METHOD FOR ANALYSING THE RISK OF OVERUSE INJURY IN GYMNASTICS

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The purpose of this study was to propose and assess a method for the evaluation of all loads experienced during gymnastics training. The method is based on the measurement of acceleration on the gymnast. Twelve gymnasts performed a range of gymnastics skills with an impact component. Ground reaction forces and acceleration at the pelvis were measured. There were significant correlations between peak GRF and peak acceleration during landing from gymnastics skills for individual participants. This testing showed the potential for this method to be applied in a study of injury risk factors outside the laboratory environment. At present, this relationship means that acceleration can be used as an estimation of force, after calibrating acceleration to ground reaction force for the individual.

KEY WORDS: repetitive loading, ground reaction forces, acceleration.

INTRODUCTION: Overuse injuries account for 14-56% of injuries in gymnastics (Lowry and Leveau 1982; Caine, Cochraine et al. 1989) and injury rates have been reported to increase with increasing training intensity. (Sands, Shultz et al. 1993; Wadley and Albright 1993). There is a lack of knowledge regarding the quantity and cumulative effect of high loading skill components experienced by gymnasts during training and competition. While there have been lab based studies of impact forces in gymnastics (Panzer, Bates et al. 1987; Panzer 1989; McNitt-Gray 1991; Smith and Wilkerson 1991; Koh, Grabiner et al. 2001), the methods used are not transferable to the gymnastics training setting and are difficult to apply to studies of cumulative load and its role in the causation of overuse injuries. A method for measuring exposure to impacts in gymnastics, both magnitude and repetition, may quantify training intensity.

Development of an accelerometer based method for load measurement is proposed. Accelerometers are attached to the gymnast and the method is not reliant on the location of instrumentation fixed in the gymnastics environment. It is proposed that the accelerometer data are used in a load-injury model. Equation 1 is an example of how the magnitude of acceleration and number of impacts might be incorporated into this model. The model and its characteristics would need to be investigated during prospective studies of loading and injury.

$$I = \sum_{i=1}^{j} \alpha + \left[\beta_1 l + \beta_2 m + \beta_3 f + e - \chi t_r\right]_i$$

Equation 1. Load-injury model, I is the injury risk index value, α is a constant β1 to β3 are constants, l = number of low loading impacts, m = number of medium loading impacts, f = number of fracture level impacts, χ is a constant and tr = rest time in hours and e is an error factor.

The paper describes the method for measuring acceleration data from a population of 12 gymnastics performing 9 different skills.

METHOD:

Acceleration measurement: Acceleration data were collected using a Microstrain telemetric V-Link data logger with two accelerometers (IC sensors 3031-050) mounted orthogonally. Acceleration was sampled at 352Hz: restricted by limitations of the data-logging system. The accelerometer array was positioned to approximate the location of the centre of mass of the whole body as much as practically feasible to allow collection of data during landings on both upper and lower limbs. A waist belt with data-logger and accelerometers was placed on the gymnasts' pelvis so accelerometers were positioned at the sacrum, located centrally in the coronal plane. Accelerometers were oriented so that saggital plane accelerations (apelvis) were obtained: one approximately antero-posterior and the second approximately vertical when the gymnast was standing still. Waist and leg straps on the belt were tightened as much as permitted by the gymnast and secured by Velcro. The mass of the system was 0.3 kg.

Data Collection: Twelve competitive female gymnasts were recruited from gymnastics clubs in the Sydney metropolitan area. Participants were aged between 11 and 20 and at the time of testing were competing between levels five and ten in Australia.

Participants completed a warm up and practiced the study skills. Gymnasts then performed a range of gymnastics skills including both dance (leaps and jumps) and acrobatic skills, all of which had some degree of impact, and which were able to be performed in the limited space available (2m approach distance). The skills included are seen in Table 1.

Vertical GRF data from two Kistler force platforms were collected using a Vicon 370 system and sampled at 1000Hz. Experiments were conducted in the School of Safety Science at the University of New South Wales. Two foam landing mats each ten centimetres thick and covered with carpet, were placed next to one another over the force platforms and performance area. These types of mats are commonly used in gymnastics training centres.

Data Analysis: Data were imported into Matlab® for analysis and filtered using a low pass Butterworth filter. The cut-off frequency for force data was 400Hz and for apelvis data, 15Hz. As these forms of data were collected at different sample rates, data were resampled to 500Hz using interpolation methods in Matlab®. Peak values for vertical ground reaction force and the resultant of the two accelerometers were obtained for the landing of each skill. One-way within subjects design ANOVA's with replications were used to determine differences between upper and lower body landings for peak GRF and apelvis. Correlations were performed between peak GRF and peak apelvis for individual participants as well as for pooled data.

RESULTS:

Table 1. Skills.

Skill	**n**
Straight jump	29
Tuck jump	32
Handstand pop	24
Round off	31
Back flip (hands)	20
Back flip (feet)	22
Back salto	18
Front handspring	20
Front salto	12

A total of 208 trials of nine different skills were analysed; 44 of these involved landing on the upper body and 164 involved landing on the lower body. Table 1 shows the number of samples for each skill. Repeated measures were shown to be reliable using Cronbach's alpha for both peak GRF ($p = 0.92$) and peak acceleration ($p = 0.67$).

The peak absolute GRF during landing ranged from 694 N (1.2 BW) to 6962 N (11.8 BW) with a mean of 2511 ± 665N (4.5 ± 0.8 BW). During impacts on the hands (handstand pop and back flip) there were significantly lower ($p < 0.001$) peak GRF's than during impacts on the feet (Figure 1a). The mean peak GRF was 2.3 ± 0.3 BW during landings on the upper body, while on the lower body the mean peak GRF was 5.2 ± 0.9 BW. The lower body therefore is subjected to 2.3 times the loads on the upper body, based on analysis of these skills in the laboratory.

Peak apelvis experienced during landing ranged from 7.9 $m.s^{-2}$ (0.8 g) to 135.2 $m.s^{-2}$ (13.8 g) (Figure 1b). The apelvis for the upper body landings were reduced compared to the lower body landings ($p < 0.001$) as with force variables. Accelerations experienced during upper body landings were 44 $m.s^{-2}$ ± 19 $m.s^{-2}$ (4.5 ± 2 g) while for the lower body 76 ± 12 $m.s^{-2}$ (7.8 ± 1.2 g). Lower body landings resulted in peak accelerations 1.7 times those during upper body landings.

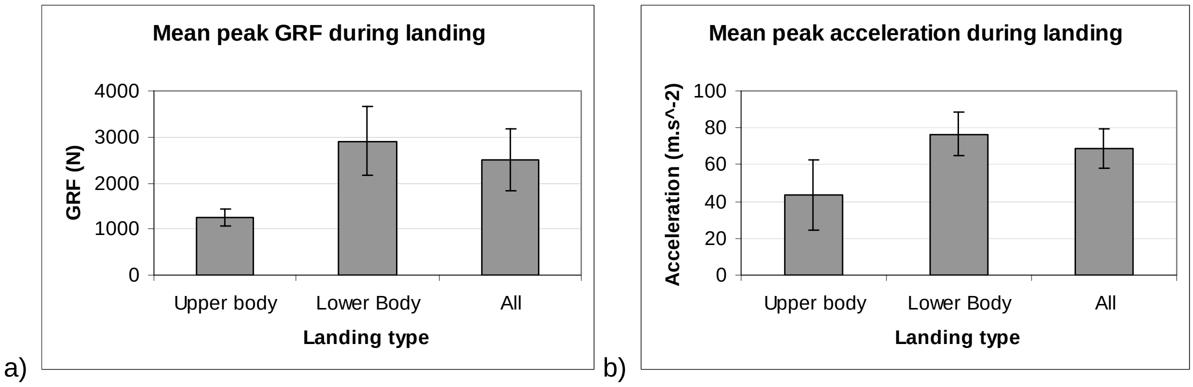

Figure 1: a) Mean peak forces experienced during landing, b) Absolute mean peak acceleration experienced during landing (± 1SD)

Significant relationships were seen between peak GRF and apelvis variables during landing for individual participants, with R values ranging from 0.59 to 0.96 and averaging 0.8 (± 0.1). An example is shown in Figure 2a. When all data is pooled the R value is 0.7 for absolute values and 0.74 for relative values. Heteroscedasticity in data pooled for all participants (Figure 2b) is caused by differing slopes for individual participants. An analysis of variance using a one-way within-subject design with replications showed significant interaction between gymnast and acceleration ($p = 0.002$).

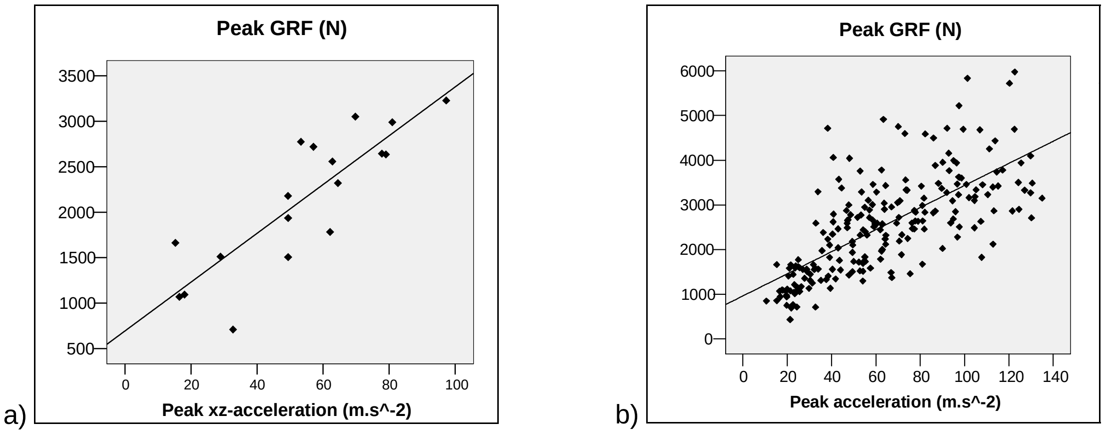

Figure 2: Scatter plots of peak force and peak acceleration for a) an individual gymnast and b) for all participants.

DISCUSSION: Landing forces from gymnastics skills were similar to those previously reported for gymnastics skills on the floor (Miller and Nissinen 1987; Smith and Wilkerson 1991; Koh, Grabiner et al. 2001). Loads on the upper body were significantly less than those on the lower body, indicated by both peak GRF and peak a_{pelvis}. This may not result in a reduced risk of injury to the upper limb compared to the lower limb. The risk of injury is related to the tolerance of the structures involved and as the upper limb is not evolved to bear high loads it may, in fact, be more vulnerable to injury even at lower levels of loading.

An analysis of measurement repeatability by skill and individual showed that there were no differences in a_{pelvis} for repeat tests. This shows that the precision of the measurement of a_{pelvis} on an individual is suitable.

As expected there was a correlation between peak GRF and peak a_{pelvis} at the pelvis during landing. Differing slopes of regressions for individual differences mean that the relationship between peak GRF and peak a_{pelvis} is dependent upon the characteristics of each gymnast and their technique. These characteristics include the response of the musculoskeletal system to load, the effects of the angular velocity of the gymnast during impact and the mounting of the accelerometers to the pelvis of the gymnast.

CONCLUSION: The method assessed showed that a_{pelvis} is a suitable vehicle for analysing the quantity and magnitude of loads experienced by gymnasts during training over a period of time. In order to develop the proposed load-injury model it is necessary to estimate GRFs from a_{pelvis} as more is known about the impact injury tolerance with reference to impact force than acceleration. With the current method it is necessary to calibrate the accelerometer-gymnast system using ground reaction forces. Methods will be more transportable if calibration is not required. Further research and improvements in instrumentation are necessary. Despite current limitations, measurement of acceleration shows potential for investigating the relationship between chronic injury and load.

REFERENCES:

Lowry, C. B. and B. F. Leveau (1982). "A retrospective study of gymnastics injuries to competitors and noncompetitors in private clubs." The American Journal of Sports Medicine 10(4): 237-239.

Miller, D. J. and M. A. Nissinen (1987). "Critical examination of ground reaction force in the running forward somersault." International Journal of Sport Biomechanics 3: 189-206.

Panzer, V. P., B. T. Bates, et al. (1987). A biomechanical analysis of elbow joint forces and technique differences in the Tsukahara vault. Diagnosis, treatment and analysis of gymnastics talent. T. B. Hoshizaki, J. H. Salmela and B. Petiot. Montreal, Sports Psyche Editions: 37-46.

Caine, D., B. Cochraine, et al. (1989). "An epidemiologic investigation of injuries affecting young competitive female gymnasts." The American Journal of Sports Medicine 17(6): 811-820.

Panzer, V. P. (1989). Dynamic assessment of lower extremity load characteristics during landing. College of Human Development and Performance. Oregon, University of Oregon Eugene.

McNitt-Gray, J. L. (1991). The influence of joint flexion, impact velocity, rotation, and surface characteristics on the forces and torques experienced during gymnastics landings. F.I.G. Scientific Medical Symposium, Indianapolis, Indiana, US, USGF.

Smith, S. S. and J. W. Wilkerson (1991). Comparison of impact forces experienced by gymnasts performing forward and backward landings. 9th ISBS Symposium, Iowa State University.

Sands, W., B. Shultz, et al. (1993). "Women's gymnastics injuries: A five year study." The American Journal of Sports Medicine 21(2): 271.

Wadley, G. and J. Albright (1993). "Women's intercollegiate gymnastics: Injury patterns and 'permanent' medical disability." The American Journal of Sports Medicine 21(2): 314.

Koh, T. J., M. D. Grabiner, et al. (2001). "Technique and ground reaction forces in the back handspring." The American Journal of Sports Medicine 20(1): 61-65.