DIFFERENCES BETWEEN TAKE-OFF BEHAVIOR DURING VERTICAL JUMPS AND TWO ARTISTIC ELEMENTS

Anna Droszez[1], Maximilian Sanno[1,2], Jan-Peter Goldmann[1,2], Kirsten Albracht[1], Gert-Peter Brüggemann[1], Bjoern Braunstein[1,2]
Institute of Biomechanics and Orthopaedics, German Sport University[1]
German Research Centre of Elite Sport, Cologne, Germany[2]

The present study analysed the possible application of vertical jumps as a diagnostic tool for the acrobatic elements backward somersault (BS) and Menichelli (MEN). Therefore, 14 female gymnasts of the German national squad performed classical vertical jumps (CMJ, SJ, DJ), backward somersaults and Menichellis during a diagnostic camp at the German Research Centre of Elite Sport (*momentum)*. Kinematic and kinetic parameters were captured by a 3D-motion capture system and two force plates. Take off velocities of the CMJ and backward somersault showed significant correlations (r=0.86). Besides possible predictions for take-off velocity of BS performing CMJ, findings did not address execution of MEN. Concerning training purposes, vertical jumping does not affect performance characteristics of acrobatic elements.

INTRODUCTION: The official scoring system for artistic gymnastics (FIG) puts high value on the appearance and execution of artistic elements. Two base elements, the backward somersault (BS) and the Menichelli (MEN) are often used to start a series of complex artistic element combinations. However, the level of execution and therefore the all over appearance and performance of an artistic element is often associated (judges' perception) with a high elevation of an athletes' Center of Mass (CoM). Therefore, athletes try to perform a high vertically directed trajectory of the CoM which is directly related to the resultant take-off velocity and the take-off angle. In the daily training routine, it is generally accepted by many coaches that high 'vertical jumpers' are also high 'backward-orientated jumpers'. From that stand point it is obvious that vertical jump training including 'reactive jumps', does play an important role if an athlete tries to increase backward-orientated jumping height. Both, vertical jump and artistic element performance, are generally determined by the mechanical power generation of the leg extensors and are extensively investigated in many aspects (e.g. Force generation: Hraski et al. 2002; Drop height: Marina et al. 2012; verbal instructions: Arampatzis et al. 2001; EMG: Mathiyakom et al., 2006, etc.). However, correlations and dependencies between vertical and backward-orientated jump performance, and therefore the trajectory of the CoM of elite female gymnasts are still unclear. Therefore the purpose of the study was to collect kinetic and kinematic data of vertical jumps (SJ, CMJ, DJ) and two artistic elements (BS, MEN) to statistically proof correlations and/or dependencies between jumps and elements, focusing on joint specific power generation and CoM displacement.

METHODS:

Fourteen female gymnasts (14±1.7 yrs; 154.3±7.4 cm; 47.1±7.7 kg) of the German national squad took part in the study. Athletes, coaches and parents were informed about the experimental setup and procedures and gave consent to participate.
Measurements started with an initial static reference position followed by 10 CMJ, 5 SJ, 5 DJ, 5 BS and 5 MEN. All conditions were tested in randomized order and the rest periods between trials and conditions were at least one minute to avoid effects of fatigue (Lesinski 2015). Before each trial, instructions were given ('Jump as high as you can'). During CMJ and SJ, subjects had to hold their hands on the hips, standing with each foot on one force plate. DJ was performed with the hands on the hips on one platform. During BS and MEN, subjects were allowed to use their arms. BS was started and landed on the same platform. For the MEN, subjects started on one platform and landed on the other on their hands.
Kinetic data were collected with two floor-mounted force plates (900 mm x 600 mm, Kistler, Winterthur, Switzerland) operating at 1080 Hz. Kinematic data (9 MxF40 cameras) were captured and processed by a 3D-motion capture system (Vicon, Oxford, UK) and related software (Nexus 1.8.2) at 120 Hz. Twelve retro-reflective markers (Ø=14 mm) were attached

to the gymnasts representing the following anatomical landmarks, processus styloideus ulnae, olecranon, acromion, C7-vertebrae, distal sacrum, spina iliaca posterior superior, spina iliaca anterior superior, trochanter major, epicondylus lateralis, malleolus lateralis, os metatarsus V, tragus. The marker-set results in a 12-segment rigid body model were connections between segments are defined as hinge joints. The origin of the global coordinate system was chosen between the two force plates to determine the following parameters for each jumping performance: flight time ($\mathbf{t_{flight}}$), jumping height (**h**), horizontal and vertical displacement of the center of mass (CoM) ($\mathbf{d_{horizontal}}$, $\mathbf{d_{vertical}}$), take-off angle ($\boldsymbol{\alpha_{to}}$), take-off velocity ($\mathbf{v_{to}}$), angular velocity of the CoM ($\boldsymbol{\omega_{CoM}}$), angular momentum (**L**), joint power ($\mathbf{P_j}$), mean relative mechanical power ($\mathbf{P_m}$) at CoM. Calculations of the CoM were done on the basis of Dempster (1959) and Winter (1990). Kinematic and kinetic data were processed with Matlab 7.10 (Mathworks, Natick, USA). To smooth raw data a fourth-order Butterworth filter was applied.

Statistics: For statistical analyses SPSS V.23 was used. All parameters were tested for normality by Kolmogorov-Smirnov test ($\alpha = 0.1$). Means of data were either tested by dependent t-test for normal distributed parameters or by Wilcoxon test for non-parametric variables ($\mathbf{h_{CMJ}}$, $\mathbf{P_{mBS}}$, $\boldsymbol{\alpha_{toM}}$). Correlations were revealed with Pearson (parametric) or Spearman (non-parametric) test. Influence of variances between $\mathbf{P_m}$ of DJ, CMJ and MEN was tested by an ANOVA. For $\mathbf{P}_{mBS}$ and **h** of all jumps, variances were analyzed non-parametrically by Friedman test. Subsequently, a Wilcoxon Test with a Bonferroni adjustment of significance for three characteristics was done. Level of significance was set on $\alpha=0.05$.

RESULTS: For each athlete, the best jump, determined by the highest amount of CoM elevation, was chosen for data analysis resulting in 14 valid trials except for the MEN with 13 valid trials.

Jumping height and take off angle: Subjects performed an ave. height of 29.5±2.8 cm (DJ), 27.3±2.6 cm (CMJ), 23.9±4.3 cm (BS) and 4.6±1.9 cm (MEN). Jumping heights of the acrobatic elements differed significantly from the vertical jumps ($p<0.001$). Significant correlation was revealed between CMJ and DJ ($r=0.59$, $p<0.05$). Mean take off angle for acrobatic elements BS and MEN was 83.4±4.7° and 53.6±6.2°, respectively.

Horizontal CoM–displacement: Horizontal displacement was defined as the horizontal distance travelled of the CoM between take off and touch down. Maximum values for each jump were 28.9 cm (MEN), 23.5 cm (BS) and 5.5 cm (CMJ). Minimum values measured were 17.8 cm (MEN), -7.1 cm (BS) and -3.7 cm (CMJ). Negative results expressed a forward movement of the jump in front of the take-off starting point. Mean horizontal displacements for the acrobatic elements (MEN: 23.3±4.4 cm, $p<0.001$; BS: 10.3±8.9 cm, $p<0.002$) differed significantly from the CMJ (1.5±2.7 cm). Horizontal displacement of the CoM during BS showed significant correlation to the take-off angle ($r=0.69$, $p<0.01$) in contrast to MEN ($r=0.22$, $p<0.05$)

CoM–lowering: Vertical displacement of CMJ, BS and MEN was measured during the lowering of the CoM before take-off in the frontal plane. During DJ, this parameter was assessed between initial ground contact and turning point of the negative phase of CoM trajectory. Comparison of the mean vertical displacement of the CoM showed significant differences ($p<0.001$) in BS (25.0±5.9 cm) CMJ (24.5±3.7 cm), MEN (23.9±5.1 cm) and DJ (10.2±2.2 cm).

Resulting take off velocity at CoM: Greatest values for mean take off velocity were found for DJ (2.4±0.1 ms^{-1}), CMJ (2.3±0.1 ms^{-1}) and BS (2.2±0.2 ms^{-1}) in comparison to MEN (1.3±0.2 ms^{-1}). There was a significant difference between vertical jumps and acrobatic elements (BS: $p<0.004$; MEN: $p<0.001$). Correlations were revealed between DJ and CMJ ($r=0.56$, $p<0.05$) and CMJ and BS ($r=0.86$, $p<0.01$). No correlations were found between MEN and CMJ ($r=0.168$, $p<0.001$) or DJ ($r=0.068$, $p<0.001$).

Angular momentum and angular velocity at CoM: Angular momentum was smallest in CMJ (1.4±1.7 kgm^2s^{-1}) compared to BS (32.0±0.1 kgm^2s^{-1}) and MEN (85.6±17.2 kgm^2s^{-1}).

Relating values of angular velocity were greatest in MEN (521.3±77.2°s^{-1}) in comparison to BS (316.6±76.8°s^{-1}) and CMJ (6.1±7.7°).

Mechanical power at CoM: Generated mechanical power normalized to body mass of each subject resulted in 48.2±4.2 Wkg^{-1} for the DJ, 27.6±2.64 Wkg^{-1} for the CMJ, 19.4±8.5 Wkg^{-1} for the BS and 6.2±2.5 Wkg^{-1} for the MEN. Mean mechanical power differed between vertical jump and acrobatic element execution ($p<0.001$) except for CMJ and BS ($p<0.028$). Values for BS and MEN showed similar significant differences ($p<0.002$). Significant correlation was also revealed for mean mechanical power of DJ and MEN ($r=0.61$, $p<0.05$).

Joint specific mechanical power: Mechanical power at the ankle, knee and hip joint during CMJ was processed (Fig. 1). Mechanical power normalized to body mass was highest in the ankle joint. Knee joint and hip joint showed differences of the relative mechanical power between left ($ankle_{left}$: 4.9±0.6 Wkg^{-1}; $knee_{left}$: 3.3±1.4 Wkg^{-1}; hip_{left}: 1.8 ± 0.6 Wkg^{-1}) and right leg ($ankle_{right}$: 4.9±1.2 Wkg^{-1}; $knee_{right}$: 3.4±1.4 Wkg^{-1}; hip_{right}: 2.6±1.0 Wkg^{-1}).

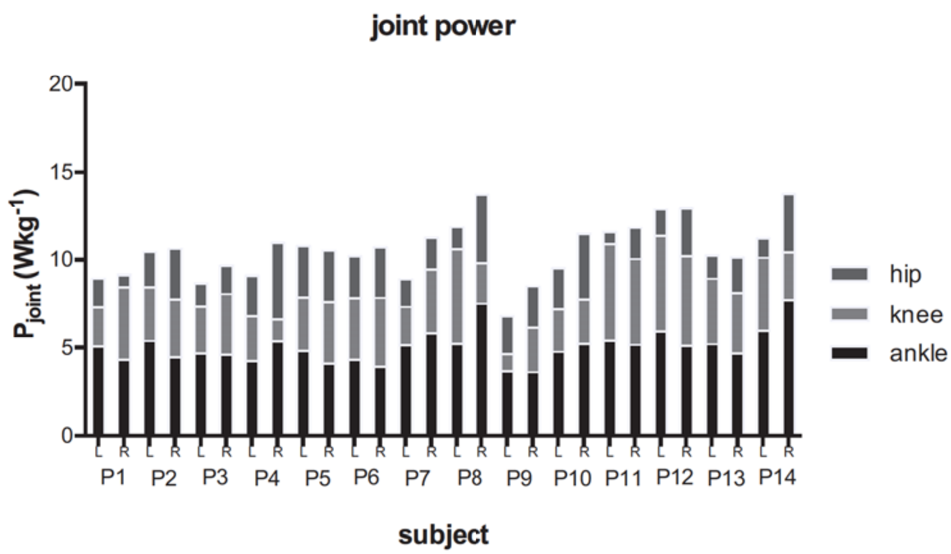

Figure 1 Joint specific mechanical power generated at the ankle, knee and hip joint during a CMJ

DISCUSSION: The study showed sign. smaller jumping heights for BS and MEN in comparison to the CMJ. Although Luhtanen & Komi (1978) showed at least 10% greater jumping heights for CMJ with arm swing, its application in BS led to 16% smaller jumping heights compared to CMJ (Mkaouer et al., 2011). Jumping height relative to body height corresponded with the findings of the current study, which showed 14% greater values for CMJ than for BS. As a result of greater take-off angles, horizontal CoM displacement in CMJ and in BS was sign. smaller than in MEN. Mkaouer et al. (2011) showed greater resulting horizontal CoM displacement in BSd (backward somersault with displacement) due to smaller take off angles in CMJ and BS (estimates of figure 9 in Mkaouer et al. 2011). Agreement of horizontal CoM displacement for CMJ and BS implied the assumption of a predominant technical component for both elements. No sign. differences were found for vertical CoM-lowering of CMJ, BS and MEN. In comparison to the study of Harman et al. (1990), values for CMJ were greater in physically active male participants (35±6 cm).

Additional arm swing decreased CoM-lowering of the participants (32±6.2 cm). Due to a greater resulting jumping height in CMJ with arm swing, less lowering of the CoM was assumed to have favourable influence on initial take-off position of the quadriceps femoris and gluteal muscles. To determine the influence of force generation and arm swing, take-off velocity at CoM was considered. Sign. greater values were found for the CMJ than for the acrobatic elements which is for the CoM in accordance with Harman et al. (1990). In the current study, application of arm swing increased resultant take-off velocity during CMJ,

whereas it decreased take-off velocity in acrobatic elements. Investigations on segmental contribution in CMJ with arm swing by Luhtanen and Komi (1978) showed, that elite athletes were not able to use more than approx. 75% of the generated energy during a multi-joint movement as a consequence of lacking segmental coordination. Because of technical similarities, take-off velocity for MEN were compared to the results for back handspring of Huang & Hsu (2009). Estimations based on data published by Huang & Hsu (2009) about the take-off velocity showed slightly greater values for the back handspring as a characteristic of its execution.
Greatest values of angular momentum and mean angular velocity were found for the MEN in comparison to the BS and CMJ. Minor relationships can be drawn to the results of Mkaouer et al. (2011) revealing joint specific angular velocities in CMJ, BS and BSd during take-off. Values for knee joint angular velocities were determined as 20% and 28% greater in CMJ than in BS and BSd, respectively. Hence, characteristics of body posture during take-off indicate the introduction of backward rotation for BS.
Relative mechanical power was greatest in CMJ compared to BS and MEN, emphasizing the idea of a technical component, which requires an optimal instead of a maximal take-off behaviour for the conduction of gymnastic elements. Basic understanding for muscular activation patterns in vertical jumping compared to BS was provided by Mathiyakom et al. (2006). They compared net joint moments (NJM) and muscle activation patterns during BS and a backward directed straight jump (BJs). Sign. smaller values of NJM for knee extension and greater NJM in hip extension were found in BS compared to BJs during the late take off phase. Significant greater activation was assessed for the gluteus maximus and semitendinosus during BS. These results were in relation to a greater amount of work done for hip extension. Although significant difference was found for the amount of work generated in plantar flexion for both techniques, activation patterns did not differ.

CONCLUSION: Technical differences between BS and vertical jumps show minor necessity for performing basic jumps to increase execution quality of acrobatic elements.
Concerning training purposes, vertical jumping does not affect performance characteristics of acrobatic elements. Nevertheless, from a training oriented perspective, increasing the capability of force generation of the lower extremities, and therefore jumping height during acrobatic and gymnastic elements may have a favourable effect on the element executions' perception for exercise judgement, which is based on the impression of movement control.

REFERENCES:

Arampatzis, A., Brüggemann, G., Klapsing, G. (2001). Leg stiffness and mechanical energetic processes during jumping on a sprung surface. *MSSE,* 33, 923-931.

Dempster, W.T., Gabel, W.C., Felts, W.J. (1959). The anthropometry of the manual work space for the seated subject. *American Journal of Physical Anthropology*, 17, 289-317.

Harman, E., Rosenstein, M., Frykman, P., Rosenstein, R. (1990). The effects of arms and countermovement on vertical jumping. *MSSE,* 22 (6), 825-833.

Hraski, Z. (2002). Correlation between selected kinematic parameters and angular momentum in backward somersaults. *ISBS - Conference Proceedings Archive*.

Huang, C., Hsu, G.-S. (2009). Biomechanical analysis of gymnastic back handspring. *ISBS - Conference Proceedings Archive*.

Lesinski, M., Prieske, O., Granacher, U. (2015) Effects of fatigue and surface instability on neuromuscular performance during jumping. Scand. J. Med. Sci. Sports. Epub, ahead of Print.

Luhtanen, P., Komi, R. (1978). Segmental contribution to forces in vertical jump. Eur J Appl Physiol, 38 (3), 181-188.

Marina, M., Jemni, M., Rodríguez, F., Jimenez, A. (2012). Plyometric Jumping Performances of male and female gymnasts from different heights. *J Strength Cond Res,* 26 (7), 1879-1886.

Mathiyakom, W., McNitt-Gray, J.L., Wilcox, R. (2006). Lower extremity control and dynamics during backward angular impulse generation in backward translating tasks. *Exp Brain Res.*, 169, 377-388.

Mkaouer, B., Jemni, M., Amara, S., Chaabèn, H., & Tabka, Z. (2011). Kinematic and kinetic analysis of counter movement jump versus two different types of standing back somersault. *Science of Gymnastics Journal*, 4(3), 61-71.

Winter, D.A. (1990). *Biomechanical and motor control of human movement*, Wiley & Sons.