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Eccentric rate of force development determines jumping performance

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1. Introduction

Critical information can be directly extracted from the force–time (F–T) curve during the vertical counter-movement jump (CMJ), such as time variables, force variables and variables linking both components [rate of force development (RFD), impulse and power]. Considering that the performance during CMJ is the result of the high level of efficiency of all these mechanisms, it is expected that the vertical performance (VP) is strongly linked to the mechanical variables responsible for the force production in concentric contraction and in elastic structural elements. More specifically, the RFD seems to play a crucial role in activities involving plyometric muscular contractions, such as sprinting or jumping.

This variable has been frequently studied but often during the concentric phase or only when the peak occurred (McLellan et al. 2011), but very rarely during the eccentric (ECC) phase.

We hypothesised that ECC–RFD is a better candidate to predict VP during jumping because it summarises what happens in the tendon-muscle system to optimise the stretch shortening cycle. The goal of this study is to (i) assess the role of selected variables of F–T curves on the VP during CMJ and (ii) predict vertical jump performance with a high level of accuracy, using the method of multiregression analysis.

2. Methods

The sample was composed of 178 males, all skilled athletes (football, basket-ball and base-ball) evolving in the national US championship. All testing was done with the subject standing on a 0.6 m × 0.4 m Bertec 4060-08 piezoelectric force sensor platform (Bertec Corp.; Columbus, OH, USA) with a sampling frequency of 500 Hz. Each subject started the CMJ in the standing position, dropped into the squat position and then immediately jumped as high as he can.

The independent variables were extracted from the F–T curve and included ECC–RFD, ECC–TIME (ECC time), TIME (total time), RATIO–TIME and CON–VF (average concentric vertical force). The ECC–RFD (N/s) was determined between the minimum and the maximum force during the ECC phase. The jump height was calculated from impulse momentum (Figure 1).

The analyses were conducted using STATBOX pro 7.2.2 for excel 2007 (FBC Software). Pearson correlation coefficients were used to determine the relationships between independent variables and the dependent variable. Then, a multiple-regression analysis technique was applied to identify the most predictive model (by stepwise regression, with backward elimination). Descriptive statistics were used to verify that the basic assumption of normality of the dependent variable was met.

3. Results and discussion

All variables were significantly correlated with VP, with low to moderate coefficients ($r = 0.21$–0.57) and with negative values for all time variables (Figure 2).

The main result of this study suggests that maximal VP during CMJ is primarily determined by ECC–RFD ($r = 0.50$, $p < 0.001$) and CON–VF ($r = 0.54$, $p < 0.001$). Indeed, the ECC RFD seems to play a major role in the performance during CMJ. Several studies have failed to find such a strong link between RFD and VP (e.g. Wilson et al. 1995). This difference of results could be probably explained by several differences in the methodological approach. Firstly, this study measured VD while simultaneously recording RFD during CMJ on a force plate, contrarily to previous studies. Secondly, the method to measure the VP is more accurate in this study (impulse method) than the flight time method, which is associated with high errors due to the variation in the take-off and the landing position. Moreover, the use of arm swings seems to be a crucial movement, because

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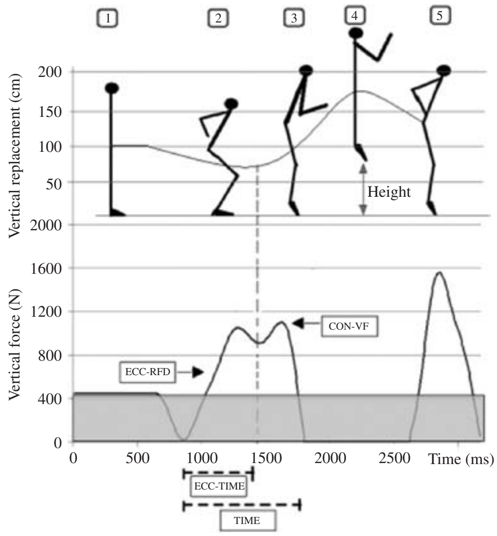

Figure 1. A typical CMJ with the recorded variables.

correlation was found only in the study in which this motion was used between RFD and VP and not in those studies in which arm swing was not used. This is due to the increase in the take-off velocity.

Further, the other explanation of this difference provides a recording method for calculating RFD. Indeed, this study is the first one which demonstrates that ECC–RFD is a strong predictor, better than the peak RFD or the concentric RFD, because it summarises the capacity of the muscle–tendon unit structure to stretch quickly before attaining the peak of force, by optimising neural factors, such as the motor unit recruitment and the motor unit synchronisation. Moreover, musculo-tendinous properties seem to have an important role in the RFD increase, such as the Achilles tendon length or the stiffness of the vastus lateralis tendon-aponeurosis, due to an increase in the elastic properties of muscle (Cormie et al. 2010). In other terms, ECC–RFD is a good predictor of VP in CMJ, because it summarises several intrinsic properties of muscle and tendons during a key moment, which greatly contributes to this performance.

The best multiple regression model explains 79% of the total variance and included ECC–RFD, CON–VF, TIME and ECC–TIME showing that high VP is the result of the combination of the mechanical variables responsible for the force production (Laffaye et al. 2007) in concentric contractions and elastic elements and could be predicted with a high level of accuracy. Indeed, a significant correlation between the ECC–RFD and the CON–VF ($r = 0.45$) confirms that a high ECC rate of force allows rapid recruitment of motor units by stretching quickly the

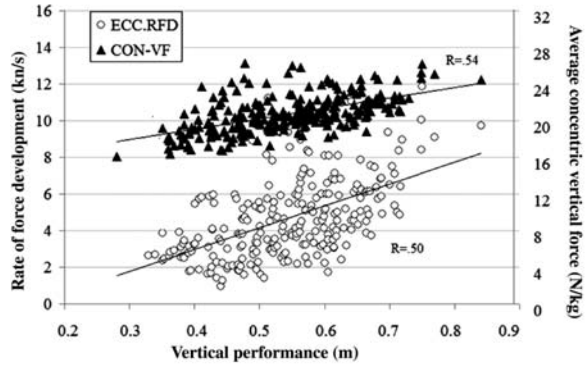

Figure 2. Linear regression model between ECC–RFD, CON–VF and VP.

muscle–tendon system and results in a higher level of force at the end of this phase. Further, a strong link between ECC–TIME and ECC–RFD ($r = -0.73$, $p < 0.001$) highlights that it is necessary to minimise the time to peak force for increasing the RFD.

4. Conclusions

Our study shows that the way to jump high requires a motor strategy based on the optimisation of the stretch shortening cycle function, by increasing the ECC–RFD and minimising the ECC–TIME which results in higher level of force and in improvement of the vertical jump performance.

Moreover, this new method to record the RFD seems to be a better predictor of jumping performance than the previous method, by summarising the ability of the muscle–tendons system to store efficiently elastic energy and to release elastic energy as well as activating the stretch reflex.

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