VALIDITY AND RELIABILITY OF ACCELEROMETRY FOR ASSESSING IMPACT LOADS IN JUMPING TASKS

Chantal Simons[1] and Elizabeth J. Bradshaw[2]

[1]MOVE Research Institute Amsterdam, Faculty of Human Movement Sciences, VU University Amsterdam, Amsterdam, The Netherlands
[2]Australian Catholic University, School of Exercise Science, Melbourne, Australia

High injury rates in gymnastics have been suggested to be related to impact loading. This study examined the validity and reliability of a tri-axial accelerometer, mounted on the upper back, to estimate impact loads. Twelve female participants performed a continuous double legged hopping task and rebound jumps from a drop of 40, 60 and 80 cm. Peak resultant acceleration (PRA) showed moderate to good reliability. Correlation coefficients between ground reaction force (GRF) and PRA ranged from r_s=0.860 for the continuous hopping task to r_s= 0.608 for rebound jumps from 80 cm, and were all significant. The results of the current study support the use of PRA to estimate impact load in jumping tasks, and show potential for this measure to be employed in a gymnastics training setting.

KEY WORDS: gymnastics, injury, force, hop, rebound jump.

INTRODUCTION: Women's artistic gymnastics has high injury rates. These high injury rates are suggested to be related to the high frequency and magnitude of impact loading during gymnastics training and competition (Bradshaw & Hume, 2012). Some biomechanical measures, potentially related to injury risk have been identified. Lower limb stiffness, assessed by repetitive hopping, has been found to be related to the occurrence of ankle injuries (Moresi et al., 2012). Also a high inter-limb asymmetry during drop-landings and rebound jumps has been identified in gymnasts (Lilley et al., 2007). The above mentioned studies have used force plates and were therefore limited to simple gymnastics skills that can be performed safely onto force platforms such as continuous and rebound jumping. To quantify injury risk, and in particular impact loading on a daily basis, accelerometers have been proposed as a possible measurement tool (Bradshaw & Hume, 2012). In track and field, measures obtained from accelerometers were a good indication of mechanical loading and were repeatable between days (Moresi et al., 2013). Previously, GRF has been related to bi-axial acceleration of the pelvis during several, more complicated gymnastics movements. It was concluded that the use of accelerometers showed the potential to be employed in studies of injury risk factors in a gymnastics training setting (Beatty et al., 2006). The current study focused on the validity and reliability of accelerations, recorded with a tri-axial accelerometer embedded in the Minimaxx S4 GPS-unit (Catapult, Victoria, Australia, 10g, 100Hz) as a measure to estimate GRF.

METHODS: Twelve healthy female participants (age = 22.5 ± 4.0 years, height = 166.7 ± 7.9 cm, mass = 66.0 ± 10.0 kg) participated in this study. The participants provided written informed consent prior to participation, and were free from injuries at the time of testing. This study was approved by the Human Research Ethics Committee at the Australian Catholic University, Melbourne. All participants attended two testing sessions, one week apart, and at the same time of day. The participants' height and body mass was measured at the start of the first testing session. Prior to testing a warm-up of 5 minutes of treadmill walking (Quinton Medtrack CR60, Cardiac Science Corporation, Bothall, WA, USA) at a self-selected pace (5.2 ± 0.5 km/h) was completed. The accelerometer was placed in the middle of the participants' upper back over the second thoracic vertebra (T2) using a tight fitting crop top (Catapult, Victoria, Australia). The participants first completed ten continuous double legged hops on a uniaxial force platform (Quattro 9290AD, Kistler Group, Winterthur, Switzerland, 500Hz). They received verbal instructions to keep their knees straight whilst using their ankles and toes to push off. The participants then performed rebound jumps from three drop heights (40cm, 60cm, and 80cm) placing each foot on a separate tri-axial force platform (9286BA, Kistler Group, Winterthur, Switzerland, 1000Hz). The participants were asked to complete one practice trial before performing three rebound jumps from each drop height (Mullineaux et al., 2001). The order of drop heights was block randomised between participants.

Data from the accelerometer was imported into custom-written MATLAB software (R2012a, MATLAB R2012a, Mathworks, Inc., Natick, MA, USA). The raw accelerations in the x, y and z directions were combined into a resultant acceleration (RA) using the following equation:

$$a_r = \sqrt{a_x^2 + a_y^2 + a_z^2}$$

where a_r is the resultant acceleration, a_x is the acceleration is the x-direction, a_y is the acceleration in the y-direction, and a_z is the acceleration in the z-direction. All accelerations are expressed in gravitational units (g). The RA was filtered with a third order low pass Butterworth filter with a cut-off frequency of 20Hz. All ground reaction force data was normalized to the participants' body weight (BW). For the continuous hopping task the first and last two hops were excluded from data analysis. The peak vertical GRF (VGRF) of the remaining six impacts was retrieved from the Quattro jump software (Kistler Group, Winterthur, Switzerland, version 1.0.9.2) and averaged. The peak resultant accelerations (PRA) of the same six impacts were also averaged for the analyses. The peak resultant ground reaction force (RGRF) for both legs was combined (added together) for the rebound jumps in the Bioware software (Kistler Group, Winterthur, Switzerland, version 5.03.0) and then imported into custom written MATLAB software. The RGRF's were then filtered with a fourth order low pass Butterworth filter with a cut-off frequency of 100 Hz. The peak RGRF during the first contact phase of the rebound jump was averaged over the three trials for each drop height. The corresponding PRA was averaged over the three trials per drop height.

Statistical analyses was performed using SPSS for Windows software (SPSS Inc., Illinois, version 20.0), with an alpha level of 0.05, to assess validity of the accelerometer data in estimating GRF's. A Shapiro Wilk test indicated that the data was not normally distributed, and therefore descriptive statistics were calculated as medians and interquartile ranges. Spearman's rank correlation coefficients (r_s) were calculated between the GRF and PRA. The correlations were interpreted as <0.1 'trivial', 0.1-0.29 'small', 0.3-049 'moderate', 0.5-0.69 'high', 0.70-0.89 'very high' and 0.90-1.0 'almost perfect' (Hopkins, 2006). Data was then log transformed prior to calculating measures of inter-day reliability and variability using a modified Hopkins (2000) spread sheet. To determine reliability, criteria of 'relative' and 'absolute' reliability measures were chosen (Atkinson & Nevill, 1998; Bradshaw et al., 2010). These measures were the difference in the mean (MDiff%), intra-class correlation coefficients (ICC), measurement error (typical error) expressed as a coefficient of variation percentage (CV%), and Cohen's effect sizes (ES). Cohen's effect sizes and assessments of overall reliability from all statistical measures were interpreted consistent with the methods of Joseph, Bradshaw et al. (2013).

RESULTS: The correlations between PRA and GRF were high (>0.60) to very high (0.70-0.89) for the hopping and jumping tasks (Table 1). The PRA estimated VGRF during the continuous hopping task within 0.14-0.15 BW (2.93-2.72%) when tested on two occasions (Table 2), one week apart. The weakest estimates of GRF were for the highest rebound jump condition; an 80 cm drop height. The PRA estimated RGRF for the 80 cm rebound jump within 1.60-1.89 BW (19.75-22.63%) for the two tests, however these estimates were still highly valid (r_s: week 1 – 0.608, week 2 – 0.645). The PRA estimates of RGRF were more accurate at the lower drop heights of 40 and 60 cm (-7.92-11.29%). Overall, the lowest loads were observed during the 40 cm rebound jump (3.98 BW), followed by the continuous hopping (5.13 BW), 60 cm rebound jump (6.08 BW), and the highest load being the 80 cm rebound jump (8.23 BW). The rebound jump showed a progressive increase in impact load of approximately 2 BW with every 20 cm increase in drop height. All of the PRA and GRF measures showed good reliability with the exception of the 40 cm rebound jump PRA which had moderate reliability.

Table 1: Spearman rank correlation coefficients (r_s) between peak resultant upper back accelerations and peak ground reaction forces (hopping – vertical, rebound jumps – resultant).

Task	Week 1			Week 2		
	r_s	p	Validity	r_s	p	Validity
Hopping	0.825	0.001	Very High	0.860	<0.001	Very High
Rebound Jump 40 cm	0.734	0.007	Very High	0.783	0.003	Very High
Rebound Jump 60 cm	0.762	0.004	Very High	0.734	0.007	Very High
Rebound Jump 80 cm	0.709	0.015	Very High	0.645	0.032	High

Table 2: Reliability assessment of measures of vertical ground reaction force (VGRF), resultant ground reaction force (RGRF), and peak resultant acceleration (PRA) during continuous hopping and rebound jumps.

Task	Measure	Week 1		Week 2		Mdiff%	ICC		CV%		Cohen's ES		Reliability
		Median	IQR	Median	IQR								
Hopping	VGRF (BW)	5.12	0.92	5.14	0.68	1.37	0.93	High	3.92	Good	0.11	Trivial	Good
	PRA (g)	4.97	0.98	5.00	1.60	2.15	0.96	High	4.95	Good	0.10	Trivial	Good
Rebound Jump 40	RGRF (BW)	3.93	1.04	4.02	1.99	-1.12	0.94	High	9.82	Good	-0.03	Trivial	Good
	PRA (g)	4.29	0.89	4.34	1.45	-2.05	0.90	High	11.90	Marginal	-0.06	Trivial	Moderate
Rebound Jump 60	RGRF (BW)	5.95	1.45	6.20	1.80	-0.10	0.89	Good	9.25	Good	0.00	Trivial	Good
	PRA (g)	5.44	1.17	5.50	1.60	-0.63	0.90	High	8.81	Good	-0.03	Trivial	Good
Rebound Jump 80	RGRF (BW)	8.35	2.80	8.10	2.20	0.76	0.94	High	6.39	Good	0.04	Trivial	Good
	PRA (g)	6.46	0.70	6.50	1.20	-2.23	0.90	High	5.99	Good	-0.14	Trivial	Good

DISCUSSION: To quantify impact loads and injury risk in gymnastics there is a need for simple measures that can be employed during training. In the current study, peak resultant accelerations during jumping tasks generally exhibited very high validity and good reliability between weeks. Correlation coefficients between GRF and PRA are all significant and range from r_s = 0.608 to r_s = 0.860. These correlation coefficients are comparable or slightly higher than previously reported correlations for drop landings and countermovement jumps (r = 0.45-0.70; Tran et al., 2010) and for running and change of direction tasks (r= 0.00-0.76; Wundersitz et al., in press). Overall, the current results suggest that PRA is a good measure for estimating impact load. However, the tasks in the current study were limited to continuous hopping and rebound jumps onto one type of surface (force platform). During gymnastics training a variety of surfaces, including spring surfaces and various mats, are utilized. The effects of these surfaces on accelerations are not yet known, which will currently impede interpretation of PRA during a gymnastics training session. Also, the findings for the relatively simple skills examined in the current study, may not be directly transferrable to more demanding skills seen in gymnastics.

A factor that could influence the relationship between GRF and PRA is the gymnasts' coordination of the movement before the instant of touchdown. Joint angles of the ankle, knee and hip vary considerably due to preceding skills (Beatty et al., 2007). A variation in knee angle during running, causing a change in effective mass has been shown to affect the otherwise linear relation between force and acceleration. When running with a more extended knee, GRF increases, while leg acceleration decreases, when compared to running with a more flexed knee (Edwards & Derrick, 2008). This implies that joint angles at the instant of touchdown, and therefore jumping technique, might negatively affect the validity of determining impact load from PRA. The participants in the current study were healthy, physically active young women with mixed sporting backgrounds. Some of them had received specific training in jumping via past or current participation in sports such as gymnastics and netball, while others hadn't. Therefore, greater variation in jumping technique can be expected within the current sample when compared to elite gymnasts. Accounting for this higher population variation, the validity of assessing impact load using PRA in gymnastics is promising.

CONCLUSION: The results of the current study indicate that peak resultant acceleration, recorded at the upper back, is a reliable and valid measure to assess impact loads during continuous hopping and rebound jumps. This measure shows potential to be employed in a gymnastics training setting. Further research into the effects of different joint angles at the instant of touchdown, and various landing surfaces on ground reaction force and acceleration is recommended.

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