ESTIMATION OF HORSE LEG MUSCLES FORCE DURING JUMPING

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The purpose of the present study was to estimate horses' leg muscle forces in jump height during jumping a spread fence of different heights. A digital camcorder was used (25 Hz) along with Ulead Studio program in order to obtain time, muscle lengths at rest, compression, extension, jump distance, and various angles in horse's legs data. The total jump distance and time of flight for each horse were measured with a precision of 10^{-2} m and 10^{-2} s respectively. Biomechanical formulae have been established in order to evaluate the muscles stiffness coefficients. Three groups of leg muscles; serratus ventralis, biceps brachii, and radial carpal extensor were considered in this study and their forces were successfully estimated.

Key words: horse, serratus ventralis, biceps brachii, radial carpal extensor, force, jumping

INTRODUCTION: So far few studies have been evaluating horses kinematics and kinetics; Shahbazi and Khosravi (2007, 2008), the CG kinematics of horses jumping over relatively small fences (=1m high) reported by Powers and Harrison (1999, 2000), and jumping over a water jump (=4.5m wide) reported by Clayton et al., (1996). An early study (Clayton and Barlow, 1989) examined the effect of fence dimensions on the limb placement of jumping horses, but no analysis was conducted on the CG kinematics and estimation of muscles stiffness. Shahbazi (2004) and Shahbazi and Erfani (2005) modeled human legs and reported reasonable stiffness coefficient values and thereafter estimated legs muscles forces in sprinters. The take-off kinematics of jumping horses in puissance competition was investigated and reported by Powers (2005). The body position and kinematics of a horses' centre of gravity at take-off are important factors determining the jump outcome. Unlike human athletes, horses are unable to significantly alter their body positions during jumping and therefore need to raise their CGs substantially, in order to clear the fence. The take-off is crucial to the jump outcome. Jumping requires the horse to raise its centre of mass high enough for all of its body parts to successfully clear the height and width of a fence. The jump should be viewed as an increased part of the suspension phase or an elevated canter stride as it occurs between the stance phase of the fore and hind limbs, for this reason jumping is mostly performed whilst cantering. So far there was no biomechanical investigation of horses' muscles kinetics in jumping and no leg muscles forces estimates were reported. The main aim of this study was to model and estimate horse's leg muscles forces in the linear CG kinematics and kinetics of take-off through establishing biomechanical relationships. These muscles were chosen because they were touchable to put landmarks .on with visible variation in length to measure for our mathematical model.

METHODS: Video recordings (25 Hz) were obtained of eight top horses jumping over a fence of 1.0 m height. A single Sony camera was set up at 10m from the fence and perpendicular to it. The field of view measured about 6m wide and encompassed one full approach stride and the take-off phase. Video recordings were then transferred into ULead Studio program in order to measure the different angles of horse's leg's joints (angles between fibula-femur and pelvis) in two distinct positions and time sequences. The muscles lengths were then measured in all three phases; at rest, compression, and extension with Matlab programs. The riders average mass was (54±1.5 kg) and the horses average mass was 540±43 kg.

Formulae:

Shahbazi and Khosravi (2008) established the necessary formulae for muscles stiffness coefficients as followings:

$\mathbf{k_3} = -M\,[v^2 A\,(\Delta l_2)^2 + 2A\eta g - \lambda_1(a_x + a_y)] / (\lambda_1 C + \lambda_3 A)$
(1)

$\mathbf{k_1} = M\,[v^2 C\,(\Delta l_2)^2 + 2C\eta g - \lambda_3(a_x + a_y)] / (\lambda_1 C + \lambda_3 A)$
(2)

$\mathbf{k_2} = [k_1\,\Delta l_1 \cos\theta_1 + k_3\,\Delta l_3 \cos\theta_3] / (\Delta l_2 \cos\theta_2)$
(3)

In which λ_1, η, λ_3 and A and C are defined as follows:

$(\Delta l'_1)^2 (\Delta l_2)^2 - (\Delta l_1)^2 (\Delta l'_2)^2 \equiv \lambda_1$, $(\Delta l'_3)^2 (\Delta l_2)^2 - (\Delta l_3)^2 (\Delta l'_2)^2 \equiv \lambda_3$, and $h'_{cm} (\Delta l_2)^2 - h_{cm} (\mathbf{\Delta l'_2})^2 \equiv \eta$
(4)

$\Delta l'_1 \sin(\theta'_1 + \theta'_2) + \Delta l_1 \sin(\theta_1 + \theta_2) \equiv A$ and $\Delta l'_3 \sin(\theta'_3 + \theta'_2) + \Delta l_3 \sin(\theta_3 + \theta_2) \equiv C$
(5)

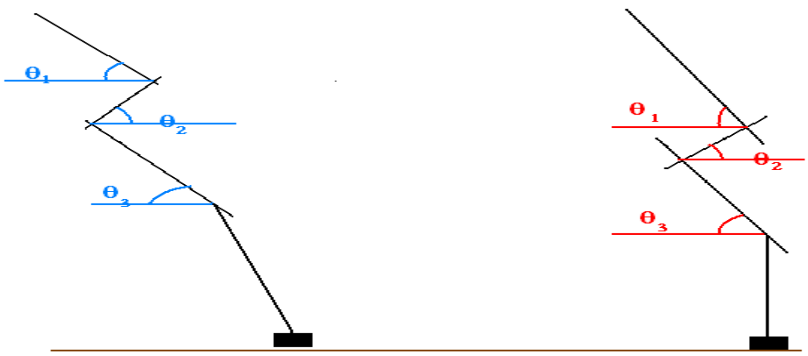

Figure1. One of the horses jumping; muscles groups at contraction (right) and in extension (left). The sticks showing the different angles in two phases.

Δl_1, Δl_2, Δl_3 are the serratus ventralis, biceps brachii, and radial carpal extensors muscle groups variations at compression phase respectively and $\Delta l'_1$, $\Delta l'_2$, and $\Delta l'_3$ are the variations in extension phase. θ_1, θ_2, θ_3 ,and θ'_1,θ'_2, and θ'_3 (Fig.1) are the angles which these muscle groups make with each other in the two phases, Shahbazi and Khosravi (2008).

RESULTS AND DISCUSSION: Eight horses jumped the fence at 1 m height, three times each. The procedures of finding the different parameters; $\Delta l_1, \Delta l_2, \Delta l_3$, $\Delta l'_1, \Delta l'_2$, $\Delta l'_3$, and θ_1, θ_2, θ_3 , θ'_1,θ'_2, θ'_3 were the same as were recited in two previous papers, Shahbazi and Khosravi (2007, 2008). In order to get precise muscles lengths ($\Delta l_1, \Delta l_2, \Delta l_3$, and $\Delta l'_1, \Delta l'_2, \Delta l'_3$) in two phases, Matlab programming was successfully used.

Table1. Values of different angles and variations of muscles lengths groups in two phases

Parameters	1	2	3	4	5	6	7	8
θ1 Deg.	52	49	37	44.5	51	43.5	45.5	47.5
θ2 Deg.	55.5	50	57	55	39	39.5	39	35
θ3 Deg.	54	47	37	45.5	51	43	48.5	49.5
θ'1 Deg.	30	35	38	23	35	27	33.5	30.5
θ'2 Deg.	69	74	66	72.5	60	62.5	59	57
θ'3 Deg.	42	47	46	43.5	52	44.5	46.5	46.5
Δl1 cm	0.0175	0.065	0.07	0.04	0.05	0.03	0.0545	0.0525
Δl2 cm	0.0375	0.055	0.11	0.015	0.07	0.0225	0.0335	0.0325
Δl3 cm	0.0175	0.06	0.02	0.04	0.03	0.0175	0.028	0.025
Δl'1 cm	0.0575	0.04	0.06	0.01	0.03	0.04	0.044	0.045
Δl'2 cm	0.0625	0.09	0.14	0.08	0.09	0.05	0.090	0.095
Δl'3 cm	0.025	0.01	0.04	0.02	0.03	0.08	0.033	0.035

Table 2. Values of muscles stiffness coefficients and corresponding forces

Muscles		1	2	3	4	5	6	7	8
serratus ventralis	k1	7.32E+06	3.69E+07	3.02E+06	6.27E+07	1.63E+07	5.91E+07	5.08E+05	5.28E+05
biceps brachii,	k2	6.54E+06	1.55E+06	7.05E+04	1.51E+05	1.12E+04	6.78E+05	5.14E+04	5.44E+04
radial carpal	k3	6.67E+06	3.95E+07	1.14E+07	6.23E+07	2.76E+07	1.01E+08	1.28E+06	1.58E+06
serratus ventralis	F1	1.28E+05	2.40E+06	2.12E+05	2.31E+06	2.51E+06	1.77E+06	2.37E+04	2.77E+04
biceps brachii	F2	2.80E+03	8.51E+04	7.75E+05	2.78E+03	2.26E+03	1.53E+04	1.47E+03	1.77E+03
radial carpal	F3	1.17E+05	2.37E+06	2.29E+05	2.14E+06	2.49E+06	1.77E+06	3.65E+04	3.95E+04

In Table 1, values of different angles along with variations of muscle lengths groups in two phases for eight horses are given. In Table 2, muscles stiffness coefficients and corresponding forces are given. As can be seen, the values for the same angle vary remarkably from one horse to another, this means that the values depended remarkably on the rider technique and skill for jumping. The serratus ventralis muscle group force varied between; 2.4×10^4 to 2.5×10^6 N. and for biceps brachii muscle group force varied between; 2×10^3 to 7×10^5 N. and finally for radial carpal extensors muscle group varied between; 3.6×10^4 to 2.5×10^6 N.

CONCLUSION: The mechanical modeling suggested by Shahbazi and Khosravi (2008) has been used to evaluate the force of horse's leg muscle groups at take-off in jumping over a fence of 1m height. Mathematical formulae have been used to calculate these muscle forces. By using this method, the kinetic variables at take-off were found and riders, trainers and the owners of horses would be able to recognize their horse's muscle force and strength and can take necessary actions to improve their horse in jumping. The model needs filming and then measuring the time of flight of CM, the different leg joint angles in two positions; and the muscles measurements in different positions. With the help of Matlab programming and finally the use of the established formulae one can achieve horse leg muscles group forces.

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