DIFFERENCES IN MUSCLE DEMAND ACROSS TAKE-OFF TECHNIQUES IN THE BACK HANDSPRING STEP OUT IN WOMEN'S GYMNASTICS

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The back handspring step out (BHS) is a foundational skill in balance beam routines that can be performed using three different take-off techniques (Simultaneous Flexion, Sequential Flexion, Double-Bounce). However, it is unclear if the different techniques require different levels of muscle demand. The purpose of this study was to use modelling and simulation to quantify muscle demand across the three techniques. While there were no differences in total average muscle demand between techniques, the Sequential Flexion technique required more demand from the knee and hip flexors, while the Simultaneous Flexion and Double-Bounce techniques required more demand from the knee and hip extensors. Thus, gymnasts using each of these techniques should target these specific muscle groups for increased strength and power.

KEYWORDS: Gymnastics, Biomechanics, Balance Beam, Modelling and Simulation.

INTRODUCTION: While gymnasts are judged in competition based on kinematic requirements outlined in the Code of Points (FIG, 2022), gymnasts can perform a given skill using different techniques while satisfying those requirements. Given the high biomechanical demands of various skills in gymnastics, a better understanding of the differences between techniques used is crucial for targeted muscle training routines. The back handspring step out (BHS) in women's artistic gymnastics is a foundational skill in balance beam routines (FIG, 2022). However, few studies have analyzed the take-off technique used in a BHS (Small & Neptune, 2024b) or have assessed differences in muscle demand between the different take-off techniques used. Previous work identified three unique take-off techniques that gymnasts use in the BHS to generate the necessary linear and angular momentum for the skill (Small & Neptune, 2024b): Simultaneous Flexion, Sequential Flexion and Double-Bounce (Fig. 1).

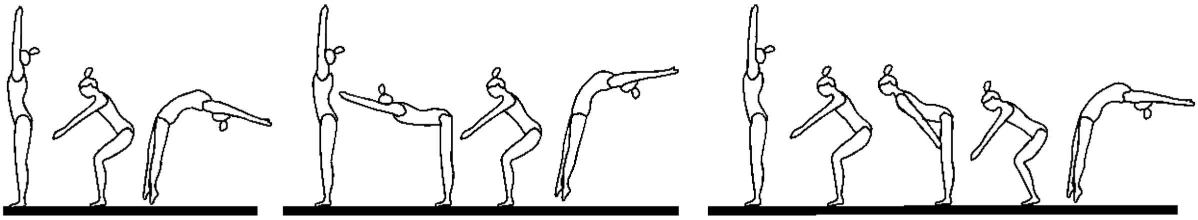

Figure 1: Schematic of the three identified techniques for the back handspring step out [adapted from Small & Neptune (2024b)].

These techniques generate different ground reaction force (GRF) profiles, with the Simultaneous Flexion technique having lower GRF peaks and impulses and a lower maximum pelvis height (Small & Neptune, 2024b), which, along with the differences in kinematics, may require lower muscle demand. Muscle demand is an important consideration due to its influence on energy expenditure and fatigue. Gymnastics routines cause high heart rates and blood lactate levels (Marina & Rodríguez, 2014; Montgomery & Beaudin, 1982), and high-level gymnasts perform up to 1,700 gymnastics elements each week (Jemni, 2017). Therefore, gymnasts should aim for increased efficiency performing their skills as fatigue can affect their technical performance (Marina & Rodríguez, 2014). Thus, determining how take-off technique influences muscle demand could help improve overall performance. The purpose of this study was to quantify the influence of BHS take-off technique on muscle demand using musculoskeletal modelling and simulation. We hypothesized that the Simultaneous Flexion technique would have the lowest muscle demand of the three take-off techniques due to its lower GRF peaks and impulses.

METHODS: Simulations were generated using previously collected experimental BHS data (Small & Neptune, 2024b). Briefly, twenty-one female gymnasts (age: 15.3±3.6 years, mass: 49.6±9.6kg, height: 154.0±7.2cm, gymnastics skill level (1-10): 8.3±1.2) participated in this Institutional Review Board approved study. Three-dimensional full-body kinematic and GRF data were collected. Gymnasts completed three BHSs on a 2.7m long and 0.1m wide floor-mounted balance beam and were grouped into the three techniques based on their kinematics (Simultaneous Flexion: n=6; Sequential Flexion: n=5; Double-Bounce: n=10) (Small & Neptune, 2024b). Because the balance beam during the experimental set up was placed on top of the force plates, the trials on the balance beam yielded resultant GRFs. Therefore, the gymnasts also performed a BHS on the floor starting with each foot on a separate force plate to provide an estimate for the GRF decomposition across the feet. In OpenSim 4.4, a 12-segment musculoskeletal model with 23 degrees of freedom and 92 Hill-type muscle actuators on the lower body (Delp et al., 2007; Seth et al., 2018) was used to simulate the BHS take-off. The model was scaled to fit the anthropometry of each gymnast. An inverse kinematics analysis determined the joint angles from the start of the skill (center of mass (CoM) velocity >0) until toe-off (GRF =0), indicating the take-off phase. The GRFs from the BHS trials on the beam were decomposed to the left and right foot based on the distribution of the GRFs from the BHS on the floor. The corresponding decomposed GRFs were applied at the respective center of pressure. Static optimization estimated the muscle forces. Muscles were combined into groups with similar biomechanical functions (Table 1). Muscle demand was assessed using muscle stress that was calculated as the percentage of the maximum isometric force at each time step, which is equivalent to the instantaneous muscle force divided by the physiological cross-sectional area of the muscle. Muscle stress was then averaged over the take-off phase for each functional muscle group and then averaged over all muscle groups for the total average muscle stress.

Table 1: Muscle analysis groups.

Name	**Abbr.**	**Muscles Included**
Iliopsoas	IL	Iliacus, Psoas
Adductors	ADD	Adductor Magnus, Longus and Brevis, Pectineus, Quadratus Femoris
Erector Spinae	TRUNK	Erector Spinae, External and Internal Obliques
Rectus Femoris	RF	Rectus Femoris
Gluteus Medius	GMED	Anterior, Middle and Posterior Gluteus Medius and Minimus, Gemellus, Piriformis, Sartorius
Gluteus Maximus	GMAX	Superior, Middle and Inferior Gluteus Maximus
Biarticular Hamstrings	HAM	Semimembranosus, Semitendinosus, Biceps Femoris Long Head, Gracilis
Gastrocnemius	GAS	Medial and Lateral Gastrocnemius
Soleus	SOL	Soleus, Tibialis Posterior, Flexor Digitorum and Hallucis Longus, Peroneus Brevis and Longus
Tibialis Anterior	TA	Tibialis Anterior, Extensor Digitorum and Hallucis Longus, Peroneus Tertius
Vasti	VAS	Vastus Intermedius, Lateralis and Medialis
Tensor Fasciae Latae	TFL	Tensor Fasciae Latae
Biceps Femoris Short Head	BFSH	Biceps Femoris Short Head

One-way analyses of variance (ANOVA) tests were used to assess differences in muscle stress across techniques for the functional muscle groups. If the ANOVA revealed significant effects, Tukey post-hoc tests were performed to identify pairwise differences. Significance levels were set at p<0.05 and reported for the ANOVAs.

RESULTS: IL (p=0.001), GMAX (p=0.002), GAS (p=0.009), TA (p=0.013) and BFSH (p=0.004) had differences in muscle stress between the Sequential Flexion and the other two techniques

(Fig. 2). For the Sequential Flexion technique, muscle stress for the knee flexors (GAS and BFSH) was higher and trended lower for the knee extensors (RF and VAS). For the muscles crossing the hip joint, muscle stress was higher for the hip flexors (IL) and lower for the hip extensors (GMAX and HAM) (Fig. 2).

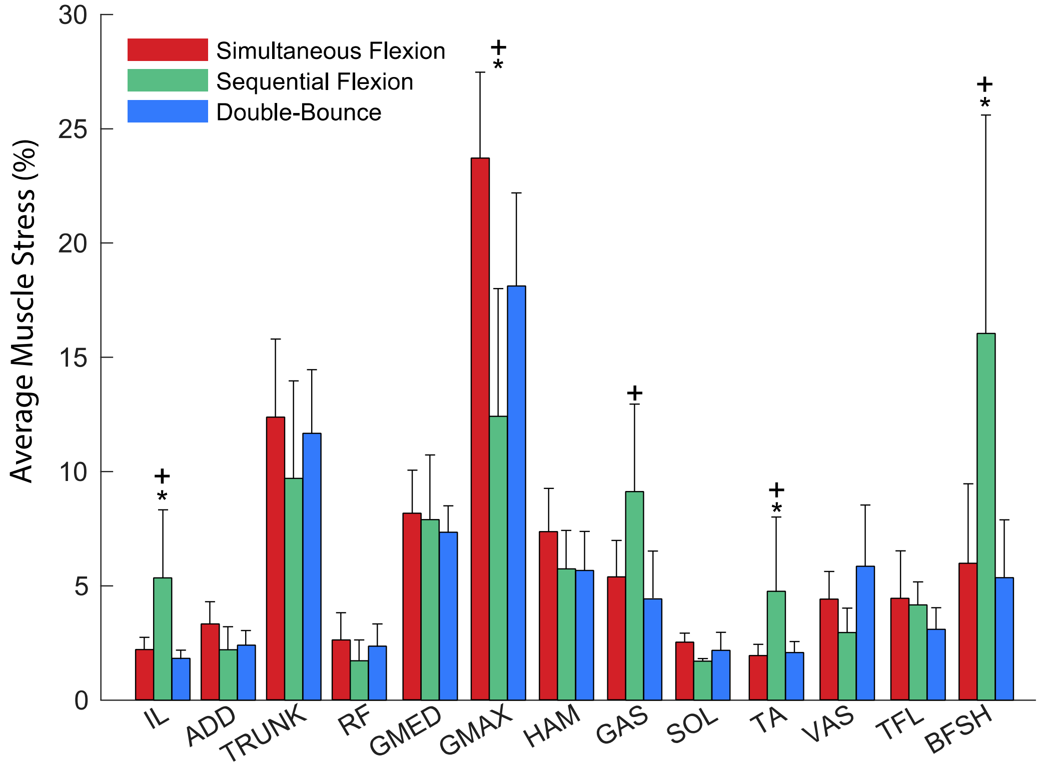

Figure 2: Muscle stress across the functional muscle groups. "*" indicates a significant difference between Simultaneous Flexion and Sequential Flexion, and "+" indicates a significant difference between Sequential Flexion and Double-Bounce.

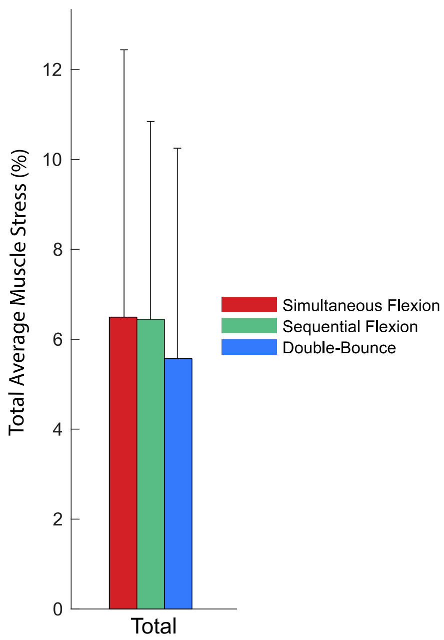

Figure 3: Total average muscle stress.

Across all techniques, GMAX, GMED, TRUNK, BFSH, GAS and HAM had the highest muscle stress during the take-off phase (Fig. 2). When averaging across all muscles, differences between techniques were eliminated (Fig. 3).

DISCUSSION: This study assessed the influence of BHS take-off technique on muscle demand. We hypothesized that the Simultaneous Flexion technique would have the lowest muscle demand of the take-off techniques, which was not supported in the total muscle demand. However, there were important differences in individual muscles between the techniques. The Sequential Flexion technique had higher demand in some knee and hip flexors muscles but lower demand in the knee and hip extensors. Muscle demand was higher in IL for the Sequential Flexion technique due to the large trunk flexion without knee flexion occurring in this technique. Thus, IL required more demand to maintain balance over the base of support, as previous work found a larger IL contribution to maintaining balance control using this technique (Small & Neptune, 2024a). In related tasks such as horizontal jumps, IL is largely activated due to its role in moving the body's CoM forwards (Nagano et al., 2007). The

Simultaneous Flexion technique had the highest GMAX demand because this technique reached the largest hip flexion angle. Furthermore, GMAX in the Sequential Flexion technique was also found to have a lower contribution to balance control than the other techniques (Small & Neptune, 2024a), consistent with its lower demand in this technique. GAS and BFSH also had higher muscle demand in the Sequential Flexion technique due to the knees remaining extended during trunk flexion. Previous work also found that BFSH had a larger contribution to sagittal plane angular momentum generation in the Sequential Flexion technique and that across all techniques, GAS was crucial for body propulsion (Small & Neptune, 2024a). Overall, while the three techniques have differing kinematics, they all can produce the necessary momentum to complete the skill and have similar total muscle demand, which may partially explain why both higher and lower level gymnasts self-select different techniques in the take-off phase (Small & Neptune, 2024b).

CONCLUSION: Given the importance of the BHS as a foundational skill on the balance beam, a better understanding of the underlying biomechanics is crucial. This study identified the muscle demand required for the three different techniques used in the take-off phase of the BHS. While there were no differences in total muscle demand between techniques, there were important individual muscle differences that gymnasts and coaches should consider when training. Higher demand for the knee and hip flexors was observed in the Sequential Flexion technique, and therefore gymnasts who use this technique should focus on training these muscle groups for safer and better performing BHSs. In contrast, higher demand for the knee and hip extensors was observed for the Simultaneous Flexion and Double-Bounce techniques, and thus gymnasts using these techniques should target these muscles for training. Regardless of the technique used, GMAX, GMED, TRUNK, GAS and HAM had the highest demand during the take-off and should be a focus for training routines aimed at improving the performance of the BHS.

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