Agreement between force and deceleration measures during gymnastics landings

Elizabeth J. Bradshaw[1,2], Karen Grech[1], Corey W.J. Joseph[4], Mark Calton[5], and Patria A. Hume[2]

[1]Centre for Sport Research, School of Exercise and Nutrition Science, Deakin University, Melbourne, Australia.

[2]Sports Performance Research Institute New Zealand, Auckland University of Technology, Auckland, New Zealand.

[3]School of Behavioural and Health Sciences, Australian Catholic University, Melbourne, Australia.

[4]Centre for Movement Disorders and Gait, Monash Health, Cheltenham, Australia.

[5]Gymnastics Victoria, Melbourne, Australia.

Corresponding Author:

Dr Elizabeth Bradshaw

Centre for Sport Research, School of Exercise and Nutrition Sciences, Deakin University, 221 Burwood Highway, Burwood VIC 3125 Australia

Phone +61 3 9244 6646

Email liz.bradshaw@deakin.edu.au

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Abstract

This study examined the measurement agreement between force platform and inertial measurement unit (IMU) measures of gymnastic landings. Seven female gymnasts performed three trials of backward somersaults off a 90 cm vaulting box using competition landing technique with the feet together and a small to moderate squat. Two force platforms (1000 Hz) covered with a 6 cm deep carpeted landing surface measured the ground reaction forces. One inertial measurement unit (500 Hz) fixed on the second thoracic vertebra measured peak resultant deceleration of the gymnast. Measurement agreement between vertical and resultant peak force measures, and resultant peak force and peak deceleration was assessed using mean differences, Pearson's correlation, and Cohen's effect size statistics. There was perfect measurement agreement between vertical and resultant peak forces ($R=1.0$, $p<0.001$), but only moderate measurement agreement between resultant peak force and peak resultant deceleration (Mean Difference = -2.16%, $R=0.4$, p=ns). Backward somersault landings can be assessed using either uni-axial or tri-axial force platforms to measure ground impact load/force, as the landing movements are almost purely vertical. However, force measures are not the same as peak resultant decelerations from IMUs which give an indication of impact shock. Landing load/shock measures are potentially important for injury prevention.

Keywords: Force, Acceleration, Deceleration, Impact, Gymnastics

Introduction

Biomechanical assessment of landings is commonly employed in artistic gymnastics for research and injury prevention program testing. Landings are thought to contribute to the high injury rates in gymnastics (Slater, Campbell, Smith, & Straker, 2015). Injuries from landings are usually caused by large forces and decelerations (Beatty, McIntosh, & Frechede, 2005), especially if in combination with high repetitions, uneven loading between limbs, or unusual foot placement caused by technical errors (Hunter & Torgan, 1983; Grapton, Lion, Gauchard, Barrault, & Perrin, 2013).

Drop landings are most frequently used to examine landing loads via ground reaction forces (GRF) (e.g. McNitt-Gray, 1991; Seegmiller & McCaw, 2003) as they require less skill and generate similar deceleration conditions to non-twisting floor tumbling landings and apparatus dismounts. The forces observed during drop landings (~7 Body Weight [BW]) are however considerably lower than landings after a backward (~10 BW) or forward (~12 BW) somersault (Slater et al., 2015). These are both common movements in gymnastics but are seldom utilized in research and injury prevention program testing. This may be based on the assumption that the drop landing movement is almost vertical, due to the use of portable uni-axial force platforms that only measure vertical forces, or for safety reasons during test administration.

Accelerometers, such as inertial measurement units (IMU), have also been used to assess landing impacts (Beatty, McIntosh, Frechede, 2005). IMUs provide linear acceleration values in a sensor-fixed Cartesian reference frame (X,Y,Z; Settuain, Millor, Gonzelez-Izal, Gorostiaga, Gomez, Alfaro-Adrian, Maffiuletti, Izquierdo, 2015), as well as measures of orientation and angular velocity. This wireless technology provides a new alternative for sports movement assessment that is no longer restricted to a predefined space due to cables/wires and/or the requirement to land onto a force platform (Settuain et al., 2015). There are conflicting studies that suggest accelerometers may provide a good estimate of GRF (Simons & Bradshaw, 2016), or over-estimate GRF by 1.5 BW (Beatty et al., 2005). As the body is not a fixed system, GRFs measured at the feet are not necessarily the same as accelerations measured at the lower or upper back due to shock attenuation (Simons & Bradshaw, 2016). Simons and Bradshaw (2016) also identified good agreement between peak force and acceleration measures for hopping (~5 BW) which have comparably lower impact load to somersault landings. In addition, the size and mass of the accelerometers can create soft tissue movement, and thereby, introduce artefact into the signal, especially when used on relatively small bodies such as paediatric populations and gymnasts (Forner-Cordero, Mateu-Arce, Forner-Cordero, Alcantara, Moreno, Pons, 2008).

IMU technology provides the opportunity to objectively assess and monitor a gymnast's impact loads during training, as well as other technical aspects such as rotational speed (angular velocity) about the somersault (sagittal) and twist (longitudinal) axes. However, the relationship between GRF and accelerations and decelerations of the body during common gymnastics loading tasks needs to be examined to guide interpretation of future findings (e.g. injury risk thresholds) when using IMU technology. Furthermore, the majority of these studies only reported the vertical component of the GRF (McNitt-Gray, 1993; Stater et al., 2015), which does not take into account the stabilisation of landing by incorporating the horizontal and medial-lateral forces (Simons & Bradshaw, 2016).

The purpose of this study was to examine measurement agreement between resultant peak force with vertical peak force and peak resultant deceleration of backward somersault landings using force platform and IMU technology. It was hypothesised that high measurement agreement would be identified between the force measures, and medium measurement agreement between the force and deceleration measures.

Methods

Participants

Seven female artistic gymnasts aged 10-15 years (Height = 145.3±11.6 cm, Mass = 37.5±8.9 kg) participated in this study. The gymnasts were injury-free at the time of testing, completed an average of 22 hours of training per week, and were competing in levels 6-10 in the national and international development program streams. This study was approved by the university ethics committee. The parent of each gymnast provided written consent, and each gymnast provided written assent.

Procedure

The gymnasts were asked to complete one session of data collection in the motion analysis laboratory. The gymnast's height and body mass was measured using a stadiometer (Stadi-O-Meter, Novel Products Inc, Rockton, Illinois, USA) and scales (HW-PW200, A&D Company Ltd, Japan). The gymnast was then asked to warm-up for five minutes on a cycle ergometer (828E Ergomedic bike, Monark, Vansbro, Sweden) followed by gymnastics specific static and dynamic stretching. An iso-inertial measurement unit (IMU; 40 x 28 x 15 mm, 12 g, 500 Hz, iMeasureU, Auckland, N.Z.) was fixed to the skin using double sided tape and Fixomull® stretch tape (Jiaxing How Sport Medical Instrument, Jiaxing, Zhejiang, China) on the upper back, over the second thoracic vertebra (T2). The IMU was located on the upper back in this study, instead of the lower back, to lower the risk of device damage or gymnast injury as a result of a fall. The gymnasts completed a second, shorter warm-up to familiarise themselves with the somersault while wearing the IMU, and then completed three experimental trials. Landings were executed from a backward somersault off a 90 cm high foam vaulting box (A13-129, Acromat, Australia) to replicate the velocity conditions of apparatus dismounts. Gymnasts performed the landings barefoot and landed onto two 3 cm carpeted landing mats (Total Depth = 6.4 cm, AB-100, Acromat, Australia). The gymnasts were asked to land using the competition technique. The competition technique requires the gymnast to land with the feet together and a small to moderate squat.

Data Collection

Two tri-axial force platforms (OR6-6-2000, AMTI, Watertown, MA, U.S.A., 1000 Hz) embedded in the landing surface captured the gymnasts landing movement. The IMU data were captured separately using an iPad (iPad Air 2 WiFi 128 GB, Apple Inc., Cupertino, California, U.S.A.) via a Bluetooth connection and the manufacturer’s application (app) software (Sensor Demo mode, IMU Suite, version 1.9).

Data Analyses

Peak resultant ground reaction forces for each trial were identified and normalised with reference to the gymnast's body weight (BW). Acceleration data were downloaded from the iPad onto a personal computer using Lightening software (iMeasureU, Auckland, N.Z.). Raw accelerations in x, y and z directions were then combined into a resultant acceleration using the equation: $a_r = \sqrt{a_x^2 + a_y^2 + a_z^2}$ where a_r is resultant acceleration, a_x is acceleration in the x-direction, a_y is acceleration in the y-direction, and a_z is acceleration in the z-direction. All accelerations were expressed in gravitational units (g) (one gravitational unit is equal to the gravitational acceleration of -9.81 m/s^2). Peak resultant deceleration was identified for each trial (Figure 1).

<Insert Figure 1 about here>

Statistical Analyses

Normality of the data set was determined using a Shapiro-Wilk test in SPSS Statistics software (version 22, IBM, Armonk, NY, U.S.A.). Measurement agreement was tested between the resultant ground reaction forces and vertical forces, and the peak decelerations using differences in the mean percentage, Pearson's correlation analysis, and Cohen's effect size statistics. Mean difference was interpreted as 0.00-4.99% 'good', 5.00-9.99% 'average', and >10.00% 'poor'. The magnitude of the correlations was interpreted as <0.10 'trivial', 0.10-0.29 'small', 0.3-0.49 'moderate', 0.50-0.69 'high', 0.70-

0.89 ‘very high’, >0.89 ‘almost perfect’ and 1.00 ‘perfect’ (Hopkins, 2006). Effect sizes (ES) were interpreted as 0.0-0.2 ‘trivial’ 0.21-0.60 ‘small’, 0.61-1.2 ‘medium’, and >1.2 ‘large’ (Saunders, Pyne, Telford, Hawley, 2004; Bradshaw, Hume, Calton, Aisbett, 2010). Overall measurement from these three measures was interpreted as ‘high’ when the mean difference was <5.0%, correlation coefficient was >0.89, and effect size was <0.21, ‘moderate’ when one the ‘high’ criteria was breached, and ‘low’ when more than one of the ‘high’ criteria was breached.

Results

The vertical and resultant ground reaction force data, as well as the deceleration data, are presented in Figure 2. The measurement agreement results are displayed in Table 1.

<Insert Figure 1 and Table 1 about here>

Peak Resultant and Peak Vertical Ground Reaction Forces

Only a negligible difference was observed between peak resultant and peak vertical force measures (Mean Difference = 0.07%) indicating that the backward somersault movement is almost purely vertical. Measurement agreement was high between the peak resultant and peak vertical force measures (Table 1).

Peak Resultant Ground Reaction Force and Peak Resultant Deceleration

The correlation between peak resultant ground reaction force and peak resultant deceleration were not significant ($p>0.05$). However when accounting for a mean difference slightly greater than 2%, and a trivial effect identified between measures, this represented a moderate measurement agreement overall.

Discussion and Implications

Due to negligible differences between vertical and resultant peak landing forces, this study identified that backward somersault landings were almost purely vertical (Figure 2). This may justify the use of only vertical components of force (McNitt-Gray, 1993; Stater et al., 2015), and not medial-lateral and horizontal forces (Simons & Bradshaw, 2016) when determining backward somersault landing loads. However, only moderate measurement agreement was revealed between the peak resultant force and peak deceleration measures. These measurement agreement results indicate that for backward somersault landings, the impact forces (loads) cannot be adequately estimated using an IMU/accelerometer. This is consistent with the findings of Simons and Bradshaw (2016), as higher impact loads did not have high agreement compared with lower impact load landings, which may be due to the influence of the non-rigid, elastic gymnastics surface. In this study two 3 cm deep carpeted gymnastics mats (total depth = 6.4 cm) were used that contained Acrolite foam (Acromat, Australia). These mats are typically used for floor tumbling in kindergym and recreational gymnastics where a sprung floor is not essential. The use of an IMU/accelerometer still provides a potential method of calculating the total shock (deceleration) that a gymnast experiences during training on the various surfaces (Bradshaw, Rice, Landeo, 2018). This may be a particularly useful tool/measure in the management and prevention of overuse injuries. That is because while the foot, ankle and knee are most commonly reported as the highest risk regions for injury in gymnasts (Dallas, Kirialanis, Dallas, & Gourgoulis, 2015); the most common injury type are stress fractures in the wrist and lower back regions (Stensrud, 2016).

A limitation of this study was the small sample size. This was due to the difficulty in recruiting a larger number of gymnasts for testing in the laboratory as they were reliant upon parents for transportation. Further research is required to determine the peak decelerations of other lower extremity impacts in gymnastics, as well as the reliability of these measures. An advantage of using IMU/accelerometers is that the testing can be completed in the gymnasts' regular training hall so that recruiting volunteers for testing should be easier.

The practical implications of these findings are that given the impact movement from a backward somersault landing is almost purely vertical, uni-axial or tri-axial force platforms can be used for measuring landing loads (forces). This is important when considering measuring load data during interventions such as injury prevention programs as uni-axial portable force platforms are less expensive than tri-axial inbuilt (laboratory) force platforms, and can also be transported to the gymnasts training hall. A measure of the landing load is important for injury prevention programs aimed at reducing acute and overuse lower extremity injury.

Peak deceleration measured on the upper back is not an appropriate estimate of landing loads, but does provide a good measure of landing shock. This should be considered when collecting this type of data. Deceleration measures via IMU technology does not restrict movements to a small space like a force platform does, and therefore, IMU's can be used when measuring gymnastics skills in the training environment. Measuring landing shock in the training environment is an integral tool for better understanding the training shock magnitude of gymnasts. A measure of landing shock magnitude may be advantageous for injury prevention programs aimed at reducing stress fractures, particularly in the lower back region.

Conclusions

As hypothesised, there was high measurement agreement between the force measures, and moderate measurement agreement between the force and deceleration measures for backward somersault landings. Force and deceleration measures of landings cannot be used interchangeably. Force measures indicate the landing load whilst the deceleration measures indicate the landing shock and therefore how well the gymnast controls the landing. Both these measures are potentially important for injury prevention in artistic gymnasts.

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Tables

Table 1: Measurement agreement results

Technique	Mean Difference (%)		Correlation		Effect Size		Summary
	Result	Interpretation	Result	Interpretation	Result	Interpretation	
Peak Vertical Force (BW) & Resultant Landing Force (BW)	0.07	Good	1.000	Perfect	0.005	Trivial	High
Peak Resultant Landing Force (BW) & Peak Deceleration (g)	-2.16	Good	-0.427	Small	0.121	Trivial	Moderate

Figures

Figure 1: Example resultant acceleration profile for the three experimental trials for one gymnast

Figure 2: Peak vertical and resultant ground reaction forces, and peak (upper back [T2]) decelerations for the backward somersault landing