LEG STIFFNESS ASYMMETRY DURING COUNTERMOVEMENT JUMP

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The purpose of this study was to identify whether the value of stiffness during two-legged countermovement jump in dominant lower limb is similar to the one in non-dominant lower limb. The research was conducted on 35 basketball players. Each participant performed three countermovement jumps with arm swing to the maximum height. Measurements employed a two Kistler force plates and a BTS SMART system for motion analysis. Leg stiffness (understood as an inclination of the curve of ground reaction forces vs. height of the greater trochanter of the femur) was computed for these parts of countermovement and take-off phases where its value was relatively constant and force-length relationship was similar to linear. Statistically significant differences were found during the comparison of the stiffness in the dominant and non-dominant lower limb.

KEY WORDS: basketball, cmj, elasticity, force-length curve, quasi-stiffness, vertical jump.

INTRODUCTION: Elasticity is a property of macroscopic bodies which consists in ability to recover the previous shape and volume after mechanical forces that cause deformation are removed. The ability to absorb and recover elastic energy in human body is observed in tendino-muscular groups. Elastic energy is used during locomotion movements performed in stretch-shortening cycle (SSC) for example vertical jumps. Performing a countermovement before take-off (lower limbs flexion) leads to the rapid extension of muscles, tendons and other compliance tissues (in lower limbs and trunk) before the contraction, which helps accumulate elastic potential energy and, consequently, doing greater work in the concentric phase. The factor that causes an increase in the work done during a contraction is the phenomenon of tissue elasticity, which reveals during SSC and the stretch reflex (Farley, Blickhan, Saito, & Taylor, 1991; Komi & Gollhofer, 1997; Moran & Wallace, 2007). Thanks to the ability of tendino-muscular groups to absorb and release elastic energy, this energy is added to the contraction work. The quantitative measure of body elastic properties is stiffness, which represents the measure of resistance to strain. Stiffness is a ratio of the value of the cause of the strain to quantitative measure of strain.
Leg stiffness is a concept that relates to the limb as a whole system rather than only to tendino-muscular systems. With this approach, leg stiffness depends on the stiffness of all the compliant tissues such as ligaments, blood vessels or bones (Latash & Zatsiorsky, 1993). Tendon stiffness is almost constant, whereas muscle stiffness might vary over a broad range. Muscle tension causes the increase in its stiffness and ability to accumulate elastic energy, whereas relaxing the muscle increases susceptibility to deformation. The maximally excited muscle achieves greater stiffness than tendons (Zawadzki & Siemieński, 2010). It is expected that both relatively high and low values of leg stiffness might lead to injury of soft tissues and joints. Also, magnitude of inter-limb asymmetry in leg stiffness may increase the potential injury risk during jumping (Hobara, Inoue, & Kanosue, 2013; Pruyn et al., 2012).
Therefore, the purpose of this study was to identify whether the value of stiffness during two-legged countermovement jump (CMJ) in dominant limb is similar to the one in non-dominant lower limb. Movement patterns for both lower limbs during countermovement and take-off phases in CMJ are similar. Therefore, the question can be asked whether stiffness will be similar in dominant and non-dominant lower limb during these phases.

METHODS: The study was conducted among 35 basketball players. The study group was characterized by the following mean parameters (±SD): body height - 190.4 ± 8.1 cm, body mass – 81.9 ± 10 kg, age – 19.5 ± 1.7 years. Training experience was 6.8 ± 2.5 years. The tests were carried out in the Biomechanical Analysis Laboratory at the University School of Physical Education in Wrocław, Poland with the quality management system certificate (ISO 9001:2009). The research project was approved by the Ethics Committee of the University School of Physical Education in Wrocław, Poland, and the procedures complied with the Declaration of Helsinki regarding human experimentation.

Ground reaction forces were measured using two Kistler 9286A force plates (Winterthur, Switzerland) in order to ensure measurement of the ground reaction forces for each limb separately. The kinematic data were recorded by BTS SMART system (BTS Bioengineering, Milan, Italy) for comprehensive motion analysis based on technology of passive markers that reflect infrared radiation (IR). The system features 6 cameras with frame rate of 120 Hz. In order to facilitate synchronization of the measurements, the sampling rate for the signal from force plates was set at 240 Hz. BTS SMART Analyzer software aids synchronization of the data recorded.

The reflection markers were located at the height of the greater trochanters of the femur (conventional upper end of the lower limb). It was adopted that the change in the height of the greater trochanter represents a measure of the change in the "length" of virtual spring (which represents lower limb). The participants stood on the plates (each feet on separate plate) and at a signal performed a countermovement jump with arm swing to the maximum height (three times). Landing was performed on the same platforms as take-off. The focus was also on simultaneous take-off from both lower limbs. The analysis concerned the highest jump performed by each participant.

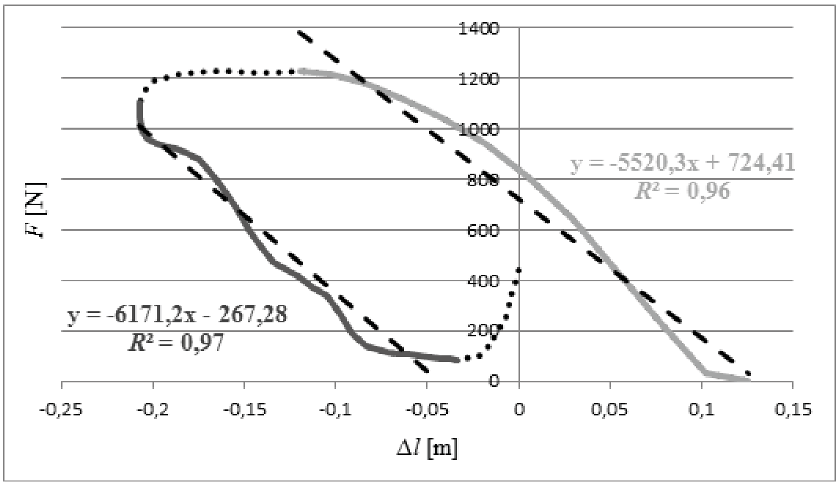

Figure 1: Ground reaction force in left lower limb for one of the study participant depending on vertical displacement of the greater trochanter of the femur with respect to the ground with trend lines for the parts studied and values of determination coefficient R^2 that represent the quality of match trend line to parts of profiles of the $F(\Delta l)$ curve (Struzik & Zawadzki, 2016).

Leg stiffness (K) was determined as a ratio of changes in ground reaction forces to the respective changes in the height of the greater trochanter of the femur (recorded by BTS Smart system based on marker displacements). Countermovement is understood as lowering the position (through flexing lower limbs), followed by immediate take-off. Therefore, the countermovement phase starts at the moment of a decline of the ground reaction force curve with respect to the value equal to body weight and ends at maximum knee joint flexion (maximum greater femoral trochanter displacement). The end of the countermovement phase is also the beginning of the take-off phase, which ends at the moment when the feet losing contact with the ground (value of ground reaction forces drops to zero) and beginning of the flying phase. Leg stiffness was calculated in the parts of the countermovement phase and take-off phase where slope of the force (F) curve with respect to the Δl (change of the length) axis was relatively constant and the $F(\Delta l)$ profile was nearly linear (Figure 1). It is only these parts that allow for expression of leg stiffness by means of a single numerical value. For the countermovement phase, this was the part between the lowest value of ground

reaction force and the lowest position of the greater trochanters of the femurs, marked dark grey in Figure 1. The boundaries of the part for the take-off phase were represented by local maximum of ground reaction forces (points from which ground reaction forces only decreased) and the moment of take-off from the plates, marked light grey in Figure 1. Therefore, this calculation was approximate in the above parts of the $F(\Delta l)$ curve slope, with its slope coefficient equal numerically to stiffness (Struzik & Zawadzki, 2013; Struzik & Zawadzki, 2016).
Asymmetry (A) between stiffness in dominant and non-dominant lower limb (for countermovement and take-off phases separately) was evaluated from the following equation (Błażkiewicz, Wiszomirska, & Wit, 2014):

$$A = ((K_{ND} / K_D) - 1) \cdot 100\%,$$

where K_D is stiffness in dominant lower limb and K_{ND} is stiffness in non-dominant lower limb.
Due to the normal distribution, analysis of the differences between the variables was based on the *t*-test for dependent variables. The level of significance was set at $\alpha = 0.05$. Advanced Statistica 12 software package was used for this purpose.

RESULTS: Table 1 presents mean values (±SD) of leg stiffness in the countermovement and take-off phases of the CMJ. Statistically significant differences were found during comparison of stiffness in the dominant and non-dominant lower limb ($p > 0.00001$) for both (countermovement and take-off) CMJ phases. The values of leg stiffness was significantly higher in dominant limb. Leg stiffness asymmetry reached 22% in countermovement phase and 8.9% in take-off phase.

Table 1
Mean values (±SD) of leg stiffness in the phases of CMJ for dominant (K_D) and non-dominant (K_{ND}) lower limb

	K_D (kN/m)	K_{ND} (kN/m)	Δ (kN/m)	A (%)
Countermovement phase	3.9 ± 1.3	3.2 ± 1.0	0.7 ± 0.7*	22
Take-off phase	3.9 ± 0.5	3.6 ± 0.5	0.3 ± 0.3*	8.9

Δ - differences between dominant and non-dominant lower limb,
* - significant differences at $p < 0.00001$.

DISCUSSION: The profile of the $F(\Delta l)$, which in the countermovement phase and the take-off phase of single CMJ is similar to linear, allowed for calculation of leg stiffness in parts of these phases. According to the stiffness division of Latash and Zatsiorsky (1993), stiffness calculated from described method should, with respect to living bodies, be termed as quasi-stiffness, which is an ability of human body to oppose to the external displacements with disregard to the profile of displacements with respect to time.
An uneven growth of the core muscles in basketball players is caused by performing the activities connected with the specific nature of the sport and the habitual use of the dominant body parts. Lack of equal distribution of training load leads to substantial functional asymmetry and the asymmetry in muscle force distribution, mainly in the area of lower limbs. This phenomenon is unfavourable and is conducive to injuries (Schiltz et al., 2009). Therefore, the statistically significant differences between the stiffness in dominant and non-dominant lower limb should be regarded as a negative phenomenon.
Pruyn et al. (2012) and Hobara et al. (2013) determined the level of differences in leg stiffness during unilateral hopping. The undesired state was the value of difference which exceeds 7% and 10%, respectively. Therefore, the values of leg stiffness asymmetry equal to 22% in countermovement phase and 8.9% in take-off phase should be considered as high and undesirable. Leg stiffness asymmetry may be due to a slightly different lower limbs movement patters during two-legged CMJ exhibit by different bilateral values of ground reaction forces and angles in ankle, knee and hip joints during countermovement and take-off. High value of leg stiffness asymmetry might lead to an injury or considerably reduce the

sports value of the competitor. This fact emphasizes a very important role of the strength and speed-strength trainings with properly load to both body sides. Coaches should pay more attention to similar lower limbs movements patters during two-legged exercises and balanced bilateral strength level development.

CONCLUSION: The value of stiffness was higher in dominant lower limb. Therefore, despite that the movement patterns during two-legged CMJ is similar for both lower limbs, the significant asymmetry of leg stiffness may exist during countermovement and take-off phases.

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