BIOVARIABILITY: THE STARTING POINT FOR DEVELOPING RELIABLE MOTOR FEED-BACK PROCEDURES IN SPORTS

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Modern technologies allow multifactorial analyses of sports movement. Their output might be used as a reliable feed-back for sports motor applications, but individual variability must be assessed first, to gain more insight on treating data, interpreting results and presenting suggestions. Former studies evidenced important aspects of multijoint coordination and successfully interpreted the role of many kinematic/kinetic measures. Nevertheless they didn't examine biovariability extensively. In this work a common, widely-studied field test (vertical jump) was chosen to evaluate intra/intersubject variance. Results showed a considerable variability in many kinematic and kinetic parameters. Some suggestions on treating data are proposed. Some indications of possible applications are presented.

KEY WORDS: biovariability, individual motor characterization, motion analysis, vertical jump.

INTRODUCTION: Experts in training, coaching and rehabilitation are increasingly turning to sport biomechanics in order to gain effective, quantitative methods and instruments to assess training methodologies, to evaluate the athlete's fitness and to monitor individual characteristics in performing selected sports movements. Useful feed-back for learning or correcting specific motor tasks is one of their demands. To date, reliable methodologies and technologies are applied, with positive outcomes, to answer similar questions in many fields, such as clinics or ergonomics, while it seems that a gap still remains in the world of sports. This delay might be due to: heterogeneity of survey questions, relevance of measuring-systems resolution, lack of uniformity and standardization in sports analysis procedures. Different hypothesis or inconsistent methodological approaches might lead different research groups to discordant findings. Significant investigations into sports movements and common field tests have been carried out, but basic phenomena investigation and interpretation have been preferred, as the whole field of multifactorial sports analysis was still unexplored. Hence inter and intraindividual variability has often been neglected, focusing only on common patterns and on average performances of groups. The achieved results evidenced very important aspects of multijoint coordination and the role of some kinematic or kinetic quantities (Bobbert and Van Ingen Schenau, 1988), but they were not directly exploitable on the field. However, the multifactorial approach is a powerful instrument but it brings along a huge amount of information, especially if intra/inter-subject variance cannot be neglected. As previously suggested (Hatze, 1986), similar performances in motor tasks do not result from equally homogeneous motor strategies, both within and between individuals. The exact repetition of stereotyped movements seems to be impossible, either. Therefore, biovariability should be assessed before proceeding and it should considered with the successive definition of testing procedures and data analysis (Bartlett, 2004): its knowledge is essential to recognize performance enhancements (Hopkins et al., 1999) and to set up useful feed-back by comparing registered variables with a desired reference.
As biovariance in the multifactorial approach of sports movements had never been examined extensively, a well known and analyzed motor task was chosen for this study. The purpose of this work is to investigate intra and inter variability of kinematic and kinetic parameters in vertical jump (VJ) exercises, in order to better understand if a set of significant indexes can be extracted. Some suggestions on treating data and interpreting results in sports motor evaluation are proposed too.

METHODS: Six male and six female (N = 12) young track-and-field sprinters of national and international class were the subjects of this study. Their age, height and body mass were (mean ± standard deviation): 16.4 ± 1.0 years, 1.71 ± 0.06 m, 59.4 ± 9.2 Kg (Table 1). All the subjects didn't show any remarkable lower limb injury or dysfunction, at the time of the experiments. Furthermore, they were supposed to be in good shape as they were next to the most important competitions of their agonistic season. They used to practice 4-5 times a week, 2-3 hours a day and they were pretty familiar with the test they undergo in this study. After a standard 20 minutes warm up routine, each subject was asked to perform 10 double legged maximal counter movement vertical jumps, keeping their arms akimbo. A 2 minutes rest between each jump was respected to avoid fatigue. The 3D coordinates of 10 retroreflective hemispherical markers (12 mm diameter), glued onto subjects' lower limbs in agreement with a 4-stick model proposed by Pedotti and Frigo (1992), were estimated by an automatic motion analyzer (ELITE, BTS, Italy) at a sampling frequency of 100 Hz. Simultaneously, ground reaction force (GRF) of one foot per trial was measured by a piezoelectric force platform (Kistler 9284, Kistler, Switzerland) at a sampling frequency of 500 Hz. The GRF data for each side were collected in random order. Four TV cameras, paired off on the two sides of the subject, were used to monitor simultaneously the kinematics of both legs. Anthropometric measures and specially designed algorithms were used to estimate and filter 3D coordinates of internal joint centers and joint angles. Net joint moments at the three main joints of the lower limbs were computed using the Newton-Euler free body dynamic equilibrium equations. Net joint powers were calculated by multiplying net joint moments and joint angular velocities. The jump action was defined as the time interval from the start of the countermovement (t_i) to the instant the toes lost contact with the force platform (t_f). t_f was identified by looking at vertical GRF (R_y). t_i was identified by looking at R_y pattern coupled with greater trochanters markers vertical displacement. After rejecting unsuitable trials, as many as 80 selected parameters (P_i i=1,...,80) were extracted from each subject's kinematic and kinetic patterns. A specialized algorithm was developed in Matlab language (Matlab 6.5, The MathWorks inc) for their automatic estimation. They included: jumping height (H); duration ($\Delta t = t_f - t_i$); vertical GRF peak ($R_{y\text{-}MAX}$); joint standing and maximal flexion angles; joint angles, angular velocity and acceleration at take off and together with kinetic variables peaks; joint peak moments (M_{MAX}) and peak powers (P_{MAX}); time of occurrence of peaks; joint work, positive-negative work ratio, and many others derived from those. When necessary, time parameters were normalized with Δt, and kinetic ones with body weight and height, to allow comparison among different trials or different athletes. Individual mean curves were calculated by normalizing single trials over the movement phase; cubic spline interpolation was applied to the original data points to obtain 100 samples independently from the actual movement duration as its intra individual variability was very low. Parameters were computed from mean patterns too (P_i' I=1,...,80). Basic statistics (means (μ), standard deviations (σ), coefficient of variation ($CV = \sigma/|\mu|$), correlation with H) were computed for all the parameters and used for intra and interindividual analysis. Coefficients of correlation with H were estimated both within ($r_{H,Pi}$) and between subjects ($R_{H,Pi}$). As most of the 100m (t_{100m}) and 200m (t_{200m}) season best performances were obtained by all the participants within 2 weeks from the testing session, correlations between VJ parameters and competition results ($R_{t100m,Pi}$, $R_{t200m,Pi}$) were evaluated as well.

RESULTS and DISCUSSION: The anthropometric characteristics and the skill level of the analyzed population, keeping males and females separately, are reported in Table 1.
The coefficients of variation ranged between 7.6% (body weight of women) and 1.8% (male height). These small CVs suggest that the chosen male/female samples were very homogeneous, both from an anthropometric and a sports skill level point of view. As reported in the previous section, the whole population was extremely homogeneous as well.
Intrasubject CVs were calculated for each parameter by considering all suitable trials, and were used as individual variability index. Table 2 reports some of those.
H, $R_{y\text{-}MAX}$ and Δt revealed little variability. For these parameters μ_{CV} was always sensitively lower than 10%. Furthermore, their mean values were affected by no more than two people's outlying values. Peak moments and powers (and many other parameters, not reported in Table 2) showed to be less homogeneous: joint peak moments ranged between 6.9% (ankle) and 11.7% (knee), while joint maximal powers ranged from 13.1% (knee) and 17.8% (hip). It

must be pointed out that, for all these 6 parameters, at least half of the individual CVs exceeded 10%. These results agree with previous works on biovariability and suggest to proceed by using means of parameters taken from a proper number of trials (Rodano and Squadrone, 2002) rather than selecting arbitrarily a single "best jump".

Differences between individual mean-curves parameters and means of parameters taken from intrasubject trials were assessed too (i.e. $P_i'–P_i$ i=1,...,80). A rigorous evaluation of reliability might be carried out, for each parameter, through a LOA (Limits Of Agreement) analysis (Atkinson and Nevill, 1998). Simpler and preliminary observations were done, in this work, by looking at relative differences ($RD_i=[(P_i' - P_i)/ P_i]*100$ i=1,...,80) between the two methods of extracting values. Results showed that the two procedures seem consistent for most of the parameters ($RD_i < 5\%$). Nevertheless, caution in using mean curves must be paid, as few RD_i were sensitively greater than 10%: resampling with a fixed number of point, independently from single trials Δt, might involve patterns contraction or distortion. Therefore, further and more rigorous investigations are to be performed.

Intersubject CVs was calculated for each parameter by considering individual means, and was used as interindividual variability index. Table 3 reports some of those.

Table 1 Anthropometric characteristics and skill level. M and F stands for female or male population.

	Age	Weight	Height	t_{100m}	t_{200m}
μ_F	16.2	51.5 Kg	1.67 m	12.41 s	25.55 s
μ_M	16.7	67.3 Kg	1.76 m	11.06 s	22.56 s
CV_F	8.2%	7.6%	2.2%	2.2%	1.8%
CV_M	3.1%	6.9%	1.8%	2.3%	1.7%

Table 2 Intra-subject coefficients of variation of some relevant parameters. CV_{MIN} and CV_{MAX} are, respectively, the lower and the highest values among the 12 intra-individual CV recorded. The third line reports the mean value of the 12.

	H	R_{y-MAX}	Δt	M_{h-MAX}	M_{k-MAX}	M_{a-MAX}	P_{h-MAX}	P_{k-MAX}	P_{a-MAX}
CV_{MIN}	1.1%	1.9%	2.2%	3.3%	3.8%	4.5%	8.8%	5.1%	7.7%
CV_{MAX}	16.6%	17.1%	10.3%	17.2%	37.9%	10.2%	27.7%	22.5%	21.4%
μ_{CV}	5.8%	6.5%	6.9%	9.5%	11.7%	6.9%	17.7%	13.1%	13.8%

Table 3 Inter-subject coefficients of variation of some relevant parameters.

	H	R_{y-MAX}	Δt	M_{h-MAX}	M_{k-MAX}	M_{a-MAX}	P_{h-MAX}	P_{k-MAX}	P_{a-MAX}
CV_F	5.3%	9.5%	9.4%	15.7%	13.3%	13.1%	33.0%	14.6%	25.0%
CV_M	7.5%	7.3%	6.5%	13.5%	13.3%	13.8%	25.2%	12.6%	21.7%
CV_{M+F}	6.6%	8.3%	7.7%	20.8%	13.0%	13.7%	37.8%	13.9%	22.5%

Typical parameters of VJ (H, Δt, R_{y-MAX}) showed lower than 10% coefficients of variation. Most of the other extracted parameters (normalized maximum peak of joint moments and powers, time of occurrence of peaks, intervals between peaks, normalized work, positive-negative work ratio,...) gave evidence of less homogeneity (CV > 10%). There was no increase in uniformity within groups, even considering males and females separately. Furthermore, the correlation coefficients, calculated between parameters and heights of the subject's successive trials ($r_{H,Pi}$), showed that individual performance doesn't seem related to any common factor. Therefore, everyone seems to exploit his own abilities and to compensate his/her deficiencies: similar performances in vertical jump exercises do not result from homogeneous motor strategies. Two athletes evidenced significative asymmetries and anomalies in some kinematic and kinetic parameters during VJ test; they underwent ham-strings injury few days later. This suggests that multifactorial approach could provide useful feed-back for motor strategies characterization and correction, for training/rehabilitation programming, and for injury prevention. If biovariability is not neglected, more consistent evaluations could be achieved, avoiding false positives or negatives.

Correlations between H and t_{100m}, and between H and t_{200m} were 0.019 and 0.029 respectively. The parameters that influenced H most (e.g. peak hip moment, $R_{H,Mh-MAX} = 0.83$) were not the same that were related with better sprint track performances (e.g. peak ankle moment, $R_{H,Ma-MAX} = 0.9$). Therefore H didn't seem to be a good predictor of sprint track performances, while other parameters better complied with t_{100m} and t_{200m}. This didn't come out completely unexpected, as H might be mainly related to lower limbs power and to proximal joints (hip and knee) output in particular, while 100m and 200m events might be linked to other motor factors (e.g. distal joints stiffness).
All the exposed observations suggested that a multifactorial approach of VJ test, and maybe of sports movements in general, would be very useful for motor behavior investigation and for biofeedback, while further efforts must be spent for performance prediction applications. Laboratory and track test should be coupled. Between-subject correlation should not be used, while within-subject one could give more hints of performance-related parameters. No competition performances should be referred to, as they are not achieved in controlled environment and they could be deeply affected by random and psychological factors as well. Specific track test should be designed, in order to separate the different phases of 100m or 200m races, where several neurophysiologic factors are involved (e.g. for sprint events: 30m from starting blocks, 30m running start).

CONCLUSION: The variability analysis showed the presence of a large intra and intersubject variability in many kinematic and kinetic parameters during countermovement jump tests. The individual variance remarks what previously suggested by other authors: the exact repetition of the same movement is impossible. Furthermore similar performances in jumping height or track events can be achieved through completely different motor strategies. If a well-known movement, considered by many as being rather stereotyped, presents such a variability, a much greater variance might be expected in more complex tasks.
The potentialities of modern technologies could be fully used to support conditioning and rehabilitative programs, but differences within and between subjects should not be neglected, in a contest where even the smallest improvement matters and should be recognized.
The mean of parameters taken from a consistent number of trials can be used as a useful feed-back information for characterizing the athlete's motor peculiarities and for identifying his abilities or deficiencies. Further efforts must be spent to synthesize the huge amount of variables that a multifactorial analysis provides: the most significant ones should be selected or integrated as indexes, to get information to be exploited by expert and field practitioners.
Periodic monitoring gave clues of injury-prediction potentialities, too. Two athletes, who evidenced significative asymmetries and anomalies in some kinematic and kinetic parameters during VJ test, underwent ham-strings injury few days later. As this "inductive" way, which starts from observation of individuals, is a rather heavy task to be accomplished by a single lab, more insight will be gained only when standardized test protocols, data collection procedures and data treatment methodologies are defined and shared.
To resume, all these results and observations converge toward other authors' considerations (Rodano and Squadrone, 2002; Bartlett, 2004): more emphasis should be placed on the individual signature of movement coordination and optimization of performance.

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