LANDING ASYMMETRY IN BACK TUCKED SALTOS AND THE EFFECT OF TAKEOFF ASYMMETRY

Nicolas Hallgrimson, Alison Oates, Marta Erlandson and Joel Lanovaz

College of Kinesiology, University of Saskatchewan, Saskatoon, Canada

Landing asymmetry is an injury risk factor in gymnastics. This study examined whether takeoff force asymmetry is related to landing asymmetry during back tucked saltos in competitive gymnasts. Each gymnast performed an isometric leg strength test followed by multiple back tucked salto trials with no takeoff instruction, leaning with 60% asymmetry to the right, and 60% asymmetry to the left using a standard asymmetry index. Forces were measured at takeoff and landing. The novel experimental approach successfully produced distinct takeoff asymmetry levels. There was a significant rightward asymmetry in baseline landing peak vertical force, possibly due to right leg strength dominance. Landing asymmetry was also generated in the left and right leaning conditions. Both takeoff and leg strength asymmetries may play a role in landing force asymmetries in back tucked saltos.

KEYWORDS: force, leg strength, gymnastics

INTRODUCTION: Artistic gymnastics is a sport characterized by sequencing acrobatic elements into a routine that demonstrates strength, flexibility, balance, and explosive movement patterns. These explosive movements often involve high loading and puts gymnasts at increased risk for injury, whether that be from acute trauma or chronic exposure. Injury rates in artistic gymnastics are high and most injuries occur in the lower leg (Kirialanis, Malliou, Beneka, & Giannakopoulos, 2003). The most common event and exercise phase in which injuries occur is during landings on floor exercise (Kirialanis, Malliou, Beneka, & Giannakopoulos, 2003) where gymnasts experience ground reaction forces up to 14 times their body weight (Panzer, 1987).

Many mechanisms of injury in gymnastics have been examined including: frequent and high force deceleration impact loading at landing, leg stiffness, joint angles at contact, and range of motion (Bradshaw & Hume, 2012). One injury risk factor that has not been researched extensively is bilateral landing asymmetry. Landing asymmetry is defined as performing a two-foot landing with more load on one limb compared to the other. Based on several specific landing tasks, Panzer (1987) concluded that the asymmetric ground reaction force and impulse values have a high potential to cause injury. Interestingly, even for trials in which the gymnast landed in a “wipeout” scenario, the sum of both legs for the impulse values was less than the corresponding values for only one leg in a poor, asymmetric trial.

Few research studies have examined the potential causes of these landing asymmetries. Cuk and Marinsek (2013) proposed that landing asymmetries are potentially caused by lack of flight amplitude, lack of angular momentum, and lack of control of longitudinal angular velocity. All of these occur during the flight phase but are mainly determined during the takeoff, where the forces determine flight amplitude and angular momentum. As these variables cannot be altered once in flight, any unwanted forces causing angular momentum in any axis other than transverse, will affect the landing. It is likely; therefore, that takeoff force asymmetry is related to landing force asymmetry.

Investigations of landing asymmetry in gymnasts has mainly used vertical jumping and isolated drop landing tasks (Lilley, Bradshaw & Rice, 2007; Moresi, Bradshaw, Thomas, & Greene, 2013); however, no previous research has examined landing asymmetry using actual gymnastics skills such as saltos (an airborne rotation about the transverse axis), which are likely more applicable to how a gymnast will land during competition or training. The purpose of this study was to examine whether takeoff force asymmetry is related to landing force asymmetry during back tucked saltos in competitive gymnasts. We used a novel approach to manipulate takeoff asymmetry and examined the corresponding effects on landing. We hypothesized that manipulation of takeoff

force asymmetry in a particular direction would result in a corresponding change in landing force asymmetry.

METHODS: Eleven skilled male competitive gymnasts (provincial to international level, ages 14-29 years, height 1.67±0.06 m, mass 61.8±8.6 kg), who were injury free at the time of data collection participated in this study. Prior to performing any movements, isometric knee extensor strength was tested. Gymnasts performed three isometric knee extension contractions for each leg with the knee fixed at 90 degrees. Forces were measured with a handheld dynamometer (Model 01165, Lafayette Instrument) secured to the front of the shank, 20 cm below the head of the fibula. Following the strength tests, gymnasts performed tucked backwards saltos from a raised surface (30 cm) to the floor. To begin, the gymnasts performed five normal back tucked saltos with no specific takeoff instructions (baseline). Next, the gymnasts performed three back tucked saltos with a starting vertical force asymmetry of 60% to the right (RAsym) and three trials with 60% asymmetry to the left (LAsym), in a randomized order. Asymmetry was expressed using a symmetry index (SI) (right-left/mean of right and left) (Herzog, Nigg, Read, & Olsson, 1989). Four force plates (AMTI HP400600-HF-OP-2K, Watertown, MA) measured ground reaction forces (fs=4000Hz) under each foot during takeoff and landing. The landing force plates were covered with standard floor gymnastics mats (6 cm thick) for safety (Figure 1). Starting force asymmetry for the RAsym and LAsym trials was generated by asking the gymnast to lean slightly towards one leg until the required asymmetry level was achieved. A custom visual biofeedback program was used to help the gymnasts attain a prescribed starting asymmetry within +/-10%. The gymnasts' real-time bilateral asymmetry from the force platforms was displayed on a computer screen and the gymnast was instructed to keep this value inside the target range. Once the asymmetry level was steady, the gymnast was instructed to perform the salto.

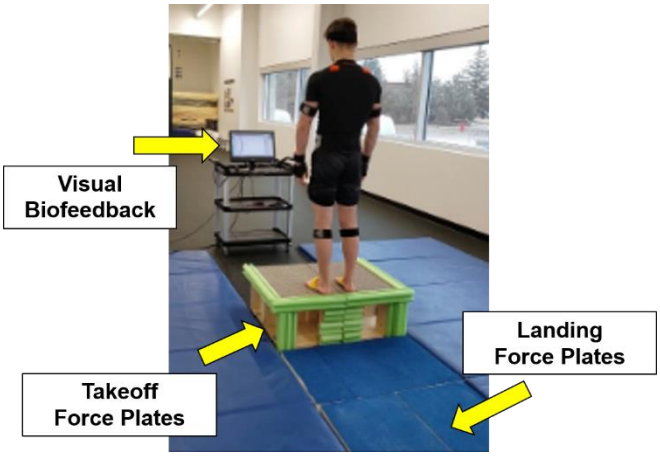

Figure 1: Experimental set-up showing a gymnast before starting a salto. Independent left & right raised platforms are fixed to the takeoff force plates and gymnastics mats are fixed to two landing force plates. Real-time symmetry index feedback is presented on the monitor.

Leg strength data were averaged and a paired-samples t-test used to compare the right and left limbs. Takeoff and landing peak vertical force were obtained and the asymmetries of these were averaged by condition and differences were assessed by using a repeated measures ANOVA. All statistical tests were completed in SPSS software (Version 26) with an alpha level of 0.05 set for all analyses.

RESULTS: The gymnasts exhibited significantly higher isometric knee extensor strength for their right leg, (left mean= 16.5±3.4kg, right mean=19.0±3.8kg, $t(10)=-3.516$, $p<0.05$). Mean baseline landing total peak vertical force was 12.4±1.8 times body weight (BW). Peak force asymmetry for

all conditions (baseline, RAsym, LAsym) at takeoff were found to be significantly different from each other (F_{GG}(1.880, 18.803)= 27.219, p<0.01) (Figure 2).

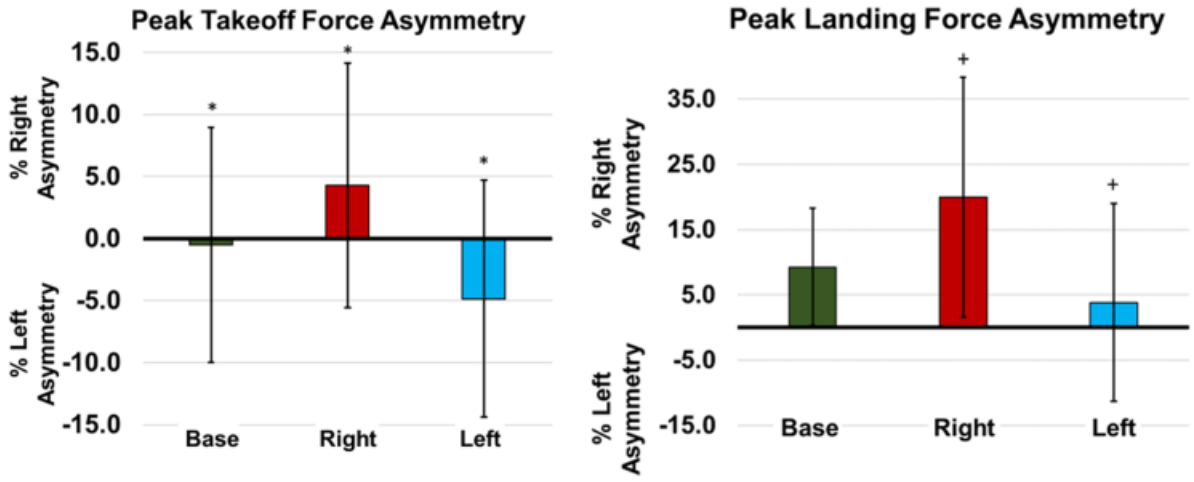

Figure 2: Mean (SD) peak vertical force symmetry index values at takeoff (Left) and landing (right) for Baseline, right & left asymmetry conditions. * = significant differences between all conditions (takeoff); + = significant differences between right & left conditions (landing).

Mean baseline landing SI was +9.2% (toward the right) and was significantly different than zero (t(10)=3.408, p=0.007). The SI for the asymmetry experimental conditions (RAsym and LAsym) were not significantly different than baseline (p>0.05); however, they were significantly different from each other (p=0.02) (Figure 2).

DISCUSSION: This study examined takeoff and landing asymmetry in skilled competitive gymnasts. The majority of previous research has looked at landing asymmetries with simple drop jumps and drop landings in competitive gymnasts. When compared to an actual gymnastics skill, these types of landings are not as ecologically valid for gymnasts during competition or training. To our knowledge, the current study is the first time landing asymmetry has been looked at with respect to the takeoff during a realistic gymnastics movement. This study utilized a novel takeoff force manipulation technique that produced significantly different right and left asymmetries at takeoff. This result validates that the leaning takeoff manipulations were successful in creating a takeoff asymmetry. The successfully induced takeoff asymmetry manipulation resulted in landing force asymmetry outlined in the hypothesis.

The peak landing forces experienced by the gymnasts in this study are consistent with previous research which reported forces up to 14 times BW (Panzer, 1987). Both this current study and Panzer's study were completed with compliant gymnastics mats over the force plates, so these values may be conservative estimates of forces seen in training and competition. Since both studies found similar findings with respect to peak vertical force, these high landing forces may be common. Asymmetries in landing, which this study found even at baseline, can disproportionately increase the stress on one limb compared the other.

The experienced gymnasts in the current study had a relatively high baseline landing SI; however, this is in line with previous work. The landing SI found in this study (~10%) was actually slightly less than previous drop landing studies with gymnasts. Moresi et al. (2013) found an average SI of 14-15% across both jump height conditions, and Lilley, Bradshaw, and Rice (2007) found an average SI of 18.1% with only two of their 15 participants having a SI under 10%. The lower baseline SI in our study could be explained by the nature of the landings, as the participants in previous studies were not landing from a gymnastics skill, which required less effort for their gymnasts. Lilley, Bradshaw, & Rice in 2007 found that ground reaction force asymmetry

decreased when drop landing height increased. They deemed this result to a decreased level of effort during the low-level jump height trials. A similar effect of effort may also be occurring in this study, where the skill requires large amounts of effort by the gymnast in order to land the skill correctly. The participants recruited for this study were also older and therefore likely to have had more years of gymnastics and landing experience compared to previous studies.

With respect to the takeoff force manipulations, the peak landing force SI for the RAsym and LAsym conditions were not different from baseline, but there was an obvious shift such that increased rightward or leftward takeoff asymmetry resulted in more rightward or leftward landing asymmetry respectively. These results partially support our hypothesis that the direction of takeoff force asymmetry influences landing force asymmetry. As stated earlier, although baseline peak takeoff asymmetry was nearly zero, on average, the gymnasts landed with a SI of nearly 10% to the right. It is possible that takeoff asymmetry did influence landing asymmetry in the expected directions but since there was already a significant level of baseline landing asymmetry, this effect was minimized. The gymnasts had significantly higher strength in their right legs which may predispose them to preferentially favour that limb during landing even though they had a symmetrical takeoff. These results may indicate that both takeoff and leg strength asymmetries may play a role on landing force asymmetries in back tucked salto movements.

It must be noted that in training and competition salto skills are normally preceded by other skills to help the gymnasts generate sufficient angular and linear momentum to complete the salto safely. While this study did not simulate this, incorrect performance of, or inherent asymmetry in the preceding skill could potentially cause the levels takeoff asymmetry generated in this study.

CONCLUSION: Gymnasts experience extremely high ground reaction forces during landings, which happen frequently during training and practice. Asymmetrical bilateral landings are an injury risk mechanism that has not been examined extensively. This study examined how takeoff asymmetry may alter landing asymmetry in a common gymnastic skill; the back tucked salto. The asymmetry manipulation used was successful in eliciting the desired takeoff asymmetry directions. Imposing a takeoff asymmetry did not result in significant differences between baseline and right and left peak landing force asymmetry but did show the expected trend. A significant landing asymmetry appears to occur normally, even after symmetrical takeoffs and may be related to leg strength asymmetry. Future work will include an increased sample size, kinematic analysis and the inclusion of female gymnasts.

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