QUANTIFYING LANDING IMPACTS DURING A LEG STRENGTH CIRCUIT IN MALE ARTISTIC GYMNASTS – A PILOT STUDY

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Measuring landing impacts in gymnastics has previously been difficult and has rarely taken place in the daily training environment. The aim of this pilot research was to quantify the number and magnitude of landing impacts experienced by elite level male gymnasts when completing a leg strength circuit that they regularly perform in training. Acceleration data revealed gymnasts were being exposed to a high number of very high magnitude landing impacts (up to 9 landings/exercise and >10 g) during the leg strength circuit. These results prompted the development of two alternate leg strength circuits, specifically developed for gymnasts recovering from injury, which do not include the high loading exercises. Tibial acceleration is a promising method for the measurement of landing impacts during gymnastics training.

KEY WORDS: IMU, wearable, accelerometer, gymnastics

INTRODUCTION: High training loads experienced in artistic gymnastics are believed to be associated with the onset of overtraining syndrome (Beatty, McIntosh, & Frechede, 2007). From the literature, overuse injuries contribute between 36% to 56% of all reported gymnastics injuries (Caine, Cochrane, Caine, & Zemper, 1989; Kolt and Kirkby, 1999). The high percentage of overuse injuries is of particular concern as these injuries generally require longer recovery times than acute injuries (Lindner and Caine, 1990) and are associated with a higher risk of re-injury, as demonstrated by Caine, et al. (1989) who reported that 83% of recurrent injuries in gymnasts were from an original overuse injury. Thus, the need to monitor training load is of great importance to reduce these injuries from occuring in the future.
Quantifying training loads in artistic gymnastics has previously been problematic for sport scientists and coaches (Sands, 1991). In the past, force plates have been used to quantify landing forces in gymnastics (Burt, Naughton, Higham, & Landeo, 2010; Panzer, Wood, Bates, & Mason, 1987), however wearable inertial sensors provide an exciting tool to objectively monitor sports movement in the training or competition environment rather than only in the laboratory. Inertial measurement unit (IMU) sensors provide linear acceleration values in a sensor-fixed Cartesian reference frame (x, y, and z) and can also provide information on orientation and angular displacement (Setuain et al., 2015).
The use of acceleration mesurements has previously been piloted in artistic gymnastics to investigate landing impacts (Beatty, et al., 2007; Bradshaw, 2016). Accelerometer measurments at the pelvis during a range of basic floor skills has been reported between 0.8 g and 13.8 g (Beatty, et al., 2007). Additionally, unpublished data from the Australian Institute of Sport, using a tibial mounted IMU, has indicated that gymnasts are experiencing extremely high cumulative lower limb loads across training sessions, with one elite male gymnast experiencing a total of 449 landing impacts greater than 4 g across a single training session. Of these landing impacts, 16% were greater than 10 g. These initial results highlight that despite the limited use of IMUs in artistic gymnastics, they have the potential to provide insight into the loading patterns of everyday training that has been previously unexamined.
This project was developed in consultation with gymnastics coaches, biomechanists and the team physiotherapist, to investigate the landing impacts experienced by athletes during the leg strength circuit the gymnasts perform at every morning training session (approximately three times per week). Therefore, the aim of this pilot research was to use IMUs to quantify the number and magnitude of the landing impacts experienced during a leg strength circuit over one week of regular training sessions in an elite level male gymnastics squad.

METHODS: Participants: Seven elite male gymnasts participated in this project (age= 20.6 ± 2.5 years, height= 165.1 ± 10.3 cm, mass= 64.8 ± 8.9 kg, weekly training hours= 16-23 hours/week); all participants at the time of data collection were senior level gymnasts who held a scholarship position to train at the National Centre of Excellence at the Australian Institute of Sport. Data collection was conducted over one week during scheduled morning training sessions. Inclusion criteria indicated that the gymnasts were relatively injury free (no major injuries) and were completing a full or only slightly modified training load. Ethics approval for this research was provided by the Australian Institute of Sport ethics committee, and all participants provided informed written consent prior to taking part in this project.

Equipment: Acceleration data were collected from small tri-axial wireless IMU sensors (IMeasureU Limited, Auckland, New Zealand). Prior to each training session, an IMU was attached to the flat distal anterior part of the tibia on one leg of the participant, with the y-axis of the sensor aligned with the long axis of the tibia, as close to the ankle joint as possible while still being comfortable for the gymnast (Moresi, O'Meara, & Graham, 2013). Data were collected at 1000 Hz sampling rate and logged to the on board memory of the IMU. Data was downloaded from the IMU at the end of each training session for processing using Lightning software (IMeasureU, Auckland, New Zealand). Every session was filmed using two cameras (50 fps; XF205, Canon, Tokyo, Japan) to cover the space of the entire gymnastics hall.

Procedure: Gymnasts completed the same leg strength circuit at every morning training session over one week (three times a week). Each exercise is completed for 40 sec in duration before moving on to the next exercise. A description of these exercises can be found in Table 1.

Table 1
Description of leg strength exrecises

	Description of exercise
Rebounds	Rebound jumps on/off a 60cm box
Leaps	Long jumps across the length of the floor
Tuck Jumps	Zig zag tuck jumps forward, backward and sideways across the length of the floor
Somersault Landings	Somersault landings either from the pommel or the vault
Scissors	Scissors between two spring boards at a 45 degree angle
Mat Running	Jogging on a soft mat
Pistols*	Single leg squats

* Excluded from analysis due to lack of jumping or landing

Data processing: Data processing and filtering was completed in LabChart software (v8.1.5, ADInstruments, Dunedin, New Zealand). The raw x, y and z signals were filtered using a low pass filter with a cut-off at 20 Hz. The cut-off frequency was determined previously via residual analysis. The resultant tibial acceleration signal was then calculated using $r = (x^2 + y^2 + z^2)^{0.5}$ and then converted into gravitational units (1 g = -9.81 $m.s^{-2}$). All analysis took place on the resultant signal to account for acceleration occuring in all directions upon landing. To synchronise the video and accleration data, each participant was asked to tap thier IMU three times while in view of the video camera. This footage was then matched up to the three peaks observed in the acceleration data. The magnitude of the landing impact peaks were exported using the Peak Analysis feature in LabChart (baseline setting was from zero and the smoothing was set to 80 ms). A threshold of 4 g was determined, based upon the fact that this would not include the walking between exercises (walking is generally <4 g at the tibia based off visual inspection of the data).

Data analysis & statistical analysis: Descriptive statistics (group means and standard deviations) were calculated for the peak resultant tibial accelerations for each exercise.

Impact categories were developed to classify the magnitude of the landing impacts to assist with interpretation of the results when feeding back to the coaches and support staff. The categories were as follows; low impact (4-6 g), medium impact (6-8 g), high impact (8-10 g) or very high impact (>10 g). These were provisional categories, as no previous literature has used a similar classification method.
Variables of interest included: (i) mean number of landing impacts for each exercise; (ii) the mean magnitude of landing impacts for each exercise; (iii) the mean overall category rating for each exercise; and (iv) the number of landing impacts in each impact category for each exercise.

RESULTS: Three leg strength circuits were performed during the week and were included in this analysis. Due to minor injuries and illness during the week of data collection, only one participant performed the full circuit on all three days. Therefore, the number of sets performed of each exercise can be seen in Table 2 (one set is equal to one gymnast performing the exercise for 40 secs in duration). The means and standard deviations for the number and magnitude of landing impacts per exercise, and the mean overall impact category rating of each exercise can also be found in Table 2. The average number of landing impacts for each exercise categorised as low, medium, high or very high is displayed in Figure 1.

Table 2
Number of sets included in analysis, mean number and magnitude of landing impacts (>4g; mean ± SD) and assigned exercise categories.

	Rebounds	Leaps	Tuck Jumps	Somersault Landings	Scissors	Mat Running
Sets included in analysis (n)	10	15	19	15	19	17
Mean no. of landings per exercise (n)	20.1 ± 1.9	43.4 ± 9.7	54.3 ± 26.6	7.4 ± 4.3	18.2 ± 16.3	2.7 ± 2.3
Mean magnitude of landings per exercise (g)	8.4 ± 1.4	7.8 ± 2.6	6.8 ± 1.4	16.6 ± 3.7	5.8 ± 1.0	5.6 ± 0.8
Mean exercise category	High	Medium	Medium	Very High	Low	Low

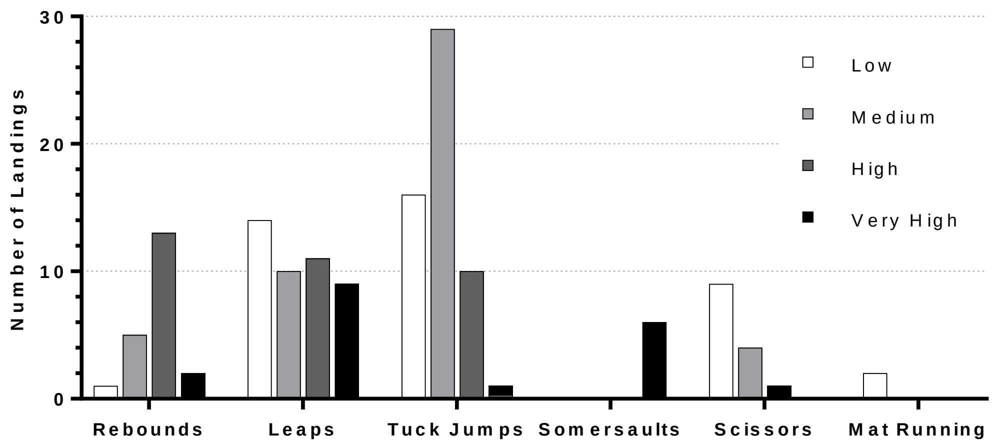

Figure 1
Number of landing impacts in each impact category for each exercise

DISCUSSION: There were two key findings from this project that the coaches and support team found particularly important: the leaps exercise has the greatest number of very high landing impacts (<10 g), and every somersault landing was categorised as very high (Figure 1). The leaps result was particularly surprising, especially for the coaching and the support staff, as it was expected that the leaps exercise was relatively low/medium impact as it was intended to be performed in a controlled manor.

These findings prompted discussions about developing two alternate versions of the circuit, a low and medium impact version. The medium impact version was developed for gymnasts who are experiencing some slight soreness in the lower limbs or back, and replaced the somersaults landings and the leaps exercise with single leg calf raises (both left and right). The low impact version was developed for gymnasts recovering from a lower limb or back injury, and takes this one step further by not only removing the somersaults and leaps exercise, but also the tuck jumps and rebounds as well. Instead, these exercises have been replaced by single leg calf raises (both left and right) and wobble board squats. Both the low and moderate versions of the leg strength circuit are currently being implemented in training.

This pilot study highlights the potential benefit of using IMUs in a gymnastics training environment and how this information can be successfully utilised to inform training prescription changes. Currently, further investigation is underway to expand these methods to include the analysis of the landing impacts of gymnastics specific skills.

CONCLUSION: Tibial acceleration is a promising method for the measurement of landing impacts during gymnastics training. This project highlights how objective loading information can be successfully implemented to inform and adapt the prescription of training activities. The very high (>10 g) impact results of the somersault landings and the leaps exercise inspired the development of a low and a medium loading version of the leg strength circuit, which is currently implemented in daily training.

REFERENCES:

Beatty, K. T., McIntosh, A. S., & Frechede, B. O. (2007). *Method for analysing the risk of overuse injury in gymnastics.* ISBS-Conference Proceedings Archive, Ouro Preto, Brazil.

Bradshaw, E. (2016) *Pilot tests of inertial measurement units during artistic gymnastics training on pommel horse and vault*. Paper presented at the Research to Practice, Melbourne, Australia; .

Burt, L. A., Naughton, G. A., Higham, D. G., & Landeo, R. (2010). Training load in pre-pubertal female Artistic Gymnastics. *Science of Gymnastics Journal, 2*(3), pp. 5-14.

Caine, D., Cochrane, B., Caine, C., & Zemper, E. (1989). An epidemiologic investigation of injuries affecting young competitive female gymnasts. *American Journal of Sports Medicine, 17*(6), pp. 811-820.

Kolt, G. S., & Kirkby, R. J. (1999). Epidemiology of injury in elite and subelite female gymnasts: a comparison of retrospective and prospective findings. *British Journal of Sports Medicine, 33*(5), pp. 312-318.

Lindner, K., & Caine, D. (1990). Injury patterns of female competitive club gymnasts. *Canadian Journal of Sport Sciences, 15*(4), pp. 254-261.

Moresi, M., O'Meara, D., & Graham, K. (2013). *Quantifying mechanical loading during training in track atheltes.* ISBS-Conference Proceedings Archive, Taipai, Taiwan.

Panzer, V., Wood, G., Bates, B., & Mason, B. (1987) *Lower extremity loads in landings of elite gymnasts*. Paper presented at the International Society of Biomechanics; , Amsterdam, Netherlands.

Sands, W. (1991). Monitoring elite gymnastics athletes via rule based computer systems. *Masters of Innovation III. Northbrook, IL: Zenith Data Systems*, p 92.

Setuain, I., Millor, N., González-Izal, M., Gorostiaga, E. M., Gómez, M., Alfaro-Adrián, J., Maffiuletti, N. A., & Izquierdo, M. (2015). Biomechanical jumping differences among elite female handball players with and without previous anterior cruciate ligament reconstruction: a novel inertial sensor unit study. *Sports Biomechanics, 14*(3), pp. 323-339.

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