GROUND REACTION FORCE PATTERNS FOR THE EVALUATION OF MOTOR RECOVERY IN ATHLETES AFFECTED BY KNEE INJURIES

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INTRODUCTION

Vertical jump is a complex multi-joint exercise widely adopted to evaluate some motor characteristics of athletes. Usually, only the vertical displacement of the body is considered, although, as any other synthetic index, it provides little information about the biomechanical and physiological contributor factors to the performance.

As it has been previously evidenced by several researchers, vertical ground reaction force (VGRF) can be used to obtain more information about the efficiency and motor coordination of the lower limbs action during vertical jump exercises. Indeed, it is the temporal and spatial coordination pattern between the angular movements of the joints'that determines the final shape and size of the VGRE Oddsson (1989) reported of a study designed to investigate the relationship between jumping height and parameters of the force-time curve of the VGRF and the height of vertical jumps executed using different strategies. Similarly, Dowling and Vamos (1993) analyzed the counter movement vertical jump (CMVJ) and the resulting force-time curves to identify the kinetic and temporal characteristics related to a good performance.

The results presented in the studies mentioned above have been obtained in experiments including only healthy test subjects. Compariqg the VGRF patterns obtained by a group of subjects who had suffered a unilateral ACL injury, with those of an healthy group of athletes, the aim of this study was to verify whether or not the VGRF recorded during the execution of CMVJs could be used to evaluate the functional restoration of the subject and, eventually, to give indications about changes in the training program.

METHODS

Four athletes, (age 27.0 ± 3.0 yr., height 179.0 ± 2.7 cm, body mass

74.7 ± 3.1 kg) who had suffered a unilateral ACL injury within the two-year period prior to the study, and 10 uninjured athletes (age 22.1± 2.7 yr., height 178.6 ± 4.8 cm, body mass 77.6 ± 7.0 kg) were the subjects of this study. All of the subjects are semi-professional rugby players playing in the Italian second league. At the time of the acquisition all the injured subjects had been reintegrated in the team training and competition programs.

The subjects were asked to perform 5 series of 5 maximal two-legged CMVJ, while keeping the arms behind their backs to minimize the contribution of the upper part of the body to the thrust of the legs. To avoid fatigue effects, between each jump and series, they stopped 2 and 5 minutes, respectively. The athletes were asked to keep one foot at time over the force platform. Jumping height was computed through the flight time by means the ballistic equation.

Ground reaction forces were recorded by a Kistler force platform at the sampling rate of 500 Hz. The force and timing parameters have been computed as illustrated in Figure 1 where a typical GRF time course is shown. In agreement with some previous studies, it is characterized by an initial decay of the force, followed by two maxima with a relative minimum.

The following parameters have been computed by referring to Oddsson and Dowling.

$t_n = t_2$ (negative impulse duration),
$t_p = t_6 - t_2$ (positive impulse duration),
$t_{mM} = t_3 - t_1$ (time elapsed between M1 and ml),
$t_{MM} = t_5 - t_3$ (time elapsed between the two maxima),
$t_{nn} = D - t_6$ (duration of the final negative impulse)

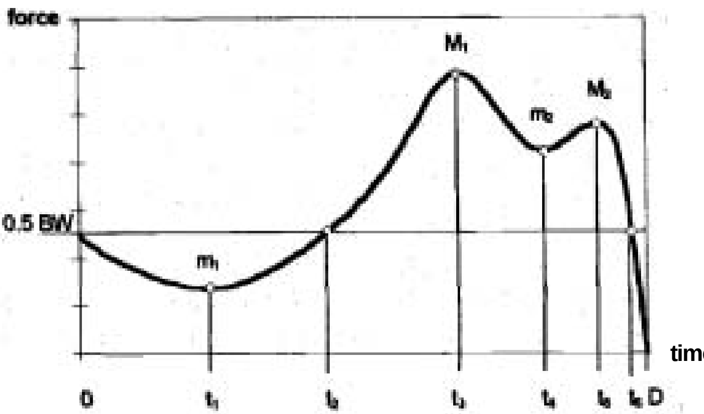


Figure 1: Averaged VGRF time course of CMVJ, the data belongs to the group of healthy subjects. The computed time and force parameters are evidenced.

The Wilcoxon-Mann-Whitney rank test for independent samples and the paired t-test were used to assess whether or not significant differences', in the selected **VGRF** parameters, exist between the two groups, and between the pathological and sound limb of the injured athletes, respectively.

RESULTS AND DISCUSSION

The mean jumping height values were 31.8 ± 5 cm and 30.8 ± 3.7 cm, respectively, for the healthy and pathological subjects. The results were comparable to those obtained in other studies involving athletes of the same level practicing similar sport activities (Bosco, 1995). The intra-individual performance variability was very low, with the individual coefficient of variance (CV) ranging from 2,1 to 4,2%. This result would confirm the good motor skills of our athletes and the absence of fatigue effects due to the experimental protocol. Moreover, the low inter-individual variability of the two groups (CV for the healthy group: 8,6; CV of the injured group: 11,7) underlines the homogeneity of the samples.

Table 1. Averaged timing parameters. Bold values indicate significant statistical difference

	t_1(ms)	t_3(ms)	t_4(ms)	t_5(ms)	t_6(ms)	D(ms)
Healthy	**322(104)**	940(92)	1083(87)	1177(95)	1237(121)	1264(97)
Pathol.	**216(75)**	1037(162)	1125(33)	1238(120)	1298(112)	1329(130)

Table 2. Timing parameters calculated as suggested by Oddsson and Dowling

	t_n(ms)	t_p(ms)	t_{mM}(ms)	t_{MM}(ms)	t_{m}(ms)	
Healthy	536(105)	**703(98)**	**618(83)**	236(46)	87(10)	
Pathol.	454(158)	**943(99)**	**801(103)**	231(63)	85(12)	

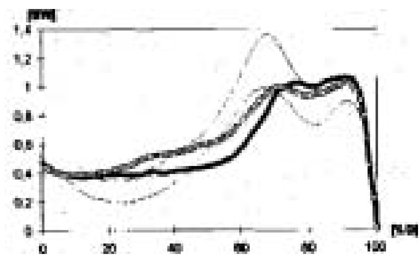
Table 3.

	m_1(%BW)	M_1(%BW)	m_2(%BW)	M_2(%BW)	
Healthy	**18.8(7.6)**	**119.6(17)**	80.9(11.5)	**93.9(5.8)**	
Pathol.	**31.0(5.8)**	**98.3(11.5)**	87.2(12.3)	**102.1(5.7)**	

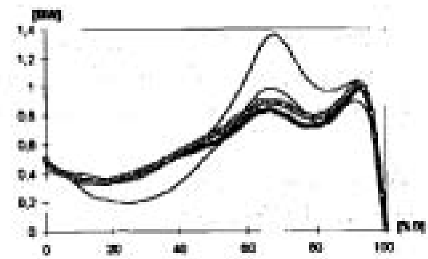
As it can be noted from Tables 1 and 2, pathological subjects reached the first minimum earlier, have a shorter propulsive phase, performed the countermovement with a longer deceleration phase and need more time to complete the total movement.

By considering VGRF amplitude (Table 3), significant differences have been found among the amplitude of m,, M, and M„ with the pathological subjects showing a higher first minimum, and, in contrast with the healthy group, the second maximum higher than the first one.

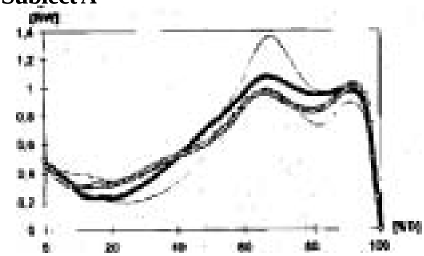
To better deepen the above differences, in Figure 2, the VGRF recorded for the pathological subjects was compared with the data recorded for the healthy subjects. Individual VRGF patterns in combination with different asymmetry levels between the sound and pathological limb are well evident.



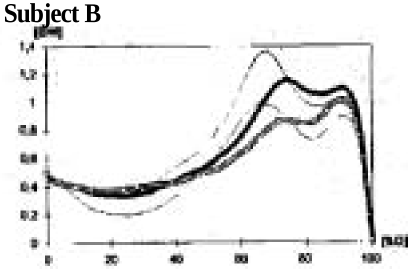
Subject A



Subject B



Subject C



Subject D

Figure 2: GRF time course during vertical jump computed in ACL subjects (- : sound limb, (. : pathological limb). Data have been normalized to BW and duration

Table 4. Time parameters for the pathological subjects. Data were computed subtracting the time parameter of the pathological limb to the time parameter of the sound limb and dividing the result by the total duration of the propulsive phase

Subject	t_1(%)	t_3(%)	t_4(%)	t_5(%)	t_6(%)	D(%)
A	0.8	2.5	1.1	-0.2	1.3	1.3
B	-5.2	**-6.7**	**-6.6**	**-6.7**	**-6.7**	**-6.5**
C	**-15.9**	**-15.8**	**-15.2**	**-18.9**	**-17**	**-17.4**
D	-9.5	-0.9	1.3	0.0	-2.0	-2.0
Healthy	3.7	1.1	1.1	2.4	2.4	2.4

Table 5. Relevant time parameters for the pathological subjects

Subject	t_n(%)	t (%)	t_{mM}(%)	t_{MM}(%)	t_n (%)
A	0.4	1.7	1.8	-2.7	-0.6
B	-5.4	-1.3	-1.5	-0.1	-0.3
C	**-9.3**	-7.8	0.1	-3.1	0.7
D	0.9	-2.9	**-10.4**	0.9	-0.5
Healthy	1.1	1.3	2.6	1.3	1.2

Table 6. Analysis of the differences in VGRF peaks for the sound and the pathological limb (computed as (VGRF(sound)-VGRF(pathological))/ maximum peak sound limb)

Subject	m_1	M_1	m_2	M_2
A	**1.1**	3.2	**6.7**	**1.2**
B	0.1	-4.5	**-6.2**	-1.7
C	**10.7**	**11.3**	**10.6**	-3.9
D	-2.9	**23.8**	**18.5**	**7.1**
Healthy	7.3	4.5	3.6	3.2

From Figure 3 and Table 4, 5 and 6, asymmetries between sound and pathological limb can be evaluated. Each subject shows individual characteristics of asymmetry:

Subject A shows a difference only in the amplitude of the second minimum m_2;

Subject B: also shows a difference in the amplitude of the second minimum m_2, together with differences in timing from t_3 to the global duration D.

Subject C shows differences in m,, M, and m_2 and in the global timing of all the propulsive phase.

Subject D shows differences in M,, m_2 and M_2 and a delay in passing from the first minimum to the first maximum.

Despite the above differences in the shape of VGRF-time curves and in many of the related parameters, the jumping height obtained by the two groups is comparable. This would confirm the conclusion of Dowling & Vamos (1993) who found the force-time curves a rather weak diagnostic tool with regard the final jumping performance.

However, even if it is very difficult to establish causal relationships, considering that pathological subjects clearly use a different strategy compared to the healthy group to produce both the eccentric and concentric work, an explanation could be given. It can be hypothesized that while in healthy subjects the extension of the knee joint follows the extension of the hip joint, when there is apathology like a ACL, this sequence is altered and the two joints extend simultaneously, meaning a simultaneous activation of the hip and knee extensors. This motor pattern may effect the transformation of the angular acceleration into linear acceleration, giving an explanation for the lower first force peak and the higher second peak. The reason for this simultaneous activation of the flexors and the extensors of the knee may be due to the need to protect the injured joint increasing the joint stiffness.

CONCLUSIONS

In this study, the VGRF measured during the execution of CMVJs were analyzed by means of selected timing and amplitude parameters. Several differences, between the groups, were evidenced in the shape and size of the curves and thus in many of the derived parameters selected for this study.

Furthermore, when uninjured athletes are considered, a typical common VGRF pattern was observed, while, considering subjects who suffered of an ACL injury, each subject showed an idiosyncratic VGRF pattern. This could mean that every pathological subject, even if considered completely recovered by physicians and coaches, tends to adopt a different jumping strategy that could reflect a non completely recovered functional status and/or the adoption of compensatory strategies.

In addition, the test we used allows to identify, even two years later, biomechanical differences between the pathological and sound limb of a subject after an ACL injury. This can only rarely be observed without the aid of a dynamic test as the one we described.

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