BIOMECHANICAL ANALYSIS OF ELEMENTARY BALLET JUMPS: INTEGRATION OF FORCE PLATE DATA AND EMG RECORDS

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The purpose of this research was to analyze the electromyographic (EMG) activity, ground reaction force and muscular behavior (concentric, isometric or eccentric) of the lower limb during elementary *ballet* jumps: "*sauté*" in first position; "*sauté*" in fifth position; "*sauté en cou de pié*". Three trials of each jump were performed by a experienced female Ballet dancer. Results pointed out the existence of a pre-activation effect before landing in almost all cases. They also showed the negative correlation of EMG on the agonist-antagonist pair *tibialis anterior* and medial *gastrocnemius* and a positive correlation of the EMG activity of *adductors* and *rectus femoris*, between medial *gastrocnemius* and *soleus*, and between *rectus femoris* and the vertical ground reaction force. However, most of the parameters measured show great sensitivity to the technical execution making it impossible to generalize these findings.

KEY WORDS: EMG, dynamometry, ballet.

INTRODUCTION: The assessment of internal forces in general Biomechanics, as well as in sport Biomechanics, remains a very difficult task, and a main topic of interest. The evaluation of internal forces, meanwhile, is determinant for the understanding of mechanical stress of biomaterials, and injuries (Simpson, 1997a, b). Equally important for this purpose is the knowledge of muscular activity (Trepman et al., 1998; Treapman et al., 1994), specially if related with internal and/or external forces. The purpose of this research was to analyze the electromyographic (EMG) activity, ground reaction force and muscular behavior (concentric, isometric or eccentric) of the lower limb during elementary *ballet* jumps.

METHODS: The present study evaluated one experienced female *ballet* dancer (25 years old, 54 kg, 158 cm) with no relevant clinical history. She performed three trials, of three different *ballet* jumps referred as 1, 2 and 3: "*sauté*" in first position; "*sauté*" in fifth position; "*sauté en cou de pié*". Results were considered as mean values of the three trials for each jump. Vertical ground reaction force was recorded using an AMTI force plate sampled at 500Hz. Forces were presented in percentage of body weight. Electromyographic data were collected using active surface electrodes, placed over eight muscles on the right side of the lower limb: *adductors*, *gluteus maximus*, *rectus femoris*, hamstrings, *tibialis anterior*, *peronaeus*, medial *gastrocnemius* and *soleus*. Electromyographic records were smoothed (RMS envelope) and presented as a percentage of the EMG obtained during a maximum voluntary isometric contraction (%MVC). The isometric condition was ensured by constraining the relevant joint movements. The jumps were recorded in videotape, at 120 images per second, and later digitized in the APAS Ariel system. Muscular contraction velocities were calculated by deriving the relative muscular length, obtained from kinematical data using the expressions from Hawkins and Hull (1990).

RESULTS AND DISCUSSION: The main results of the study are summarized in Tables 1 to 4. They exhibit the maximum relative ground reaction force on the landing [Fz(land)] and take off phases [Fz(to)] and the maximum EMG records on the landing [%mvc(land)] and take-off phases [%mvc(to)]. As these maximums don't occur simultaneously, we also report the difference between those two instants [dt(land)] and [dt(to)], where a positive value means that the maximum EMG activity occurs before the maximum ground reaction force. Note that the maximum voluntary isometric contraction for the *Soleus* was, most probably, incorrectly executed. Additionally we report the relative muscle contraction velocity at the same time that the maximum EMG record occurs. This allows the identification of the contraction regime (eccentric, isometric or concentric).

Table 1. Results on the time duration (dt), EMG records as percentage of maximal voluntary contraction (%MVC), and estimations of relative muscular contraction velocity (Veloc) of the landing phase (land) and the take-off (to) phase obtained during the "sauté" in first position (jump 1).

	Adduct.	**Gluteo Maxim.**	**Rectus Femoris**	**Hamstrin.**	**Tibialis Anterio**	**Peroneau**	**Medial Gastroc.**	**Soleus**
dt(land) s	0.02	0.01	0.02	0.00	-0.05	0.05	0.03	0.04
dt(to) s	-0.02	0.04	0.01	0.01	-0.01	0.05	0.04	0.03
%MVC (land)	0.94	0.29	1.13	0.40	0.51	0.67	0.81	3.82
%MVC (to)	0.95	0.36	1.12	0.59	0.42	0.91	0.80	4.11
Veloc (land)/s	----	----	0.29	-0.25	0.12	----	-0.16	-0.06
Veloc (to)/s	----	----	0.11	-0.05	-0.06	----	0.08	0.06

Table 2. Results on the time duration (dt), EMG records as percentage of maximal voluntary contraction (%MVC), and estimations of relative muscular contraction velocity (Veloc) of the landing phase (land) and the take-off (to) phase obtained during the "sauté" in fifth position (jump 2).

	Adduc.	**Gluteo Max.**	**Rectus Femoris**	**Hamstring.**	**Tibiali. Anter.**	**Peronea.**	**Medial Gastrocne.**	**Soleu.**
dt(land) s	0.00	-0.02	0.00	-0.04	-0.07	0.02	0.02	0.01
Dt(to) s	-0.01	0.02	0.02	0.04	0.04	0.08	0.09	0.03
%MVC (land)	1.03	0.35	0.97	0.55	0.43	0.81	0.82	3.64
%MVC (to)	0.94	0.40	0.94	0.49	0.29	0.85	1.18	4.22
Veloc (land)/s	----	----	-0.04	-0.03	-0.06	----	0.00	0.03
Veloc (to)/s	----	----	0.05	-0.09	0.07	----	-0.01	-0.04

The main EMG activity occurs in the *adductors*, *rectus femoris* and medial *gastrocnemius*. From the delay analysis, it is apparent the co-activation of the *adductors* and *rectus femoris*. A cross-correlation of the EMG records of these muscles is summarized on table 5. Although there is a large variability, some jumps show a high correlation between the EMG activity of *adductors* and *rectus femoris*. There is also a large correlation between the *rectus femoris* EMG and the ground reaction force, as can be seen in table 6. Although the EMG activation sequence varies from jump to jump (it is very dependent on the technique), a pre-activation or increased activity just before ground contact is visible (Fig. 1). Also from the delay analysis, it is apparent that the medial *gastrocnemius* and *soleus*, in jumps 1 and 3, work closely. Table 7 summarizes the cross-correlation between the EMG records of these two muscles. The correlations show that medial *gastrocnemius* and *soleus* have indeed a high correlation in their activity, although with lags varying with the type of jump. Finally, we note the negative correlations in the agonist-antagonist pair medial *gastrocnemius* and *tibialis anterior*, as can be seen in table 8.

Table 3. Results on the time duration (dt), EMG records as percentage of maximal voluntary contraction (%MVC), and estimations of relative muscular contraction velocity (Veloc) of the landing phase (land) and the take-off (to) phase obtained during the "*sauté en cou de pié*" (jump 3).

	Adduc.	**Glute. Max.**	**Rectus Femoris**	**Hamstring**	**Tibiali Anter.**	**Peroneau**	**Medial Gastrocn.**	**Soleu**
dt(land) s	0.00	-0.04	0.00	-0.06	-0.06	0.02	0.01	0.03
Dt(to) s	0.01	0.01	0.01	-0.04	0.03	0.05	0.03	0.04
%MVC (land)	0.89	0.66	1.05	0.40	0.53	0.50	0.86	3.31
%MVC (to)	0.90	0.79	1.28	0.40	0.27	0.71	1.05	4.13
Veloc (land)/s	----	----	0.01	0.12	0.00	----	0.04	-0.01
Veloc (to)/s	----	----	-0.03	0.21	0.06	----	-0.18	-0.10

Table 4. Relative ground reaction force on the landing [Fz(land)] and take off phases [Fz(to)].

	Jump 1	**Jump 2**	**Jump 3**
Fz (land)	3.54	3.11	2.63
Fz (to)	3.04	3.00	2.58

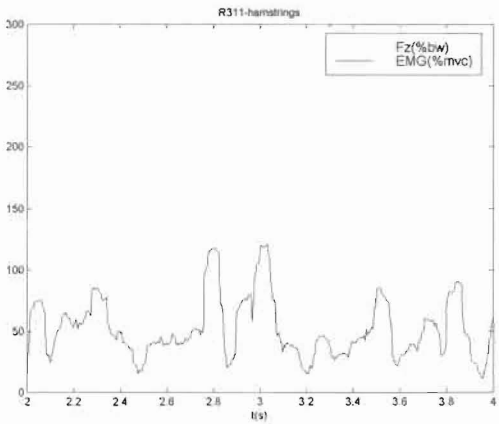

Figure 1. Example of synchronized records of ground reaction forces (Fz), presented in percentage of body weight, and EMG activity, as a percentage of maximal voluntary contraction, of the hamstrings during the first trial of the third jump ("*sauté en cou de pié*").

Table 5. Cross-correlation between EMG records from *adductors* and *rectus femoris*.

	Jump 1/exec.1	**Jump 1/exec 2**	**Jump 2/exec.1**	**Jump 2/exec.2**	**Jump 2/exec.3**	**Jump 3/exec 1**	**Jump 3/exec 2**
Correlation	0.671	0.493	0.358	0.677	0.673	0.662	0.366
Delay (s)	0.07	0.10	0.08	0.10	0.08	0.07	0.10

Table 6. Cross-correlation between EMG from *rectus femoris* and vertical ground reaction force.

	Jump 1/exec.1	Jump 1/exec 2	Jump 2/exec.1	Jump 2/exec.2	Jump 2/exec.3	Jump 3/exec 1	Jump 3/exec 2
Correlation	0.716	0.753	0.801	0.649	0.750	0.863	0.806
Delay (s)	0.20	0.14	0.16	0.14	0.12	0.19	0.18

Table 7. Cross-correlation between EMG records from medial *gastrocnemius* and *soleus*.

	Jump 1/exec.1	Jump 1/exec 2	Jump 2/exec.1	Jump 2/exec.2	Jump 2/exec.3	Jump 3/exec 1	Jump 3/exec 2
Correlation	0.802	0.704	0.735	0.694	0.754	0.705	0.694
Delay (s)	0.10	0.12	0.18	0.29	0.21	0.07	0.06

Table 8. Cross-correlation between EMG records from medial *gastrocnemius* and *tibialis anterior.*

	Jump 1/exec.1	Jump 1/exec 2	Jump 2/exec.1	Jump 2/exec.2	Jump 2/exec.3	Jump 3/exec 1	Jump 3/exec 2
Correlation	-0.466	-0.590	-0.560	-0.503	-0.549	-0.453	-0.224
Delay (s)	0.19	0.18	0.23	0.25	0.28	0.21	0.21

Other correlations have been tried but were found too weak or with lags longer than the contact phase (about 0.3s). The above relations between the medial *gastrocnemius* and *soleus* (*tricepts surae*) and the *tibialis anterior* are also present in the relative contraction velocities (tables 1 to 3). Whenever the *tricepts surae* is working eccentrically the *tibialis anterior* is working concentrically, and *vice-versa*. This is not always observed for the pair *rectus femoris* – hamstrings (although it is in co-contraction almost all the time) as they are both multi-joint muscles. Finally, as is apparent from the tables above, there are large variations in all the parameters from execution to execution as they are very dependent on the technique. However this does not change the qualitative aspects stated above.

CONCLUSIONS: Results pointed out the existence of a pre-activation effect before landing in almost all cases. It can also be concluded from the correlations obtained that co-contractions are intense and should be taken into account during biomechanical analysis of Ballet jumps, namely in an inverse dynamics approach. We also observed large changes in the recorded parameters from execution to execution and with simple changes in the jumps performed, making it problematic to generalize the quantitative results. But the qualitative conclusions – the existence of important pre-activation and co-contractions - will need to be taken into account in the inverse dynamic studies that we will follow.

REFERENCES

Hawkins, D. and M. L. Hull (1990). A method for determining lower extremity muscle-tendon lengths during flexion/extension movements. *Journal of Biomechanics*, **23** (5), 487-94.

Simpson, K. J. and L. Kanter (1997a). Jump distance of dance landings influencing internal joint forces: I. Axial forces. *Med Sci Sports Exerc*, **29** (7), 916-27.

Simpson, K. J. and M. Pettit (1997b). Jump distance of dance landings influencing internal joint forces: II. Shear forces. *Med Sci Sports Exerc*, **29** (7), 928-36.

Trepman, E., R. E. Gellman, et al. (1994). Electromyographic analysis of standing posture and demi-plie in ballet and modern dancers. *Med Sci Sports Exerc*, **26** (6), 771-82.

Trepman, E., R. E. Gellman, et al. (1998). Electromyographic analysis of grand-plie in ballet and modern dancers. *Med Sci Sports Exerc*, **30** (12), 1708-20.