# ECCENTRIC PEAK TORQUE OF THE KNEE FLEXORS AND EXTENSORS RELATES TO BACKWARD SOMERSAULT HEIGHT IN FEMALE JUNIOR ARTISTIC GYMNASTS

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***Abstract***
*Artistic gymnastics consist of a high amount of jumping actions with rotations around one or more axes. To achieve an optimal flight height to perform the desired number of rotations, the movement pattern and the floor characteristics have to be concerted optimally. To account for the required leg stiffness to utilize the floor's elasticity, the leg musculature has to generate high forces during the ground contact in an eccentric manner. Thus, eccentric strength of the knee musculature might play an important role for somersault height and run-up velocity in the vault. We investigated the correlation of eccentric peak torque of the knee flexors and extensors and vertical jumping height with backward somersault height and sprinting velocity in female junior artistic gymnasts. The results showed medium to strong, significant correlations between eccentric peak torque and backward somersault height as well as sprinting velocity. Vertical jumping height revealed significant correlations with somersault height and sprinting velocity. Eccentric strength seems to play an important role in joint stiffness regulation to utilize the elastic recoil of gymnastic floors and springboards. In the sprint approaching the vault, the same mechanism seems apparent and is in accordance with findings regarding the sprint in different sports.*
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***Keywords:*** *artistic gymnastics, velocity, strength.*

## INTRODUCTION

Artistic gymnastics is characterized by a high amount of jumping actions with rotations around one or more axes of the body. During the last decades a great increase in difficulty of the performed elements can be observed (Brüggemann, 2005). Potop (2014) points out that according to the Code of Points provisions, high difficulty and complexity of the acrobatic connections in the floor apparatus are necessary. Even if the amount of forward jumping is largely increasing today, these elements are often performed using backward take-offs preceded by a linear run-up and the combination of a round-off followed by a flic-flac (Geiblinger, Morrison & McLaughlin, 1995; King & Yeadon, 2003) and culminate in a variation of the backward somersault that enables greater flight height and angular momentum than can be achieved by performing forward or sideward somersaults (Hraski, 2002). King & Yeadon (2003) identify the vertical velocity and angular momentum as critical factors for successful performance since the product of these factors determines the amount of rotation that can be achieved. Accordingly, the results of Mkaouer, Jemni, Amara, Chaabène & Tabka (2013) indicate that a greater elevation of the centre of mass during the flight phase allows for better performance of the backward somersault.

To achieve an optimal flight height to account for enough time to perform the desired number of rotations, the movement pattern and the floor characteristics have to be concerted optimally (King & Yeardon, 2003; Sands et al., 2013). By technical evolution, the elastic behaviour of the gymnastics spring-floor has been increased and optimized through decades which requires a modification of the stiffness characteristics of the ankle and knee joint (Sands et al., 2013). Accordingly, Arampatzis, Brüggemann & Morey-Klapsing (2000) observed a positive influence of higher leg stiffness on the amount of energy that is stored in the floor surface and reutilized during the propulsive phase of the jump, while Hansen, Hvid, Aagaard & Jensen (2019) report correlations of sprint performance and rate of force development with tumbling performance in TeamGym athletes. Nevertheless, it has to be noted that TeamGym athletes perform on a tumbling track as well as on a regular gymnastics floor. To account for the desired leg stiffness to utilize the elasticity of the floor, the leg musculature has to produce correspondent high forces during the ground contact in an eccentric manner.

Comparable mechanisms can be observed when regarding the vault apparatus in artistic gymnastics. Kalinski, Atikovic, Jelaska & Milic (2016) analysed the performance in the vault apparatus of elite female gymnasts between 2008 and 2015 and concluded that a development towards more and more difficult vaults can be observed. In this apparatus as well, a high leg stiffness is aimed at to utilize the elastic properties of the spring board and to divert the horizontal movement velocity of the run-up into vertical take-off velocity (Hansen et al., 2019).

Since several studies have shown the importance of eccentric activation of the hamstrings in sprinting (Sugiura, Saito, Sakuraba, Sakuma & Suzuki, 2008; Yu et al., 2008) and eccentric training for this muscle group produced significant improvements in sprinting velocity (Ishøi et al., 2018), eccentric hamstring strength should be connected to run-up velocity for the vault.

Therefore, we hypothesize that eccentric strength of the knee flexors and extensors plays an important role for backward somersault height and run-up velocity in the vault in artistic gymnastics.

## METHODS

The aim of this study was to investigate whether eccentric peak torque of the knee flexors and extensors relate to backward somersault height and run-up velocity for the vault in junior artistic gymnasts. 18 female national level junior artistic gymnasts participated in this investigation. Eccentric peak torque for knee flexors and extensors were measured at two movement velocities. Backward somersault height and sprint velocity between 18 and 20 meters were determined on a gymnastics running surface during vault training and on an indoor track, respectively. Additionally, jump-and-reach performance was assessed. All participants completed a familiarization session to each of the testing procedures one week before the actual tests were conducted.

18 female national level junior artistic gymnasts participated in this investigation. The mean age was 12.70 ± 2.00 years, their height was 1.483 ± 0.0958 m and weight 41.50 ± 9.68 kg. All subjects and their parents or legal guardians were informed of the experimental risks involved with the research and provided informed written consent. The research design was approved

by the institutional review board. The study was carried out with respect to the use of human subjects and according to the Declaration of Helsinki.

The participants performed the combination round off – flick-flac – backward somersault on a gymnastics competition spring floor (Spieth Gymnastics GmbH, Altbach, Germany). The landing was performed on an elevation of 1 m consisting of mats to provoke maximum height in the somersault. This was done because it is a common training method for somersaults executed with a focus on height. The execution of this test is displayed in figure 1.

The height was measured as maximum difference of the greater trochanter to the floor. For this purpose, a reflective marker with a diameter of 0.5cm was placed on the right greater trochanter and was tracked in the sagittal plane with 100Hz using a Sony FDR-AX700 camera (Sony Corporation, Tokio, Japan).

The videos were analysed using the software SIMI MOTION (Simi Reality Motion Systems GmbH, Unterschleißheim, Germany).

Eccentric leg strength was determined using the ISOMED2000 isokinetic device (D&R Ferstl GmbH, Hemau, Germany) with a measuring rate of 200Hz. Peak torque measurements were performed in a prone position for the knee flexors and a supine position for knee extensors with 30°/s and 150°/s according to the protocol of Alt, Knicker & Strüder (2020). After individual warm-up the participants performed 5 maximal eccentric contractions per velocity and muscle group. The return into starting position always occurred passively at 120◦/s. Both absolute peak torque and peak torque relative to bodyweight were analysed.

Alt, Knicker & Strüder (2014) report a test-retest-reliability of ICC = 0.829-0.886 for these eccentric test modes with the used device.

The sprint test was performed - after an individual warm up - over a distance of 30 meters on an indoor track. 5 attempts were measured with a rest period of 5 minutes between attempts. Velocity in the segment between 18 and 20 meters (zero referring to the starting point) was detected with 100Hz using a LAVEG laser diode system (model LEM-300W) by JENOPTIK Technologie GmbH (Jena, Germany). This segment was chosen because the official competition rules allow a maximum length of 25 meters for the run-up in the vault and a 2 meter-segment from 7 to 5 meters in front of the table is generally used to measure the running velocity of handspring vaults (Naundorf, Brehmer, Knoll, Bronst & Wagner, 2008).

The start was executed in an upright standing position. No command was given and every tested individual started the test at an individually chosen point of time. A test-retest reliability of $r = 0.99$ ($p < 0.05$) is indicated for this test (Türk-Noack & Schmalz, 1994).

The detection of the jump-and-reach height was carried out using a wooden wall and magnesia on the participants' right hand to mark the achieved height. The difference to the previous marked reaching height in a standing position was then measured using measuring tape.

Participants were shown how to perform a maximal vertical countermovement jump. They were instructed to jump straight up and touch the highest point on the wall they could reach with the tips of the fingers of their right hand. Participants were allowed to practice until they felt comfortable with the equipment and technique. Each participant carried out 5 trials with an inter-jump rest period of at least 30 seconds. The wall was wiped clean from the magnesia marks of the previous jump before each trial.

The data was analysed using SPSS 11.5 (SPSS, Inc., Chicago, IL, USA). Kolmogorov-Smirnov test was used to check for normal distribution. As this test revealed no significant results, Pearson's product-moment correlation was used to determine the strength of the relationships. The level of significance for all tests was set a priori to $p \leq 0.05$.

According to Keiner, Sander, Wirth, Hartmann & Yaghobi (2014), the correlation coefficient was classified as follows: 0 = no correlation, 0 < | r | < 0.2 = very weak correlation, 0.2 < | r | < 0.4 = weak correlation, 0.4 < | r | < 0.6 = medium correlation, 0.6 < | r | < 0.8 = strong correlation, 0.8 < | r | < 1.0 = very strong correlation, | r | = 1 = perfect correlation.

**RESULTS**

The descriptive data are displayed in table 1. The backward somersault test showed a mean height of 1.35 ± 0.16 m. The mean run-up velocity for the vault was 7.66 ± 0.35 m/s. The eccentric strength tests show greater peak torque values for 150 °/s compared to 30 °/s.

*Figure 1.* Execution of the somersault test.

Table 1
*Descriptive data of the performed Tests.*

| | Mean | Max | Min | SD |
|---|---|---|---|---|
| BSH [m] | 1.35 | 1.70 | 1.09 | 0.16 |
| v 18-20 [m/s] | 7.04 | 7.66 | 6.56 | 0.35 |
| J&R [cm] | 47.11 | 59.00 | 35.00 | 5.50 |
| Quad 30 [Nm] | 107.33 | 211.19 | 62.11 | 38.82 |
| Quad 150 [Nm] | 108.83 | 194.50 | 74.41 | 31.19 |
| Ham 30 [Nm] | 42.14 | 86.11 | 22.23 | 18.09 |
| Ham 150 [Nm] | 44.33 | 79.11 | 28.90 | 13.72 |
| Quad 30 R [Nm/kg] | 2.58 | 3.94 | 1.69 | 0.63 |
| Quad 150 R [Nm/kg] | 2.66 | 4.28 | 1.81 | 0.64 |
| Ham 30 R [Nm/kg] | 0.98 | 1.46 | 0.59 | 0.21 |
| Ham 150 R [Nm/kg] | 1.06 | 1.41 | 0.91 | 0.14 |

BSH = Backward Somersault Height; v 18-20 = sprint velocity between 18 and 20 meters; J&R = Jump-and-reach height; Quad = Quadriceps; Ham = Hamstrings; R = relative to bodyweight

Table 2
*Correlation coefficients of the absolute peak torque values and jump-and-reach height with backward somersault height and sprint velocity between 18 and 20 meters.*

| | *J&R* | *Quad 30* | *Quad 150* | *Ham 30* | *Ham 150* |
|---|---|---|---|---|---|
| *BSH* | 0.696** | 0.709** | 0.696** | 0.840** | 0.814** |
| *v 18-20* | 0.594** | 0.345 | 0.448* | 0.474* | 0.511* |

* = p < 0.05; ** = p < 0.01

Table 3
*Correlation coefficients of the relative peak torque values with backward somersault height and sprint velocity between 18 and 20 meters.*

| | *Quad 30 R* | *Quad 150 R* | *Ham 30 R* | *Ham 150 R* |
|---|---|---|---|---|
| *BSH* | 0.241 | 0.021 | 0.748** | 0.437* |
| *v 18-20* | 0.027 | 0.000 | 0.342 | 0.258 |

* = p < 0.05; ** = p < 0.01

The calculation of the correlation coefficients of the backward somersault height with the Jump-and-reach height and the absolute eccentric strength parameters revealed significant, medium to strong correlations ($p < 0.01$) (Table 2). Interestingly the greatest correlations were observed for the eccentric peak torque of the knee flexors.

The correlations regarding the sprint velocity with the eccentric strength tests and jump-and-reach height revealed medium significant correlations ($p < 0.05$) for the eccentric peak torque of the hamstrings and the eccentric peak torque of the quadriceps while eccentric peak torque at 30°/s did not relate significantly to the sprint velocity. The greatest significant coefficient ($p < 0.01$) could be observed for the achieved height in the jump-and-reach test.

Interestingly, when calculating the peak torque values relative to bodyweight, no significant correlations for the sprint velocity were found. When using relative peak torque, only the knee flexors' strength showed significant correlations with backward somersault height (Table 3).

**DISCUSSION**

The study revealed medium significant correlations of eccentric peak torque of the knee extensors at 150°/s and the knee flexors at 30°/s and 150°/s as well as jump-and-reach height with the run-up velocity in the gymnastics vault. This is in accordance with previous findings that eccentric hamstring strength is particularly important for sprint performance. This is due to the observation that the greatest hamstring length is apparent right before ground contact of the foot while the muscles are also activated (Schache, Dorn, Blanch, Brown & Pandy, 2012; Thelen, Chumanov, Best, Swanson & Heiderscheit, 2005). In this position the hamstrings have to provide for a high amount of energy absorption (Chumanov, Heiderscheit & Thelen, 2007; Schache et al., 2012; Thelen et al., 2005) that is linked to the achieved running velocity (Chumanov et al., 2007). Additionally, low eccentric hamstring strength was identified as a risk factor for hamstring injuries while sprinting (Hicks, 2017; Jonhagen, Nemeth & Eriksson, 1994). Since propulsion in the maximum velocity phase of sprinting is believed to be realized primarily via hip extension with great back-swing velocity (Bezodis, Kerwin & Salo, 2008; Hunter, Marshall & McNair, 2005; Seagrave, 1996; Wiemann & Tidow, 1995), the main contribution of knee and ankle joints is the amortization of the ground reaction forces' vertical component to counteract a lowering of the body's centre of mass (Hunter, Marshall & McNair, 2004; Hunter et al., 2005; Simonsen, Thomsen & Klausen, 1985; Wiemann & Tidow, 1995). Thus, the stiffness of the knee joint seems to be of high importance in this phase (Bret, Rahmani, Dufour, Messonnier & Lacour, 2002; Chelly & Denis, 2001). To provide for the necessary amount of knee joint stiffness, the influence of eccentric strength of the knee extensors seems apparent. Since antagonistic co-contraction increases joint stiffness as well as short-latency stretch reflexes (Nielsen, Sinkjær, Toft & Kagamihara, 1994), a contribution of hamstring maximum strength to knee joint stiffness in sprint running is conceivable as well. Of course, it needs to be considered that the executed strength tests did not include the hip flexors and extensors that are of crucial importance for sprint performance (Bezodis et al., 2008; Hunter et al., 2005; Seagrave, 1996; Wiemann & Tidow, 1995).

Regarding the backward somersault height, significant medium to high correlations with jump-and-reach height as well as eccentric peak torque of the knee extensors and flexors at both angular velocities could be observed. The former reflects the results of Mkaouer, Jemni, Amara, Chaabène & Tabka (2012) that a backward somersault and a countermovement jump with arm swing seem to be similar kinematically and kinetically in their vertical components. The latter appears to be in accordance with the findings of Kashuba, Khmelnitska & Krupenya (2012) who report knee angles between 163.9° and 175.3° for the ground contact after the combination round off – flick-flac in approach to the vault table. In this case again, eccentric strength of both knee extensors and knee flexors seems to impact joint stiffness via co-contraction to utilise the short-latency stretch reflexes via a stretch-shortening-cycle (Nielsen et al., 1994) and to benefit from the energy stored in the elastic floor surface during the propulsive phase of the jump (Arampatzis et al., 2000).

It is noteworthy, that although eccentric muscle actions of the studies muscles are a fundamental part of daily activities, maximal eccentric strength testing must be regarded as rather unusual and therefore shows greater familiarization effects than concentric testing (Dirnberger, Huber, Hoop, Kösters & Müller, 2013). This observation is explained by different neuronal patterns specific to the type of contraction (Wirth, Keiner, Szilvas, Hartmann & Sander, 2015) which might possibly lead to initial inhibition in unfamiliar subjects (Dirnberger et al., 2013). Therefore, it is important to mention that the participants of this study were familiar with maximal eccentric contractions of the studies muscle group since they have participated in eccentric strength training as part of their athletic preparation prior to the conducted study.

## CONCLUSIONS

Eccentric strength of the knee flexors and extensors appears to be an important requirement for female artistic gymnasts in vault and floor apparatus.

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