CHANGES IN VERTICAL JUMP PERFORMANCE AS A RESULT OF ALTERING THE FORCE-TIME CURVE TO EXHIBIT A SMOOTH RISE TO PEAK FORCE

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INTRODUCTION

Optimization of performance has been examined primarily through computer simulation (Levine, Zajac, Belzer & Zomlefer, 1983; Pandy, 1990; Pandy, Zajac, Sim & Levine, 1990; Pandy & Zajac, 1991; Zajac &Winters 1990). These investigations control muscle and lever properties a priori to determine the optimum coordinative patterns for executing various skills. The general finding of these simulations suggest that too little is currently known about the multiple constraints on the human body to draw significant conclusions about human performance. Yet, computer generated optimizations of movement appear physically impossible to execute (Pandy & Zajac, 1991; Zajac & Winters, 1990). Inferences are made with no deference to actual performance profiles. Manipulation of kinetic profiles of individual performers to examine the hypothetical effect on skillfulness have not been done. Determination of an optimum curve, however, would allow performers to be tested and evaluated for technique parameters of movement that should change to attain optimal performance.

Payne, Slater, and Telford (1968) examined the kinetic patterns of the Static Jump (SJ), Countermovement Jump Without Armswing (CMNA), and the Countermovement Jump With Armswing (CMWA) produced by a skilled subject. The findings suggested that the addition of arms to the vertical jump adds an extra (second) peak to the force-time curve. The literature is void of systematic examination of the "second" peak. Shetty and Etnyre (1989) and Dowling and Vamos (1993) observed that the armswing did improve vertical jump, and found the force-time curve possessed only one peak. Dowling and Vamos (1993) indicated that 54 of 97 subjects produced force-time curves with a single peak. The anecdotal information from these two studies and pilot investigations led to speculation that a single maximum force peak in the force-time profile of vertical jumping may be an optimum pattern for skilled performance. Thus, the purpose of this investigation was to mathematically standardize the force-time curve to explore the hypothetical effect on individual performance. It was hypothesized that standardizing to a single peak would increase skillfulness whether determined by Effective Integration scores or vertical jump height for performers exhibiting multiple peaks in the force-time curve (see Figure 1).

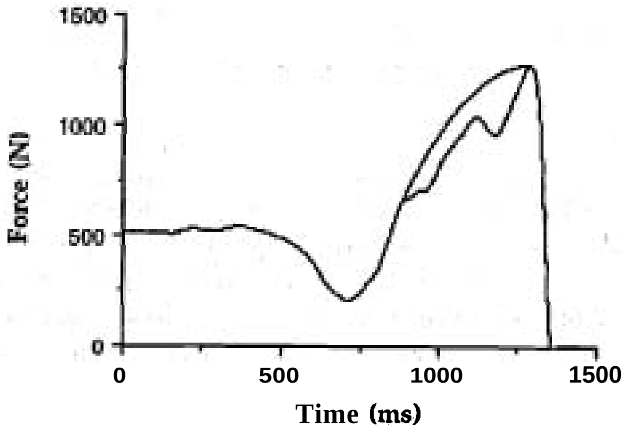

Figure 1. Standardized force-time curve using a parabolic trajectory over original force-time profile.

METHODS

Vertical ground reaction forces during the jumps were collected for 51 subjects. All subjects had 2-10 years experience in jumping intensive sports (e.g., volleyball, basketball, etc.). All subjects were in good health with no recent history of ankle, leg, knee, thigh, hip, back, or shoulder injury. Force-time data were acquired using a Kistler Force Platform (type 9281B) interfaced with a Kistler 9861A electronic unit that scaled the data and stored it in a Macintosh II computer. A purpose-made electrogoniometer interfaced with an IBM DACA A/D board connected to an American XT 286 computer was used to control crouch depth for SJ. Subjects performed multiple repetitions of maximal vertical jumps under the Countermovement Jumps with Armswing (CMWA) and Static Jump (SJ) conditions. To determine effective integration scores for vertical jumping, it was necessary for the subjects to execute three trials each of the two types of jump. The first was a CMWA jump. The second type of jump was the SJ. The subjects executed the SJ from a crouch position with hands placed on the hips. The subject maintained a stationary crouch position for 4 seconds before the "go" command was given. A time delay in the crouch allowed for the depletion of any stored elastic energy left in the muscles as a result of stretch (Wilson, Elliott & Wood, 1991). Trials were repeated if an unloading phase occurred before pushing out of the crouch position. The vertical force data were smoothed using a quintic spline.

Biomechanical variables were obtained from the smoothed vertical ground reaction force data. Each variable was related to the kinetic characteristics of the center of mass (COM) of the subject (see Figure 2). Variables used were: (a) minimum force **(Fmin)** applied to the force platform during the unloading phase of the countermovement; (b) maximum force (Fmax) applied to the force platform; (c) maximum positive slope of force (y) between the times of minimum force and maximum force applications; (d) average slope from minimum force to maximum force ($\bar{y}$); (e) force at the low point of the center of mass (↓F); (f) shape factor of the major positive impulse phase **(A)** **(i.e.,** the shape factor is a ratio of the area of the positive impulse to the area of a rectangle bounded by Fmax vertically and the duration of the time interval for the positive impulse); (g) ratio of negative impulse to positive impulse (R); (h) time for the major negative impulse phase (t1); (i) time from the low point of the COM to maximum force (t2); (j) time for the positive impulse **(t3);** (k) time from Fmax to takeoff **(t4);** and (l) time of eccentric contraction (t5).

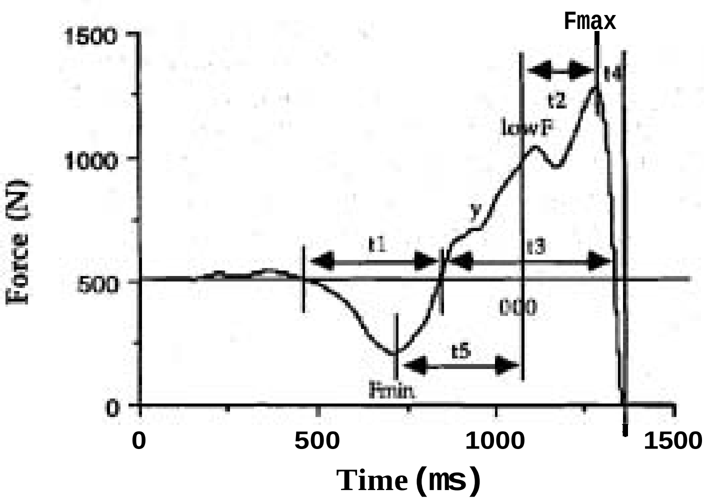

Figure 2. Biomechanical variables.

Standardization of the force curve occurred if there were two or more distinct peaks or if the positive slope of the force curve deviated by more than 5% before approaching a single peak. To "standardize" the force curve, one-half of a parabola was used. The parabola took the form of:

$f(x) = a(x - h)^2 + k$, where the axis for the parabola was the vertical line x = time, h = time of maximum force application, the vertex lies at the point (h,k), k = magnitude of maximum force application, and $a < 0$. This formula created a smooth trajectory for the force curve. The parabola ended at Fmax. Maximum force applied to the force platform was not altered. The decision not to alter Fmax was based upon the assumption that all individuals executed maximum effort vertical jumps in the original data acquisition. Forty-three of 51 trials were standardized. The remainder of the analysis examined the changes in the relationships of kinetic and temporal characteristics that occurred as a result of the standardization procedure. All standardized and unaltered trials were analyzed (n=51).

RESULTS

Performance measures for all individuals whose original data were standardized increased significantly. Non-standardized and standardized means and standard deviations for the dependent measures are reported in Table 1. Significant performance differences ($p<0.01$) were found between the non-standardized and standardized means ($F_{1,50} = 23.47$ for EIS, $F_{1,50} = 14.05$ for vertical jump height) for the variables indicated in Table 1.

Although performance measures for all individuals whose original data were standardized increased significantly, only four independent variables changed significantly as a result of forcing a smooth rise to peak force. These variables were: (a) ↓F; (b) A ; (c) R; and (d) t2. Table 1 reported non-standardized and standardized means and standard deviations for the independent measures influenced by standardization. A significant difference ($p<0.01$) was found between the non-standardized and standardized means ($F_{1,50} = 29.23$ for ↓F, $F_{1,50} = 48.30$ for A, $F_{1,50} = 26.39$ for R, and $F_{1,50} = 8.72$ for t2).

Table 1. Means and Standard deviations of nonstandardized and standardized data for all subjects. (n=51)

Variable	Nonstandardized Mean (SD)		Standardized Mean (SD)	
Fmin	0.45 BW	(0.22)	0.45BW	(0.22)
Fmax	2.59BW	(0.45)	2.59BW	(0.45)
y	16.86BW/s	(10.96)	16.52BW/s	(11.01)
y	5.35BW/s	(2.59)	5.35BW/s	(2.59)
↓F	2.15BW	(0.47)	2.22BW**	(0.44)
A	0.38	(0.07)	0.42**	(0.04)
R	-0.27	(0.07)	-0.24**	(0.06)
t1	0.40s	(0.16)	0.40s	(0.16)
t2	0.14s	(0.09)	0.15s**	(0.09)
t3	0.42s	(0.08)	0.42s	(0.08)
t4	0.17s	(0.09)	0.17s	(0.09)
t5	0.30s	(0.10)	0.29s	(0.09)
EIS_{vmax}	18.96%	(11.26)	40.43%**	(36.54)
Jump Height	33.66cm	(10.41)	50.08cm**	(33.81)

**p<.01

DISCUSSION

A significant main effect on skillfulness was found as a result of standardization of the force-time curve. This finding suggests that a smooth rise to peak force maintains positive acceleration in the system and allows the velocity of the system to maintain a consistent rise to peak. Standardization increased the force applied to the force platform at the low point of the body's center of mass. This finding would suggest that unsmooth rises to peak force or double peaks dissipate the force of the system during the eccentric phase of the vertical jump. The human musculoskeletal system can handle greater forces during eccentric contraction than during concentric contraction. Thus, subjects whose initial performances were altered were not getting the full benefit of the eccentric load imposed by countermovement. Smooth rises to peak force may allow performers to load the muscle more effectively prior to concentric impetus. Shape factor of the positive impulse also increased significantly as a result of standardization. A 1:1 ratio between perfect (rectangular) impulse and exhibited impulse is physically impossible as all muscle contractions need time to develop force. However, a smooth rise to peak force more closely approximates the ideal impulse by providing greater area under the curve than unsmooth or dual peaked curves. The negative/positive impulse ratio decreased as a result of the positive impulse becoming larger. Although a certain amount of negative impulse appears necessary, larger amounts of negative impulse are unnecessary for increased skillfulness. Time between the low point of the body's center of mass and the maximum application of force also increased significantly as the result of standardization. This result would suggest that performers who can produce a smooth rise to peak force will be able to concentrically contract the muscle over a longer period of time. Longer duration of positive impulse and shorter durations of time from low center of mass to maximum force and from maximum force to take-off lead to a more "rectangular-like" force-time curve.

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