lower extremity

EMG signals were filtered with 4th order Butterworth band-pass filter between 20-450 Hz. Average angular velocity and average angular acceleration was calculated in each phase. Time domain method was used for parameters extraction of EMG signals. Root mean square (RMS) of the EMG rectified amplitude, defined as where x_i is the *i*th sample of a signal and N is the number of sample in the epoch, was calculated in each phase.

Statistical analysis (Statistics, Pearson Correlation and test of significance) was accomplished with IBM SPSS Statistics (v 22).

RESULTS: Table 1 shows the descriptive results obtained in the four phases. Significant correlations, between 0.656 and 0.179 (p <.001, p <.01 and p <.05), were found between the kinematic parameters, hip angular velocity and angular acceleration, and the iRMS parameter of the EMG. The tables correspond for each phase of movement.

Table 1. Mean and Standard Deviation of variables: Angular Velocity and Acceleration, Rectus Femoris, Vastus Medialis and Femoral Biceps iRMS, from both Left and Right sides.

	L_Ang_Vel (º/s)	L_Ang_Acc (º/s2)	L_FR_iRMS (v)	L_VM_iRMS (v)	L_FB_iRMS (v)	R_Ang_Vel (º/s)	R_Ang_Acc (º/s2)	R_FR_iRMS (v)	R_VM_iRMS (v)	R_FB_iRMS (v)
Phase 1										
Mean	41'24	122'79	0'0103	0'0252	0'0609	39'14	128'38	0'0117	0'0372	0'0550
SD	15'54	73'96	0'0082	0'0143	0'0446	10'43	52'15	0'0078	0'0216	0'0272
Phase 2										
Mean	58'65	289'96	0'0033	0'0083	0'0498	61'87	291'34	0'0038	0'0126	0'0296
SD	19'46	141'56	0'0041	0'0114	0'0604	12'91	118'76	0'0045	0'0195	0'0295
Phase 3										
Mean	52'78	295'63	0'0033	0'0067	0'0217	57'03	280'39	0'0040	0'0103	0'0113
SD	19'76	127'45	0'0022	0'0047	0'0338	10'93	79'10	0'0026	0'0102	0'0154
Phase 4										
Mean	32'56	75'00	0'0143	0'0222	0'0252	38'70	91'88	0'0152	0'0303	0'0158
SD	12'00	61'59	0'0135	0'0153	0'0250	7'73	27'50	0'0107	0'0258	0'0115

Table 2. Pearson correlation and level of significance between kinematic and iRMSEMG. Shaded and bold p<0.05, * p<0.01 and ** p<0.001.

		FR_Left	VM_Left	FB_Left	FR_Right	VM_Right	FB_Right
Phase 1							
Ang_V	Corr.	-,057	-,009	**-,339****	-,095	-,025	-,003
	Sig.	,537	,920	**,000**	,303	,784	,972
Ang_Acc	Corr.	-,131	**-,200***	**-,385****	-,083	-,100	**-,276****
	Sig.	,153	**,028**	**,000**	,365	,277	**,002**
Phase 2							
Ang_V	Corr.	-,022	-,057	**-,334****	**-,291****	**-,389****	**-,290****
	Sig.	,812	,538	**,000**	**,001**	**,000**	**,001**
Ang_Acc	Corr.	-,005	-,097	**-,586****	-,145	**-,225***	**-,656****
	Sig.	,953	,290	**,000**	,114	**,013**	**,000**
Phase 3							
Ang_V	Corr.	**,233***	,126	-,071	**,352****	,071	-,079
	Sig.	**,010**	,171	,440	**,000**	,441	,392
Ang_Acc	Corr.	**,307****	**,197***	**-,375****	**,193***	**,251****	**-,433****
	Sig.	**,001**	**,031**	**,000**	**,035**	**,006**	**,000**
Phase 4							
Ang_V	Corr.	,081	**,181***	-,031	**-,307****	**-,187***	-,057
	Sig.	,377	**,048**	,735	**,001**	**,041**	,537
Ang_Acc	Corr.	,036	,061	-,080	**-,245****	-,052	**-,179***
	Sig.	,699	,505	,386	**,007**	,575	**,050**

The analysis of the recorded data has determined, in the first place, for the sequence and the activation period of the different muscles with the variation of hip joint velocity and acceleration. The instrumentation technique identifies the muscular action in the phases of acceleration and deceleration in flexion and extension. Initial and final instants of four phases of the motion were identified through the kinematic data: acceleration phase of the flexion, from the beginning of the record until the instant of maximum angular velocity; deceleration phase of the flexion, from instant of maximum angular velocity to maximum bending; acceleration phase of the extension, from instant of maximum bending to that of maximum angular velocity; and phase of deceleration of the extension phase, from instant of maximum angular velocity until the end of the record.

DISCUSSION: In the literature there were not enough similar cases of ballistic stretching kinematics and sEMG samples for comparison. Gianikellis et al. (2003) found a correlation between some iRMS variables and acceleration of the flexion-extension movement, similar to this case, measured with another kind of instruments (electrogoniometer) and not wireless EMG. Samukawa, Hattori, Sugama, and Takeda (2011), discussed ballistic stretches executed by the action of agonists and inactivation of antagonists. Our study result was in an opposite position as we detected a considerable activation of antagonist muscles during the phase where it was considered that they should not be active.

CONCLUSION: A methodology has been developed that allows studying electro-physiologic and functional behavior of biokinematic unity, in this case, hip joint, in ballistic stretching in terms of angular variation, angular velocity and angular acceleration. This approach provides fundamental information to deepen understanding of the neuromuscular system and it can have many applications in biomechanics analysis of human movement.

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