# ASYMMETRIES IN VERTICAL JUMP: A SUPPORT FOR FUNCTIONAL MOTOR EVALUATION?

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**Abstract: During both professional and amateur sports activities, the musculo-skeletal system is subjected to very high biomechanical demands and often runs into injuries. This risk could be much higher if motor asymmetries are present. This study aims at gaining more insight about the presence of motor asymmetries and their relationships with potential injury. Subject of the study was a population of young athletes performing VJ. The VJ test was chosen because it is a symmetric motor task and it is commonly adopted to evaluate athletic ability in performing explosive movements. Although the subjects were healthy at the time of the experiments, all of them presented at least an asymmetry in one of the 16 selected parameters. Global parameters, which give information on the final output of the movement, do not seem to be able to reflect anomalies at joints or at coordinative level. Furthermore interesting clues of relations with past injuries and competition performances were found.**

## Introduction

The implementation and application of functional evaluation tests in sports is not as advanced as it is in clinics (e.g. gait analysis) even if this is a necessity for both practitioners and experts in training and rehabilitation.

During sports activities the musculo-skeletal system often runs into injuries involving muscles, tendons and bones, both separately and together. This might be due to the high biomechanical demand these structures are subjected while performing a sports activity at any level. If the subject presents a motor asymmetry, these stresses might increase in magnitude, thus getting the injury-risk to be higher.

Although motor asymmetries might be relevant for athletes, as an unequal load of the musculo-skeletal system is assumed to be one of the causes of injuries, few studies concerning sports field [1] are available in literature. This issue is analysed by a large amount of studies, but most of them are mainly related to asymmetries of the back [2].

Few and not standardised tests are currently used to evaluate the athlete's fitness and neuromuscular qualities. Among these methods, vertical jump (VJ) is one of the most commonly used to investigate athletic ability in expressing explosive force. This test can be easily performed in a laboratory, it is considered as a quite repeatable motor task, it is well known and traditionally adopted by the sports community and it doesn't cause fatigue if rest periods between trials are respected.

Although jumping height ($\Delta H$) is often assumed as being the most useful index to evaluate the actual motor skill status and potentialities of the subject, some authors [3, 8, 9] suggested that a deeper kinematic and kinetic analysis could give more meaningful information: $\Delta H$ describes the performance of the movement but gives little information about its genesis and about coordinative factors (neuromuscular control).

The aim of this study is to quantify the kinematic and kinetic asymmetries within a population of young sprinters performing VJ tests. The double legged maximal countermovement jump (CMJ) test was chosen because it's both a symmetric and a highly demanding motor task and it requires coordinative effectiveness. Hence, it seemed to be a proper mean to discover asymmetries within athletes, with whom "common" clinical tests (e.g. gait analysis) might not be stressful enough.

The main goal would be to assess the recurrence and the magnitude of anomalies and to identify clues of relationship with previous and future injuries. This might help in setting up a quantitative procedure to assist trainers and experts in rehabilitation in the prevention of impairments that originate from an "internal disequilibrium". Systematic monitoring might be useful to plan training programs and/or specific treatments to recover the athlete's fitness and to fully exploit his potentialities.

## Materials and Methods

The subjects of this study were 12 young sprinters, six males and six females, of Italian national level. Their age, height and body mass (mean ± standard deviation): 16.4 ± 1.0 years, 1.71 ± 0.06 m, 59.4 ± 9.2 kg. A more detailed description of the population is reported in Table 1. At the time of the testing sessions, they used to practice 4-5 times a week, 2-3 hours a day and they were familiar with CMJ.

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

| | Age [yrs] | Weight [Kg] | Height [m] | $t_{100m}$ [s] | $t_{200m}$ [s] |
|---|---|---|---|---|---|
| $\mu_F$ | 16.2 | 51.5 | 1.67 | | |
| $\mu_M$ | 16.7 | 67.3 | 1.76 | 11.06 | 22.56 |
| $\sigma_F$ | ± 1.3 | ± 3.9 | ± 0.4 | | |
| $\sigma_M$ | ± 0.5 | ± 4.7 | ± 0.03 | ± 0.3 | ± 0.4 |
| $CV_F$ | 8.2% | 7.6% | 2.2% | | |
| $CV_M$ | 3.1% | 6.9% | 1.8% | 2.3% | 1.7% |

After a 20 minutes warm-up routine and some trials to better familiarise with the experimental set-up, each subject was asked to perform 10 double legged maximal counter movement VJs, keeping their arms akimbo. The hands position was imposed to reduce the influence of upper limbs and trunk inertia. A 2 minutes rest between consecutive trials was imposed to each subject to avoid fatigue and its possible outcomes.

The data were collected during the month of June, in the middle of their agonistic season; hence, the sprinters were supposed to be in good shape.

The 3D coordinates of 10 retroreflective hemispherical markers (12 mm diameter), glued onto subjects' lower limbs, were estimated by an automatic motion analyzer (ELITE, B.T.S. srl, Italy) at a sampling frequency of 100 Hz. The markers were apposed on the following anatomical landmarks: iliac crest, center of the greater trochanter, most prominent aspect of the lateral femoral condyle, lower edge of lateral malleoli, lateral side of the 5th metatarsal head (on the running shoe). 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. Before each experimental session, measurements of accuracy was assessed: the mean differences between estimated and actual measures resulted within 0.8 mm and 0.4°. A 4-stick model of the lower limb, anthropometric measures and specially designed algorithms [4, 5] were used to estimate and filter 3D coordinates of internal joint centers and joint angles, and to compute their derivatives, starting from external landmarks detection. Net joint moments at the three main joints of the lower limbs were computed using the Newton-Euler free body dynamic equilibrium equations. The regression equations proposed by Zatsiorskji and Seluyanov [6] were used to estimate each body segment mass, inertial moments, and gravity centers position. Hip and knee extension and plantar flexion moments were defined as positive. Net joint powers were calculated by multiplying net joint moments and joint angular velocities.

The jump action was defined as the time interval between the start of the counter movement ($t_i$) and the time in which the toes lost contact with the platform ($t_f$). The latter parameter was identified by analysing the vertical GRF ($R_y$); $t_i$ was recognized by coupling the examination of $R_y$ pattern and of the vertical displacement of the greater trochanters markers.

Two levels of control were adopted to recognise the unsuitable trials. First, a qualitative visual inspection of the movement performed by the operator was used to avoid macroscopically "bad" jumping actions. Then, a set of parameters was controlled, including the antero-posterior component of GRF, the stability of $R_y$ during the standing phase, the maximal flexion angle of the knee during the countermovement. After rejecting anomalous trials, a large number of parameters (about 80 per trial) were extracted from each subject's kinematics and kinetics. For their automatic evaluation a specialized algorithm was developed in MatLab language (MatLab 6.5, The MathWorks inc).

Basic statistics (means, standard deviation, coefficient of variation, correlation with jump's height) were calculated for all the parameters.

16 of the estimated parameters were selected for studying motor asymmetries; they were: the duration of the movement ($\Delta t$); the peak of vertical GRF ($R_{y\text{-}max}$); the maximum articular moments and powers, at the hip ($M_{h\text{-}max}$, $P_{h\text{-}max}$), at the knee ($M_{k\text{-}max}$, $P_{k\text{-}max}$), at the ankle ($M_{a\text{-}max}$, $P_{a\text{-}max}$); the interval between peaks regarding couples of adjacent joints in the proximal to distal order, both in absolute values ($\Delta\tau[M_{hk}]$, $\Delta\tau[P_{hk}]$, $\Delta\tau[M_{ka}]$, $\Delta\tau[P_{ka}]$) and normalised to the duration of the movement ($\Delta\tau_N[M_{hk}]$, $\Delta\tau_N[P_{hk}]$, $\Delta\tau_N[M_{ka}]$, $\Delta\tau_N[P_{ka}]$).

The former ($\Delta t$ and $R_{y\text{-}max}$) were chosen because they are, together with $\Delta H$, the most recurrent indexes in literature and daily practice. They are so widely referred to because they are straightforward and can be estimated by using only a force platform. The other ones were selected as they better represent the genesis of the performance. $\Delta H$, $\Delta t$ and $R_{y\text{-}max}$ could be addressed as "global variables": they describe the output of the whole system. Moments, powers, time to peaks or between peaks characterise the motor behaviour of each joint and might give more useful information on how each component and/or limb-side contribute to the final output.

Time between peaks both normalised and absolute, were studied to gain more insight into motor coordination aspects. The proximal to distal maximal activation is usually considered the most effective strategy [3]. Its alteration could be linked to some coordinative ineffectiveness or to latent injuries, especially if it occurs monolaterally.

The high intraindividual variability [9] suggested the use of all available trials for each subject [7], instead of selecting an "arbitrary" individual best jump. This was done to avoid the presence of false positive or false negatives. Non-parametric between-groups tests were chosen for intraindividual asymmetries assessment: the Mann-Whitney test ($\alpha$ = 0.05) was used to compare left side and right side parameters of each subject.

**Results**

All the 12 sprinters showed statistically significant asymmetries for at least one of the selected parameters. The distribution of asymmetries in the population is shown in figure 1.

4 subjects (33% of the sample) presented six or seven statistically significant asymmetric parameters.

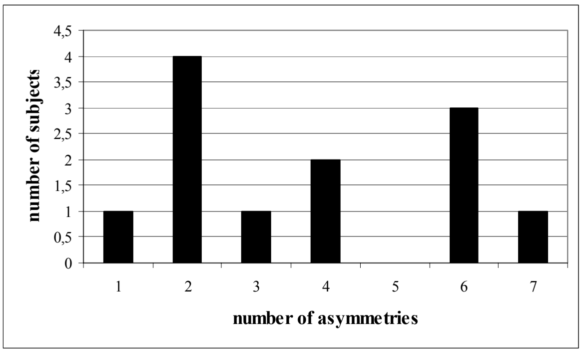


Figure 1: Distribution of asymmetries in the examined population of sprinters.

15 out of the 16 measured variables had at least one subject, who was asymmetric (figure 2).

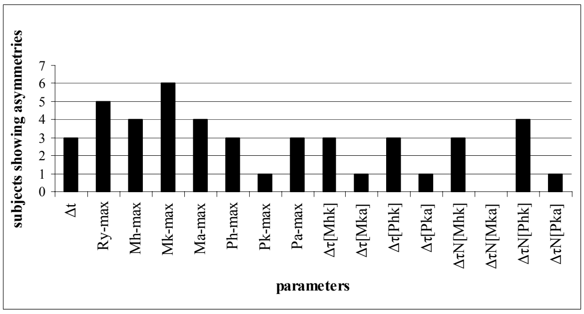


Figure 2: Incidence of asymmetry on each parameter

The most recurrent difference between left and right side regarded the peak knee moment ($M_{k\text{-}max}$): 6 athletes presented this kind of asymmetry. The other parameters showed different occurrences of asymmetry, except $\Delta\tau_N[M_{ka}]$.

For the male sample a correlation analysis between the rate of asymmetries and competion performances in the 100m and 200m events was conducted. This data were also compared with the mean VJ height (table 2).

Table 2: Comparison between asymmetries and performance.

| Subject | $t_{100m}$ [s] | $t_{200m}$ [s] | ΔH [m] | Number of asymmetric parameters |
|---|---|---|---|---|
| sub1 | 10”63 | 22”06 | 0.554 | 1 |
| sub2 | 10”99 | 22”49 | 0.533 | 2 |
| sub3 | 11”13 | 23”04 | 0.618 | 2 |
| sub4 | 11”40 | 22”88 | 0.561 | 4 |
| sub5 | 11”00 | 22”22 | 0.636 | 5 |
| sub6 | 11”20 | 22”72 | 0.538 | 6 |

Coefficients of correlations between the number of asymmetries and $t_{100m}$, $t_{200m}$ and ΔH were, respectively (figure 3): R=+0.59 ($R^2$=0.35), R=+0.18 ($R^2$=0.04) and R=-0.1 ($R^2$=0.01). None of them has statistical relevance.

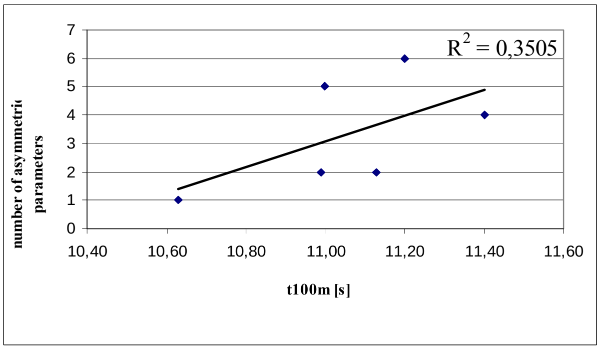


Figure 3: Correlation between number of asymmetries and performance on 100m

The results related to interval between peaks of joints moment and power showed that 4 subjects presented asymmetries concerning at least one of the eight considered parameters. Figure 4 shows an inversion in intervals activation: right-side median is positive, left-side one is negative. Comparing figure 4 and 5, which are both referred to the same subject, it is possible to notice that there could be significant asymmetries for related parameters (both of them involved the same joints).

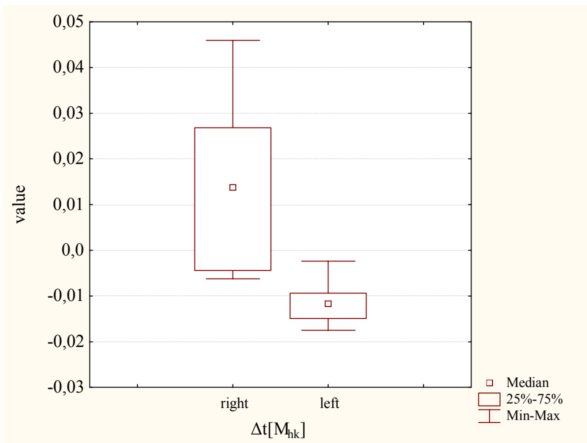

Figure 4: $\Delta\tau[M_{hk}]$ of a female sprinter

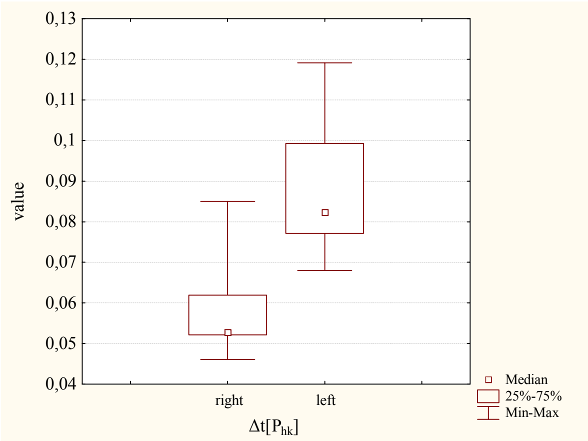


Figure 5: $\Delta\tau[P_{hk}]$ of the same subject in figure 4

For one of the subjects an intraindividual comparison between two different testing sessions was done (figures 6 and 7). The second one was performed 3 months later than the first. 5 out of the 16 analysed parameters showed statistically significative asymmetries during the first session. 4 of these asymmetries were no more present three months later, while the remaining unbalanced condition appeared to be inverted.

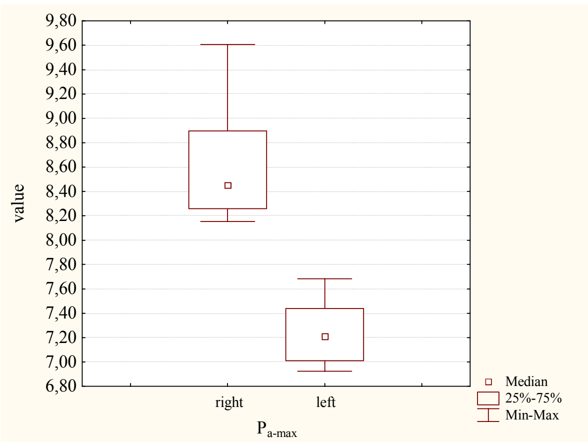


Figure 6: $P_{a\text{-}max}$ of a sprinter at his first testing session

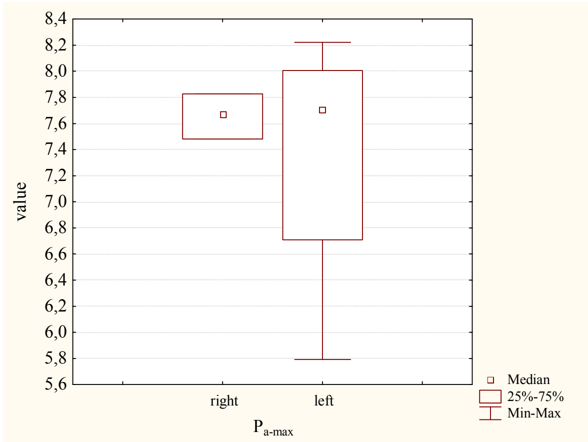


Figure 7: $P_{a\text{-}max}$ of the same sprinter in figure 6 at his second testing session, three months later

**Discussion**

Although the selected sample consisted of 12 young sprinters who did not present any evident pain or musculo-skeletal disorder at the time of the test, every subject showed at least one asymmetric parameter.

4 out of the 12 subjects presented six or more asymmetric parameters and all the considered variables, except $\Delta\tau_N[M_{ka}]$, showed at least an occurrence of statistical difference. Global parameters did not seem to be good predictors of individual asymmetry or, at least, to be good enough: the number of subjects who evidenced a “global” asymmetry, duration of the movement and/or maximum reaction force, did not comply with the widespread occurrence of “internal” disparities (articular kinetics and coordination). This consideration is reinforced by noticing that half of the athletes did not manifested any asymmetric global parameter but had many differences in the internal ones.

By looking at these elementary observations a couple of considerations can be extracted: first, a seemingly symmetric motor task does not result from an equally balanced motor strategy, because both kinetic and temporal parameters often show statistically significative differences between the right and left limb; second, if so many asymmetries were found by looking at just 16 parameters, many more should be expected inside the whole set of the estimated ones.

The dimension of the sample is too small to get significative information from the quantitative results of the correlation between performances and number of asymmetries. Nevertheless, some interesting hints can be extracted from the qualitative observation of data. It’s quite evident that the athlete with less asymmetries is the one with more proficient track results, and that the subject with the higher number of anomalies is one of the worst by looking at both track results and jumping height. These observations are far from being definite conclusions, as young athlete’s performances are likely to be affected by many factors other than motor asymmetries; however, they can suggest the path for


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further investigations, in order to discover if the fewer asymmetries the better track results. In fact, the most interesting clues of potentialities about asymmetry-monitoring come out from the two case study presented at the end of the previous section. A girl manifested asymmetries in many kinetic and temporal parameters and underwent hamstrings injury few days later. The most relevant anomaly involved the inversion of joints maximal activation in the left side: the proximal to distal sequential activation [3] was not respected and the knee reached its peak moment before the hip. It must be noticed that this subject did not evidenced any asymmetry in $\Delta t$ and $R_{y\text{-}max}$ , thus reinforcing the need for an analysis that does not stop at a global-performance level but tries to understand individual strategies [9]. By looking at the second example (longitudinal monitoring), it could be observed that, after 3 months, the athlete recovered most of his previous asymmetries, thus showing how such a procedure could be exploited to understand the influence of different training/rehabilitative strategies on individual motor behaviour.

Possible relations between actual motor asymmetries and previous injuries or pathologies were inspected. Although none of the subjects presented any relevant disease and everyone thought to have solved past problems, some indications of links with existing asymmetries were found. For instance, a girl who had had several injuries involving her ankles, manifested many asymmetries related to ankle kinetics and proximal to distal maximal activation between the knee and the ankle.

## Conclusions

The selected sample consisted of 12 young healthy athletes who were performing a seemingly symmetric movement. Nevertheless statistical differences between left and right side of the same subject were found in many kinetic and kinematic parameters. The global parameters (i.e. parameters that somehow summarise the whole movement, such as the jumping height, the duration of the movement or the ground reaction force) are not always able to make these anomalies emerge, thus suggesting a deeper analysis which involves kinetic variables.

The analysed parameters and the emerging functional asymmetries gave clues of sensitiveness to previous or potential injury. Therefore, training and rehabilitative programs could benefit from looking at their evolution within the subject.

Further efforts should be spent in order to gain more insight in the way asymmetries influence performance and injury-risk, to better understand whether statistical significance matches the physiological one and, finally, to deepen the correlation between asymmetries and functional anomalies.

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