JUMPING HEIGHT CAN BE ACCURATELY PREDICTED FROM SELECTED MEASUREMENTS OF MUSCLE STRENGTH AND BIOMECHANICAL PARAMETERS

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The ability to jump high is an important factor for successful performance in several team and individual sports. A large variety of training methods are employed to increase jumping ability (Bobbert, 1990). However, specific and efficient training of jumping ability for an individual athlete requires a detailed knowledge of factors limiting the vertical jump. Both coach and athlete would benefit from increased information about such factors (e.g. muscle strength), and a scientifically based test to ascertain individual deficiencies in the performance of a vertical jump (Oddsson, 1987).

The height of a vertical jump is determined by the vertical velocity at take-off. which in turn is the result of the angular impulses (muscle torques multiplied by their durations) at all joints involved in the movement The individual magnitudes and temporal coordination of these angular impulses will determine the shape and size of the vertical impulse from the ground (Hay. Vaughn, & Woodworth, 1980). The complexity of this coordination suggests that several factors related to strength as well as speed of movement limit the performance of a jump (Bobbert & van Ingen Schenau. 1988). The purpose of this study was to relate different biomechanical parameters and muscle strength to vertical jumping height

METHODOLQGY

Subjects and procedure

Twelve male students of physical education participated in the study (mean body height 1.81±0.05 m; mass 75.6±4.9 kg). All were habitually active and participated in sports; two of them were considered elite athletes (skating and weightlifting). Each subject performed four different forms of maximal vertical jumps (see Figure 1) on a Kistler force platform: (1) a "Rocket" Jump (RJ) from a fully crouched position on "tip toes" with the thighs resting against the calf muscles to avoid counter movement; (2) a

Counter Movement Jump (CMJ, hands held on the hips); (3) a Counter Movement Jump with a full arm swing (CMJP) and (d) a series of Bounce Jumps (BJ, hops at maximal height, with minimal ground contact time and minimal flexion at the knees and hands at the hips). Subjects were instructed to keep their body in a similar position during take-off and landing.

The vertical ground reaction force was recorded using a Mingograph inkwriter (Siemens-Elema 803, frequency response DC-1200Hz). Subjects performed two jumps of each kind, the best of which was used for subsequent analysis.

Muscle strength produced by the knee extensor muscles was measured isokinetically in a sitting position with a dynamometer (Seger, Westing, Hanson, Karlson & Ekblom, 1988) during concentric, isometric and eccentric muscle contractions (Seger, Westing, Hanson, Karlson & Ekblom, 1988). Torque was measured during one low (30 deg/s) and one high (270 deg/s) angular velocity in the concentric and eccentric modes, respectively. Isometric muscle torque was measured at 40 deg of knee flexion.

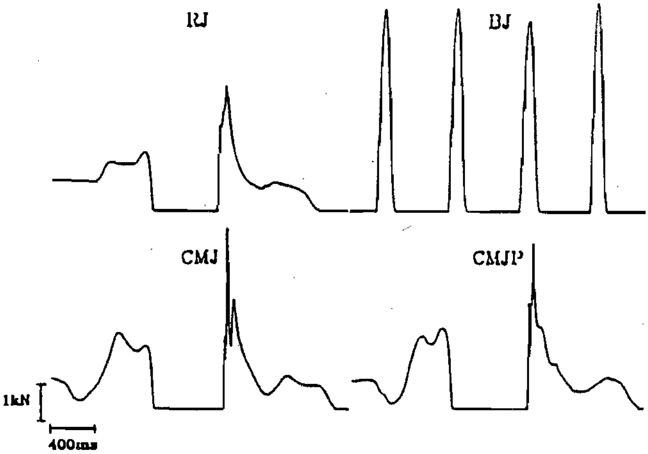

Figure 1. Example of recordings of vertical ground reaction force from one subject performing a Rocket Jump (RJ), a series of Bounce Jumps (BJ), a Counter Movement Jump without (CMJ) and with armswing (CMJP).

Analysis and statistics

Peak force and flight time were measured from the recordings of the vertical ground reaction force for the different vertical jumps. In addition, ground contact time was measured during BJ. Jumping height was calculated from flight time (Bosco, Luhtanen, & Komi, 1983). Potential energy change from lowest center of gravity position (assumed to occur at peak force) to peak height of the jump divided by time between peak force and take-off was used as a measure of power developed during BJ (Asmussen & Bonde-Pedersen, 1974).

Biomechanical parameters calculated from the forceplate data and measurements of muscle strength were entered into a stepwise multiple regression analysis, with jumping height during a CMJ as the independent variable. Differences between means were tested for significance using a one-way analysis of variance, followed by Tukey's range test ($p<.05$).

RESULTS

Jumping height and muscle strength

Figure 1 shows an example of the vertical ground reaction force recorded during the different forms of jumping. Subjects jumped lowest during BJ (0.30±0.07 m) somewhat higher during RJ and CMJ (0.35±0.06 and 0.38±0.08 m, respectively) and highest during CMJP (0.43±0.08 m). Height of CMJP was significantly larger than BJ height

Highest peak torques were produced during eccentric contractions (298±53 and 303±59 Nm for 30 and 270 deg/s, respectively) and lowest torques occurred during fast concentric contractions (135±26 Nm at 270 deg/s). Intermediate torques were seen during slow concentric (248±44 Nm at 30 deg/s) and isometric conditions (221±35 Nm).

A linear regression analysis showed a significant relationship between CMJ height and all muscle strength measurements ($r=.60$-$.78$, $p<.05$, Figure 2) except for eccentric torque at 30 deg/s ($r=.39$, $p>.05$).

Multiple regression analysis

In the multiple regression model the variation in isokinetic and isometric muscle strength explained 83% ($r=.91$) of the variation in the height of the counter movement jump. The biomechanical parameters explained 55% ($r=.74$) of the variation in jumping height The best fit was obtained when both biomechanical parameters and data on muscle strength were entered into the model (see Figure 3). In this situation the proportion of explained variance increased to 94% ($R=.97$). The parameters which significantly contributed to the explained variance in this situation were power developed during BJ, the ratio of flight time to ground contact time during BJ, the ratio of height during BJ to height during RJ, and torque developed during eccentric (30 deg/s) and isometric contractions.

DISCUSSION

The results of this study indicate that vertical jumping height can be accurately predicted from measurements of muscle strength and certain biomechanical parameters. In the group of subjects tested, muscle strength measured during eccentric, concentric and isometric quadriceps contractions was a better predictor of jumping height than biomechanical parameters alone. It can be concluded that several interacting physiological and biomechanical factors determine jumping height.

A common experience among coaches is that a group of non-trained jumpers will

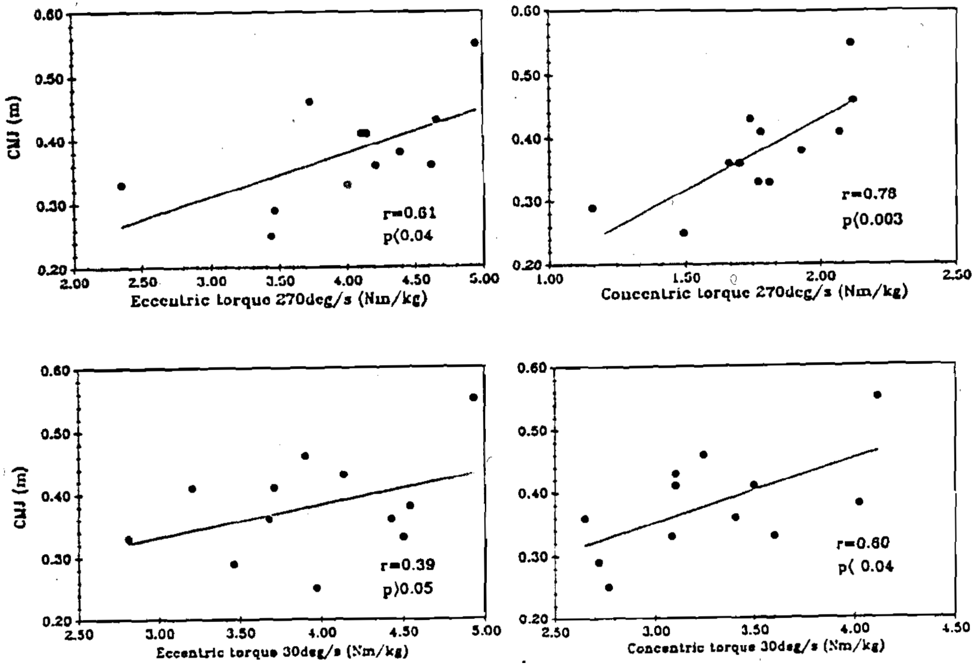

Figure 2. Peak torque (expressed per kg of body weight) produced during eccentric (left) and concentric (right) quadriceps contractions at 30 and 270 deg/s in relation to jumping height of a maximal counter movement jump (CMJ). The line indicates line of regression (r - simple regression coefficient)

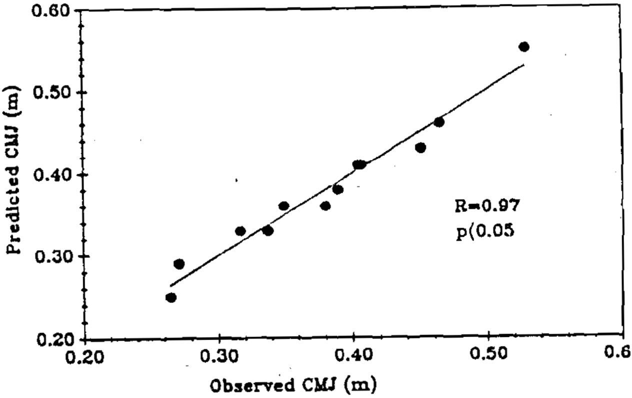

Figure 3. Predicted and observed values of counter movement jump (CMJ) from a multiple regression analysis when both measurements of muscle strength (torque/mass) and biomechanical parameters were entered into the model. The line indicates line of regression (R - multiple regression coefficient).

increase their vertical jumping ability with almost any kind of training program related to the muscles involved in jumping. As the athlete increases his/her level of performance, a general program to increase jumping ability becomes inefficient, a common experience especially among elite athletes. In this situation the specificity of training must improve if performance should continue to increase. Specificity is a well known and very important principle used in physical training. This principle suggests that the muscle adapts to the specific stimulus it is being exposed to, i.e. a muscle trained at a certain speed will increase strength at that speed, or if trained at a certain angle, then its strength will increase at that angle (Sale & Mac Dougall, 1981). Specificity of training requires a detailed knowledge of factors limiting the performance, as well as of training methods influencing these factors. The results of this study will form a basis for a test of such factors in the individual athlete. This test will guide the coach and athlete towards customizing a way of training for vertical jumping.

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