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How take-off technique affects muscle demand in the back handspring step out in female gymnasts

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ABSTRACT

When performing the back handspring step out (BHS) on the balance beam, most gymnasts use one of three take-off techniques: Simultaneous Flexion, Sequential Flexion or Double-Bounce. However, it remains unclear which technique results in the lowest muscle demand that could help reduce energy expenditure and fatigue and improve overall performance. The purpose of this study was to use musculoskeletal modelling and simulation to quantify the influence of take-off technique on muscle demand (integrated muscle power) and contributions to the critical biomechanical functions of whole-body angular momentum generation and control and trunk propulsion (mechanical power delivered to the trunk). Simulations of female gymnasts ($n = 21$; age: 15.3 ± 3.6) were generated using their self-selected BHS technique on a balance beam. Differences in muscle demand were small across the techniques. However, the vasti, ankle plantarflexors, gluteus maximus and hamstring muscle groups experienced large demand during the BHS take-off. The gluteus medius and ankle plantarflexors were crucial for maintaining balance. The hamstrings, ankle plantarflexors and vasti generated needed momentum and delivered power to the trunk. These results provide targets for muscle strengthening and conditioning to improve balance control and increase the height and distance of the BHS, which is needed before adding additional skills in combination.

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Introduction

Gymnastics involves highly complex motor skills that require precise muscle coordination to successfully complete. Given the high demand on the body's joints and muscles during gymnastics routines, a better understanding of the biomechanics of specific routines is crucial for improving training methods and performance. The back handspring step out (BHS) in women's artistic gymnastics is a foundational skill that occurs in balance beam routines starting as young as 10 years old through the collegiate and Olympic levels (Fédération Internationale de Gymnastique, 2022). The BHS take-off requires the gymnast to produce both linear and angular momentum, and variations in technique can successfully produce these momentum components (Fédération Internationale de Gymnastique, 2022). For example, previous research investigated differences in hand position (Burton et al., 2017; Richter & Boucher, 2017) and elbow

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flexion (Koh et al., 1992) at hand contact in the two-footed BHS on the floor. However, few studies have researched the take-off technique in a BHS on a balance beam (Small & Neptune, 2024b), and no studies have analysed muscle demand or how muscles work in synergy to perform the various BHS biomechanical functions.

We previously identified three unique take-off techniques that gymnasts use in the BHS to generate the necessary momentum for the skill (Small & Neptune, 2024b): 1) the trunk and knees flex at the same time during take-off phase (Simultaneous Flexion), 2) the trunk reaches its maximum flexion and then the knees flex during take-off phase (Sequential Flexion) and 3) the trunk and knees flex at the same time and then the knees extend and flex again to produce a second countermovement (Double-Bounce) (Figure 1). These three techniques generate different ground reaction force (GRF) profiles, with the Simultaneous Flexion technique having lower GRF peaks and impulses (Small & Neptune, 2024b), which may require less muscle demand. However, the Sequential Flexion technique had significantly lower spine extension angles at hand contact (Small & Neptune, 2024b), which may be important for reducing back injuries

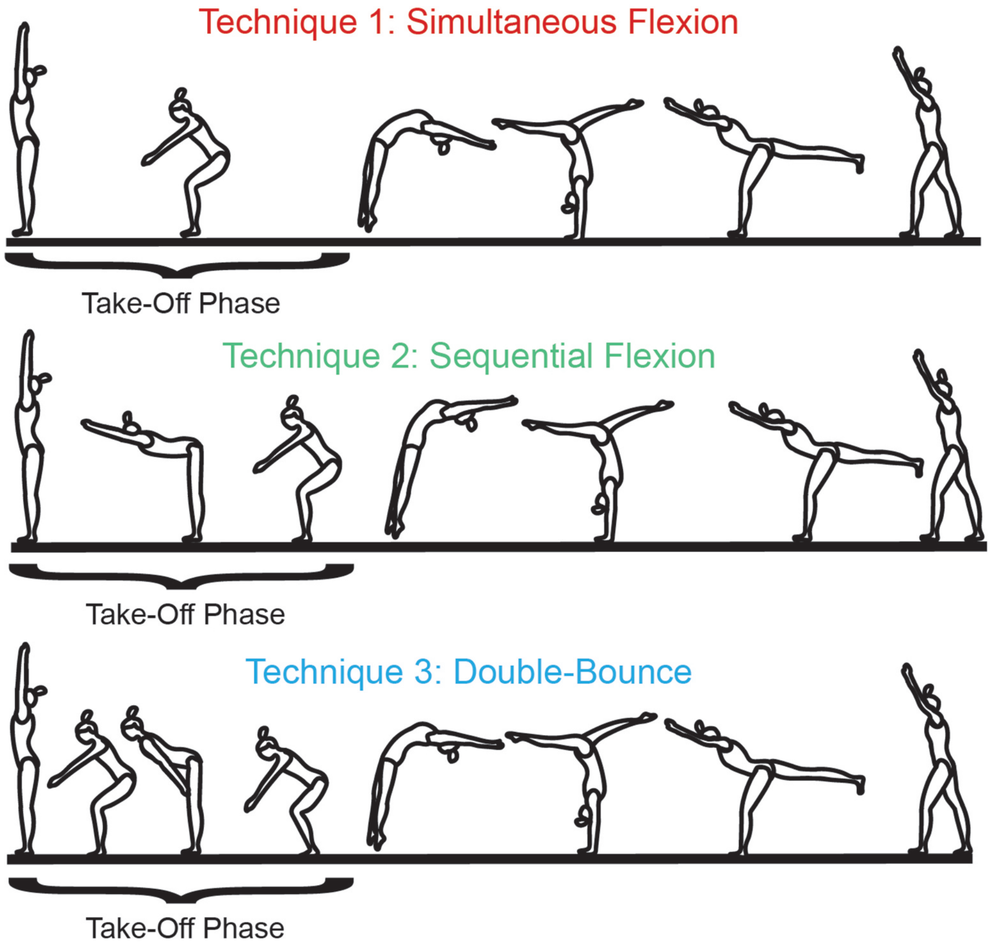

Figure 1. A schematic of the three different take-off techniques.

(Pimentel et al., 2020). Thus, more work is needed to determine which technique is more advantageous relative to the others.

While these biomechanical differences are important factors in considering which technique to teach young gymnasts, muscle demand is also an important consideration due to its influence on energy expenditure and fatigue. Given that gymnastics routines cause both high heart rates and blood lactate levels (Marina & Rodríguez, 2014; Montgomery & Beaudin, 1982) and that high-level gymnasts can perform up to 1,700 gymnastics elements every week (Jemni, 2017), gymnasts must be economical in their skills as fatigue can affect technical performance (Marina & Rodríguez, 2014). Thus, identifying which take-off technique requires the least muscle demand could help improve overall performance.

In addition to exerting significant muscle demand to perform the BHS, gymnasts must tightly control their balance to stay within the narrow constraints of the balance beam. Whole-body angular momentum (H) is a mechanics-based measure that has been used to assess balance control in a variety of locomotor tasks (Neptune & Vistamehr, 2019) as well as in the BHS, where higher ranges of frontal plane H correlate with higher point deductions in gymnastics (Small & Neptune, 2024b), which indicates a worse performance (Fédération Internationale de Gymnastique, 2022). H is partially mediated through foot placement by changing the moment arm between the centre of pressure and the body centre of mass (CoM). Thus, constraining the centre of pressure to the narrow balance beam can limit the ability of gymnasts to alter H. In order to complete the BHS, gymnasts not only have to maintain their frontal plane balance, but also generate the necessary sagittal plane angular momentum to rotate the body and deliver power to propel the trunk upwards and backwards to achieve the necessary height and horizontal displacement (Small & Neptune, 2024b). Previous research found that the trunk was an important segment for controlling the BHS, in part due to its large mass (Small & Neptune, 2024b), and thus the power delivered to the trunk may require a large portion of the overall muscle demand during the BHS take-off.

The purpose of this study was to use musculoskeletal modelling and simulation to quantify the influence of take-off technique on muscle demand and individual muscle contributions to two critical biomechanical functions in the BHS take-off: angular momentum generation and control and trunk propulsion. We hypothesise that the Simultaneous Flexion technique will have the lowest overall muscle demand due to its lower GRF requirements. We also expect differences in overall muscle demand will arise from differences in the muscle contributions to angular momentum generation and control and the work done to linearly propel the trunk across the three take-off techniques.

Materials and methods

Experimental data

Simulations were generated of previously collected experimental BHS data (Small & Neptune, 2024b). Briefly, 25 female gymnasts who could perform a BHS on the balance beam were recruited from the local community. Four were excluded due to abnormally high hip flexion angles, resulting in 21 gymnasts used for the simulation analyses (Table 1).

Table 1. Gymnast demographics (mean ± standard deviation).

	Total Average	Simultaneous Flexion Technique (*n* = 6)	Sequential Flexion Technique (*n* = 5)	Double-Bounce Technique (*n* = 10)
Age (years)	15.3 ± 3.6	16 ± 5.3	14.8 ± 3.4	15.2 ± 2.9
Height (cm)	154.0 ± 7.2	153.8 ± 58.6	151.0 ± 10.7	155.5 ± 4.7
Mass (kg)	49.6 ± 9.6	48.0 ± 19.8	45.2 ± 10.1	52.8 ± 9.7
Skill Level in Gymnastics (1-10)	8.3 ± 1.2	8.2 ± 3.3	8.6 ± 1.5	8.3 ± 0.9
Leading Leg (Left/Right)	7 Left/14 Right	3 Left/3 Right	1 Left/4 Right	3 Left/7 Right

All gymnasts provided informed consent to participate in this protocol approved by the Institutional Review Board. All gymnasts were free from any musculoskeletal or neuromuscular injuries that would affect their performance of a BHS on a balance beam. Three-dimensional full-body kinematic and GRF data were collected. Electromyographic (EMG) data from 14 electrodes placed on bilateral gluteus maximus, gluteus medius, rectus femoris, biceps femoris long head, vastus medialis, medial gastrocnemius and soleus were also collected.

The gymnasts were given as much time as they needed to warm up in order to perform a BHS on the balance beam. They performed three trials of a BHS on a floor beam as if they were in a competition, and each BHS was judged by a trained expert based off of the Code of Points (Fédération Internationale de Gymnastique, 2022). Because the balance beam during the experimental setup was placed on top of the force plates, the trials on the balance beam only had 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.

Musculoskeletal model and simulation

Gymnasts were split into each of the three techniques based on their kinematics (Small & Neptune, 2024b) (Table 1), and their highest-scoring BHS, representing the best performance, was simulated. Using 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 kinematic analysis then determined the joint angles by minimising the difference between the experimental and model body segment markers from the start of the skill (i.e., when the CoM velocity > 0) until toe-off (when the 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 off of the distribution of the GRFs from the BHS on the floor. The corresponding decomposed GRFs were applied at each foot's centre of pressure. Static optimisation was used to estimate the muscle forces that reproduce the experimental joint moments while minimising the sum of muscle activations squared at each time step. To help validate the results, the timing of the resulting muscle activations were compared with the corresponding experimental EMGs. Muscles were combined into groups with similar biomechanical functions for additional analysis (Table 2).

Table 2. Muscle analysis groups.

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

Muscle demand

To determine the muscle demand, muscle power was calculated as the product of the musculotendon force and velocity. The positive and negative muscle power was then integrated over the take-off phase and averaged across the legs to determine the positive and negative work done by each muscle group.

Muscle contributions to angular momentum generation and control

To further understand the biomechanical functions that contributed to the differences in muscle demand, individual muscle contributions to sagittal and frontal plane angular momentum generation and control were calculated during each take-off phase by the individual muscle contributions to the external moment as:

$$\dot{\vec{H}} = \vec{r}\, x\, \vec{F}_{GRF} \;= \vec{M}_{ext} \tag{1}$$

where $\dot{\vec{H}}$ is the time rate of change of whole-body angular momentum, $\vec{M}_{ext}$ is the contribution of each muscle to the external moment, $\vec{F}_{GRF}$ is each muscle's contribution to the GRF calculated from a GRF decomposition technique (Hamner et al., 2010) and $\vec{r}$ is the moment arm between the CoM and the centre of pressure (Neptune & McGowan, 2016). Sagittal and frontal plane external moments were averaged across the take-off phase and across both legs.

Muscle contributions to work done on the trunk

In addition, we performed a segmental power analysis to determine muscle power delivered to the trunk during the take-off phase and summed that power in the vertical and anterior-posterior (AP) directions (Fregly & Zajac, 1996). Net muscle power delivered to the trunk was then integrated over the take-off phase to determine each muscle's net mechanical work done to linearly propel the trunk.

Statistical analysis

To determine differences in the individual muscle contributions to muscle demand, sagittal and frontal plane average external moments and muscle work delivered to the trunk across the take-off techniques, one-way analysis of variance (ANOVA) tests were used to test for differences across the techniques. If the ANOVA identified significant differences, Tukey HSD *post-hoc* tests were performed to identify pairwise differences across the three techniques and to correct for multiple comparisons. The significance level was set at $p < 0.05$.

Results

Muscle demand

The Simultaneous Flexion technique trended towards the lowest total average negative muscle work, while the Double-Bounce technique trended towards the highest total average negative muscle work. The Sequential Flexion technique trended towards the highest total average positive muscle work (Figure 2a). However, these differences were small. Across techniques, the only muscle groups that produced differences in muscle work across the techniques were TFL, VAS, TRUNK and IL (for statistical results, see Appendix A). Of note, the Double-Bounce technique had larger VAS work than the other techniques (Figure 2b). Across all techniques, GMAX, HAM, PF and VAS produced high levels of negative muscle work, while VAS, PF and HAM produced high levels of positive muscle work. Therefore, GMAX, HAM, PF and VAS as well as GMED will be the focus in the following sections.

Muscle contributions to angular momentum generation and control

The only differences in individual muscle contributions to the external moment across the three techniques were small differences from IL, TA and BFSH (for statistical results, see Appendix B). Across all techniques, PF rotated the body backwards and outwards. VAS acted to rotate the body forwards while HAM rotated the body backwards. GMAX slightly rotated the body forwards and inward, while GMED also rotated the body inward (Figure 3).

Muscle contributions to work done on the trunk

The only differences between the muscle work done on the trunk across techniques were small differences from IL and ADD (for statistical results, see Appendix C). Across all techniques, the muscles did more positive trunk work than negative, and VAS, PF and HAM had the largest positive contributions to trunk work (Figure 4). The Sequential Flexion technique trended towards more total average trunk work than the other two techniques (Figure 4 and Appendix C).

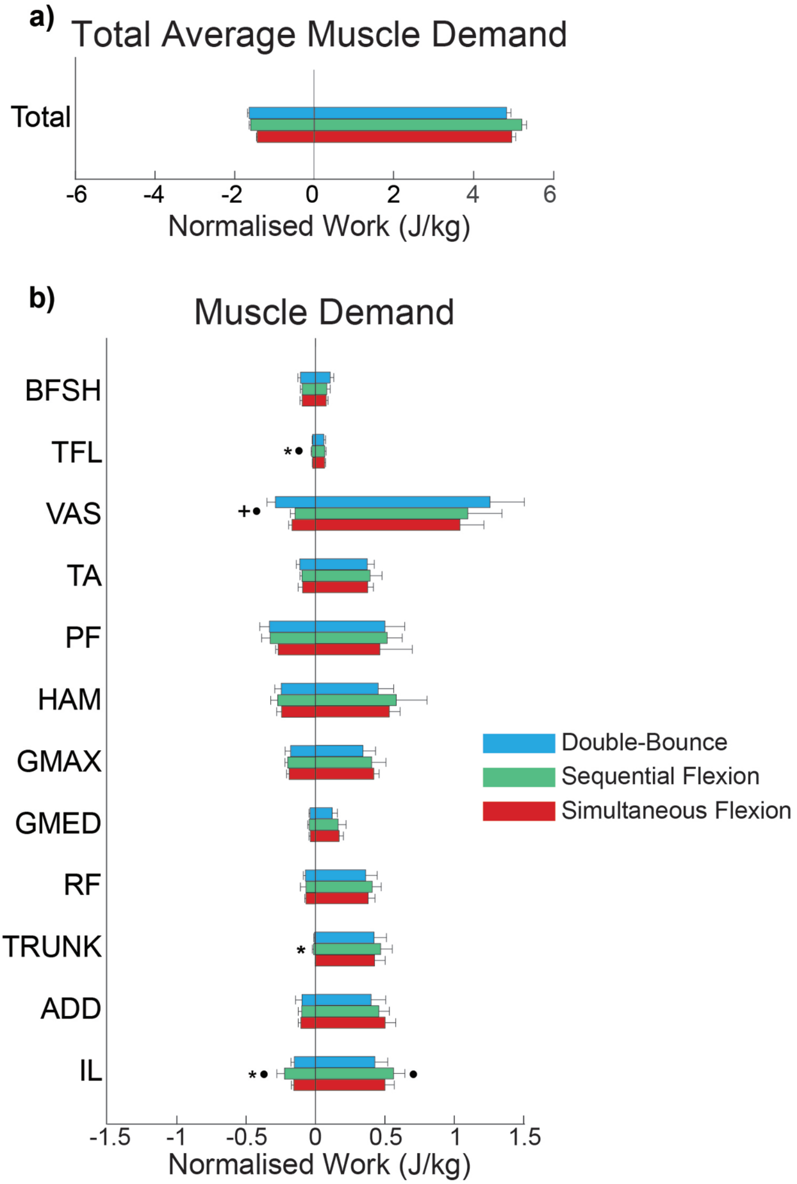

Figure 2. Muscle demand for a) the total average muscle work summed across all muscles and b) the individual functional muscle groups across the three techniques (Double-Bounce = blue, Sequential Flexion = green, Simultaneous Flexion = red) normalised by body mass for each gymnast. A '*' indicates significant difference between the Simultaneous and Sequential Flexion techniques. A '+' indicates a significant difference between the Simultaneous Flexion and Double-Bounce techniques. A '•' indicates a significant difference between the Sequential Flexion and Double-Bounce techniques. The significance level was set at $p < 0.05$.

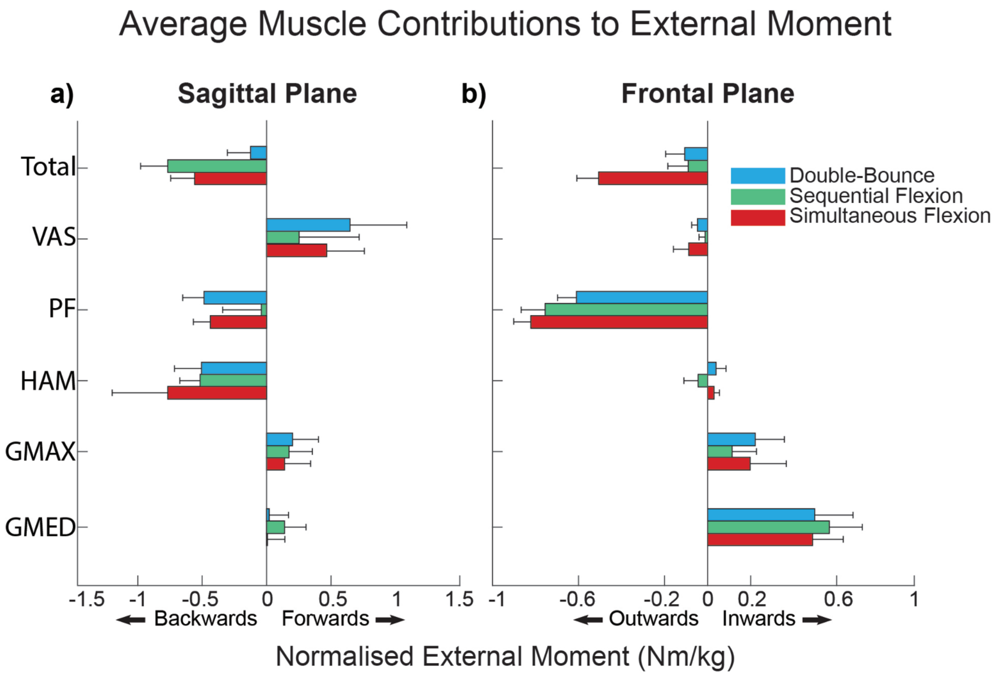

Figure 3. Primary muscle contributions to a) sagittal and b) frontal plane external moment for the functional muscle groups across the three techniques (Double-Bounce = blue, Sequential Flexion = green, Simultaneous Flexion = red) normalised by body mass for each gymnast. Outwards indicates the moment is directed away from the beam, while Inwards indicates it is directed towards the centre of the beam.

The Simultaneous Flexion and Double-Bounce techniques had small negative power peaks earlier in the take-off phase from VAS and PF as they absorbed power from the trunk (Figure 5). In the Double-Bounce technique, PF had two positive contributions. For all techniques, a large portion of the power was delivered to the trunk at the end of the take-off phase by HAM and GMAX, when the majority of propulsion occurs.

Discussion and implication

This study used musculoskeletal modelling and simulation to quantify the influence of take-off technique on muscle demand in the BHS to inform coaching and targeted muscle strengthening and conditioning. To better understand the differences in demand, we further explored individual muscle contributions to the critical biomechanical functions of angular momentum generation and control and trunk propulsion. We hypothesised that the Simultaneous Flexion technique would have the lowest muscle demand due to its lower GRF requirements. We also expected differences in overall muscle demand would arise from differences in the muscle contributions to angular momentum generation and control and the work done to linearly propel the trunk across the three take-off techniques, which was partially supported in specific muscles.

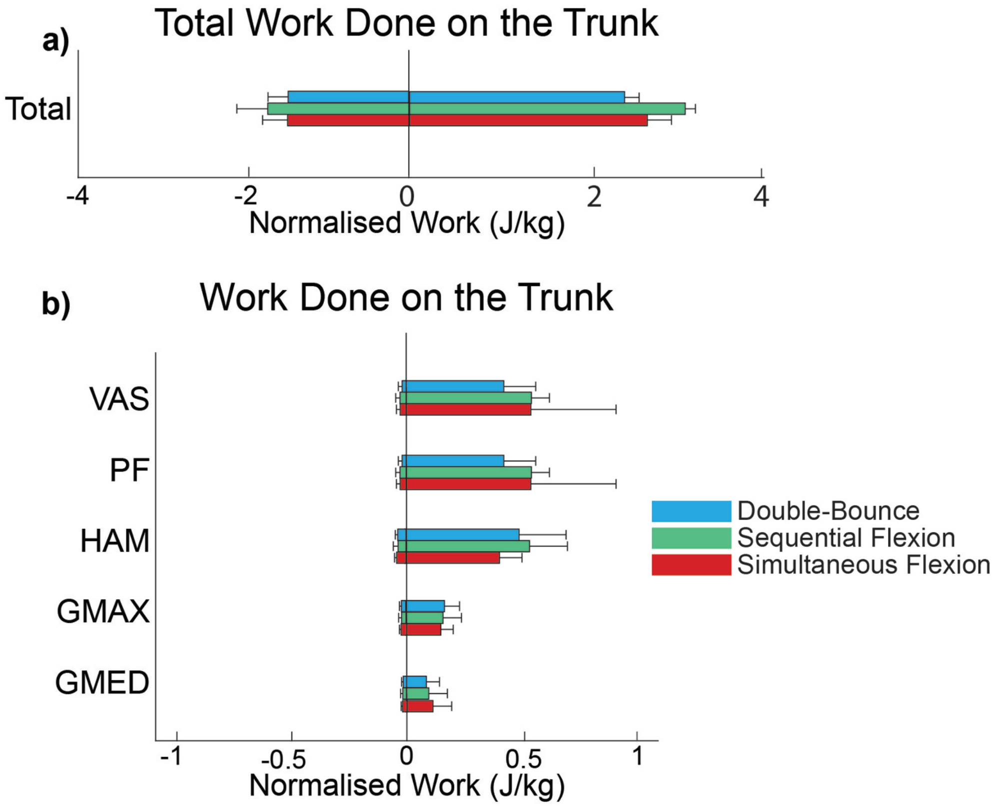

Figure 4. Work done on the trunk segment for the a) total and b) primary functional muscle groups across the three techniques (Double-Bounce = blue, Sequential Flexion = green, Simultaneous Flexion = red) normalised by body mass for each gymnast.

Muscle demand

The Simultaneous Flexion technique trended towards the lowest overall negative muscle work, and the Sequential Flexion technique trended towards higher overall positive muscle work than the other two techniques (Figure 2a). However, these differences were small (eta-squared = 0.04) and resulted from only slight differences across specific muscles (Figure 2 and Appendix A), partially supporting our hypothesis. The larger negative muscle demand in the Double-Bounce technique was due to the kinematics of the double-bounce, which required the gymnasts to decelerate their motion twice. The Simultaneous Flexion technique has also been shown to have the lowest GRF peak and impulse out of the three techniques (Small & Neptune, 2024b), in agreement with the lower muscle work found in some muscles in the present study (Figure 2). Across all techniques, the larger positive relative to negative muscle demand is similar to other tasks like walking or jumping where much of the net muscle work output is required to raise the CoM (Nagano et al., 2007, Neptune et al., 2004). Overall, the three techniques had 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 &

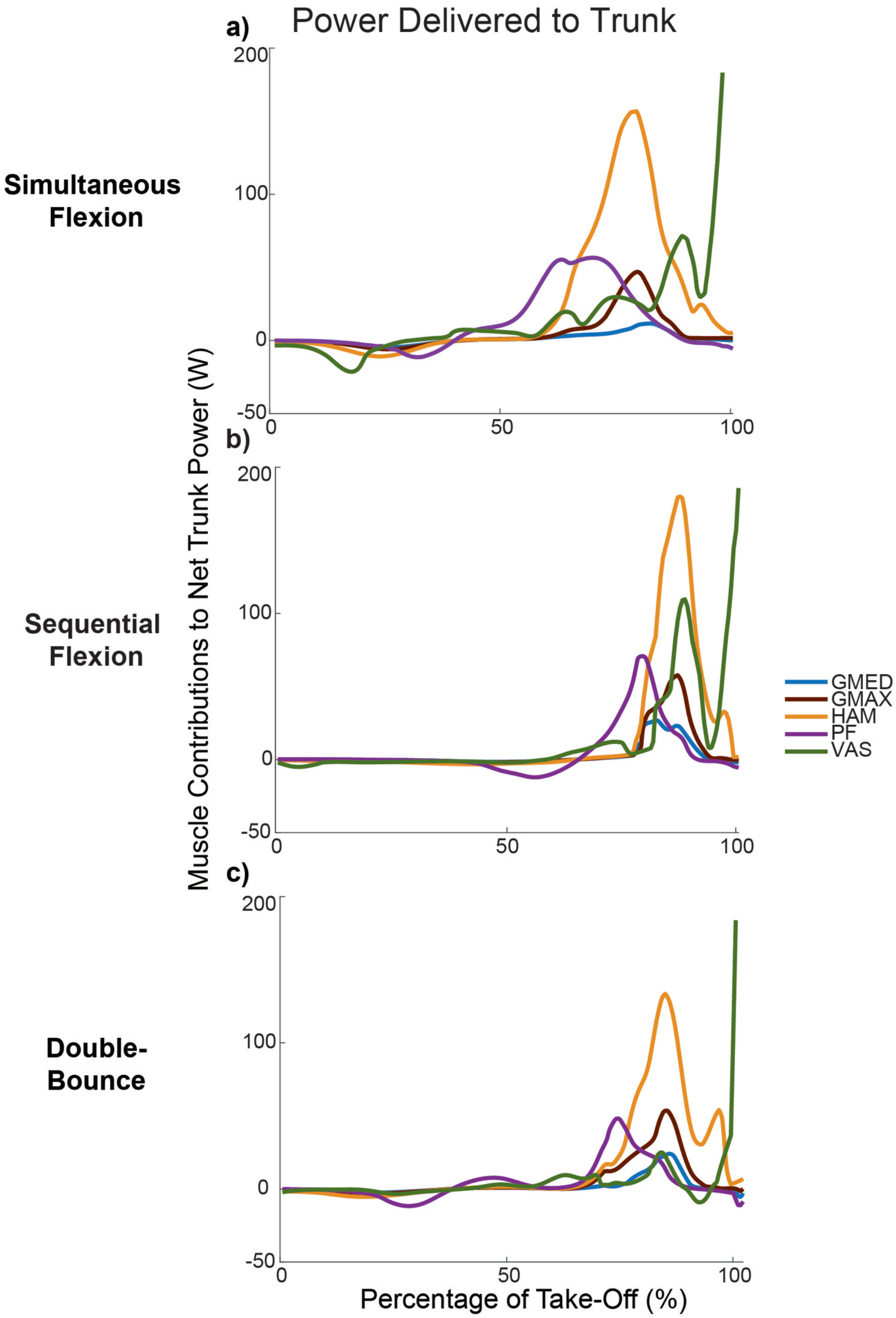

Figure 5. Primary individual muscle contributions to the net power delivered to the trunk from a representative gymnast for each technique: a) Simultaneous Flexion, b) Sequential Flexion and c) Double-Bounce.

Neptune, 2024b) as energy expenditure or fatigue is likely not a factor differentiating the techniques.

Further investigation into the demand from individual muscle groups found that VAS generated both high positive and negative work across techniques, due to its important role in controlling the body's forwards rotation (Figure 3a) as well as extending the legs at the end of take-off (Figure 5). The Double-Bounce technique had higher negative work from VAS relative to the other techniques, due to the two countermovements associated with this technique. The Sequential Flexion technique had higher negative and positive IL work than the Simultaneous Flexion or Double-Bounce techniques (Appendix A), due to the large trunk flexion without knee flexion in this technique. Thus, IL required more muscle demand to maintain balance over the base of support (Appendix B). 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). Furthermore, PF had high positive and negative muscle work, due to its role in propulsion (Figure 4), similar to its role in other tasks such as walking (Neptune et al., 2001). GMAX and HAM also had high work across the three techniques (Figure 2), which is consistent with previous analyses of jumping that found HAM and GMAX were crucial in accelerating the trunk upwards (Pandy & Zajac, 1991). While the differences across techniques were small, VAS, PF, GMAX, GMED and HAM were the primary muscle groups for the generation and control of required momentum in the BHS, and gymnasts should focus on strengthening and conditioning these muscle groups for a successful BHS, regardless of technique used.

Muscle contributions to angular momentum generation and control

The sagittal plane external moment is crucial for generating the necessary angular momentum to produce the BHS flip, and in the sagittal plane, the Sequential Flexion technique trended towards a larger total average backwards external moment (Figure 3a). This difference in sagittal plane external moment affected the timing of the peak hip flexion and extension of the leading and trailing legs, respectively. A *post-hoc* analysis of the hip kinematics found that the legs in the Sequential Flexion technique split later (Figure 6a, d) due to the muscles contributing more to rotating the body backwards. Gymnasts should be aware of this timing difference and focus on training the full split of the legs, given the desirability of achieving the full split of the legs as part of the performance of the BHS (Fédération Internationale de Gymnastique, 2022). Since this split occurs later in the Sequential Flexion technique, the gymnast has less time to reach the full flexion/extension of the hips to create the split of the legs.

HAM and PF also produced large backwards angular momentum, which is consistent with their functional roles in other tasks. For example, PF is also responsible for propulsion in walking (Neptune et al., 2001), and HAM also assists in accelerating the trunk upwards in normal jumping (Pandy & Zajac, 1991).

The frontal plane external moment is crucial for controlling balance (Vistamehr et al., 2016), and the Simultaneous Flexion technique trended towards higher total average outwards external moment than the other techniques (Figure 3). GMED and PF were the largest contributors to controlling frontal plane angular momentum (Figure 3b). They contributed in opposite directions to maintain equilibrium in the frontal plane, similar to other tasks such as walking (Neptune & McGowan, 2016). Because of the importance of

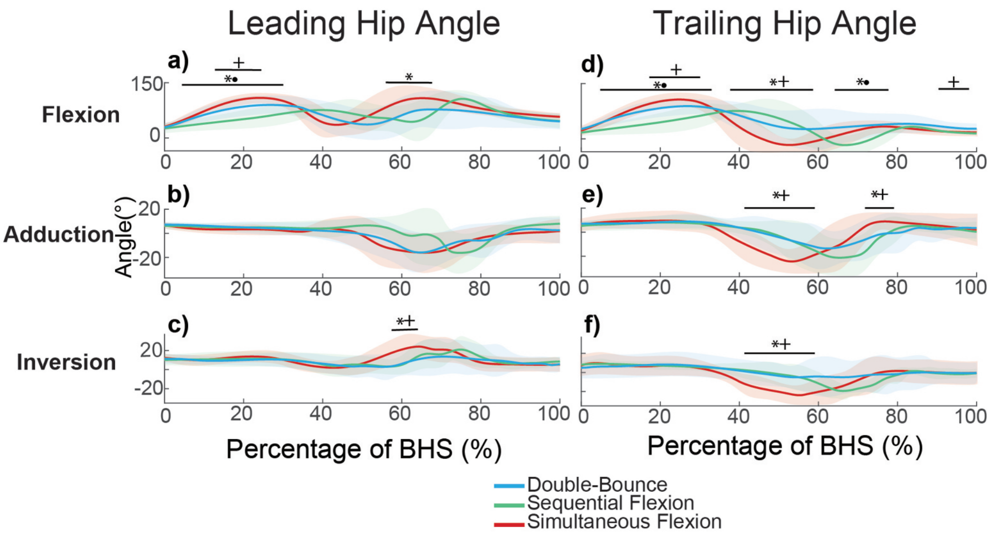

Figure 6. The hip angle across the three planes for the (a—c) leading and (d—f) trailing legs for the entire back handspring step out (BHS) (take-off through landing) across the three techniques (Double-Bounce = blue, Sequential Flexion = green, Simultaneous Flexion = red). A '*' indicates significant difference between the Simultaneous and Sequential Flexion techniques. A '+' indicates a significant difference between the Simultaneous Flexion and Double-Bounce techniques. A '•' indicates a significant difference between the Sequential Flexion and Double-Bounce techniques. The significance level was set at $p < 0.05$ and calculated using statistical parametric mapping (Pataky, 2012).

PF in both the sagittal and frontal planes, it should be a target for strengthening and conditioning. Interestingly, while GMED played an important role in balance control, its muscle demand was relatively low due to the low amount of hip abduction in the BHS (Figure 2). GMAX also contributed to controlling frontal plane angular momentum, which is consistent with the role of GMAX and GMED in pelvis stabilisation in jumping (Gallego-Izquierdo et al., 2020).

Muscle contributions to work done on the trunk

The Sequential Flexion technique trended towards more total average work done on the trunk than the other two techniques (Figure 4 and Appendix C). To understand this result, we further analysed the primary muscle contributors to trunk power. Overall, muscle groups delivered more power to the trunk than they absorbed, with VAS, PF and HAM contributing the most (Figure 4). Earlier in the take-off for the Simultaneous Flexion and Double-Bounce techniques, VAS and PF had negative power peaks, because the knees flexed earlier and these muscles were thus able to absorb energy from the trunk and assist in braking the trunk's motion. For all techniques, PF first counteracted the overall downward acceleration of the trunk and absorbed energy from the trunk, which assisted in the transition from the countermovement to the flip. In addition, PF had a small second power contribution to the trunk in the Double-Bounce technique due to the kinematics of the double-bounce (Figure 5). Likewise, HAM also had small negative power peaks that absorbed power from the trunk earlier in take-off to maintain the forwards posture and change the direction of the trunk. This negative HAM power occurred for all techniques (Figure 5), parallel to its role in jumping (Nagano et al., 2007). Similarly, across all techniques, the majority of the power delivered to the trunk at the end of the take-off phase occurred when the trunk quickly moves upwards and backwards (Figure 5).

In all techniques, VAS then generated power after the countermovement as it accelerated the trunk upwards and backwards (Figure 5). A previous study in vertical jumping also found that VAS was a primary power producer (Pandy & Zajac, 1991). Interestingly, at the end of take-off when the body quickly moves upwards and backwards, PF delivered less power to the trunk than HAM or VAS (Figure 5), but it was crucial for rotation and balance control (Figure 3). Previous studies on vertical jumping found that PF mostly accelerates the body in the final stage of push-off (Pandy & Zajac, 1991), while in the present study, PF delivered most of its power to the trunk earlier, due to the rotational aspect of the BHS as opposed to maximum height jumps. Finally, for all techniques after the countermovement, HAM and GMAX produced power and positively accelerated the trunk to generate the necessary linear momentum. During this phase, HAM did more work than GMAX (Figure 4), which is consistent with other jumping studies (Pandy & Zajac, 1991).

Limitations

A potential limitation of this study was the use of a balance beam on the floor during the experimental data collection. A competition balance beam is 1.25 m high and made out of a different material than the beam used in this experiment, which might alter the elasticity of the beam and the resulting kinematics. However, the softer floor beam was used to ensure the safety of the gymnasts. In addition, a brief subjective survey following each gymnast's participation revealed on average the beam did not affect their performance.

Furthermore, the decomposition of the GRFs applied to each foot during the simulation was an approximation because the force plate underneath the balance beam only provided resultant GRFs. We used subject-specific data on the floor with an exact GRF for each foot to determine the decomposition and performed a sensitivity analysis on the GRF distribution and centre of pressure location and confirmed the results were insensitive to moderate variations. To validate our simulation results, the simulated muscle activation timings were compared with the experimental EMG data, and we used a procedural framework that closely tracks experimental data following best practices to minimise experimental residuals (Hicks et al., 2014). The musculoskeletal model we used did not include upper body muscles, which limits our ability to investigate those contributions. However, our analysis focused on the lower body muscles, the muscles responsible for producing the power in the BHS, and previous studies in jumping have used similar models with the inertia of the arms accounted for in the torso (e.g., Nagano et al., 2007, Palmieri et al., 2015).

Finally, this skill was analysed in isolation; however, the BHS is often performed in combination with other skills. Therefore, future work should analyse how these take-off techniques affect the BHS when performed in combination with other skills on the balance beam.

Conclusion

Given the importance of the BHS as a foundational skill on the balance beam, a better understanding of the underlying roles of the individual muscles in performing the BHS is crucial. The three techniques had similar total muscle demand, which has also been confirmed using other measures of demand (Small & Neptune, 2024a). This result may partially explain why gymnasts self-select all three of the take-off techniques. While the differences in muscle demand were small across the take-off techniques, there were important individual muscle differences that gymnasts and coaches should consider when training. Across all techniques, GMED and PF were the most important muscle groups for maintaining balance, and should be a focus for conditioning to help gymnasts have safer and better performing BHS. Finally, HAM, PF and VAS were the primary power producers, and training these muscles should be an area of emphasis to increase the height and distance of the BHS, especially before adding additional skills in combination with the BHS. These results provide further insight into the muscle demand necessary to perform a BHS and guidelines for which specific muscles to train to improve the performance of the BHS.

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