VERTICAL IMPACT FORCE AND LOADING RATE ON THE GYMNASTICS TABLE VAULT

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The purpose of this study was to determine the effect of low and high intensity impact forces on the average loading rate during a forward handspring vault. Peak force, time to peak and impulse were used to characterize the impact vertical force during a vault performed by 12 female gymnasts. Reaction forces from right and left hands were measured at 500 Hz with two PASCO portable force platforms fixed to the vault table surface. Force data were split in two groups: Low intensity (LI: peak forces < 0.7 BW) and High intensity (HI: peak forces > 0.7 BW). Significant differences ($p<.05$) for force peak magnitude and impulse between groups were found. Statistically significant correlations between the loading rate and force peak ($r = .56$) and time to peak ($r = -.64$) were found for the LI group. The loading rate for the HI group correlated with time to peak ($r = -.78$).

KEY WORDS: injury, handspring, acrobatics.

INTRODUCTION: The vault is one of the female gymnastics apparatus with the highest risk of upper extremity injuries (Nattive and Maldebaum, 1993) due to the intense loading rate generated during the hands-table impact. In particular, the wrist is the site more often involved in both acute and over-use injuries (De Smet et al., 1994; Di Fiori at al., 1996; Liegling et al., 1995). Primary information from direct measurement about the vertical and anterior-posterior forces generated during the contact phase of the gymnasts` hands with table is available (Penitente et al., 2010). Further information about how these forces are involved in the development of injuries are required to identify adequate injuries prevention strategies. The role of high magnitude vertical force has been shown in the determination of injuries potential for lower extremity during running (Edington, 1980) and bilateral landing of jumping activities (McNitt-Gray, 1991). Hence, this study will focus on the analysis of the vertical impact force during the hand support phase of the handspring vault in women. A number of studies have been presented on the vulnerability of the upper extremity during forward falls on outstretched arms. Research has also identified high and repetitive impact forces as a major extrinsic component contributing to injuries during growth and development in upper extremity (Chiu and Robinovitch, 1998; Chou et al., 2001; DeGoede et al., 2003). However there is no evidence about how the magnitude of peak force (a), time to peak (b) and impulse affect the loading rate and thus the risk of injuries. The purpose of this study was to determine the interaction of LI (forces with impact peak < 0.7 BW) and HI (forces with impact peak > 0.7BW) forces on the average loading rate during the forward handspring vault performed by female gymnasts.

METHODS: Twelve American Junior Olympic National Champion female gymnasts with a mean age of 16.9 ± 1.4 yr; height of 1.60, ± 0.1 m and mass of 56.7, ± 7.8 kg participated in the study. Gymnasts provided informed consent in accordance with the U.S. Olympic Committee policies on the study of human subjects. The vault table surface that was placed below competition height (1,25 m) was equipped with two portable force platforms (Pasco Scientific, USA) (Figure 1a) fastened to a rigid wooden foundation. The force platforms surfaces achieved competition height and were covered with a thin mat (0.4 cm) to provide cushion and traction during hand contact. Forces during forward handspring vault exercise were measured in the vertical (Z) and anterior-posterior (X) planes at a rate of 500 Hz. Gymnasts participated in a self-selected warm up activity before performing a forward handspring vault landing feet-first on mats stacked to the level of the vault table (Figure 1b). Twenty-four successful trials were selected (two for each gymnast) including a simultaneously measurement of left and right hand from the two force platforms. A total of 48 impact events were used for analysis. The vertical force (Fz) was reported in Newtons and scaled to each gymnast`s body weight (BW). Four characteristics of Fz were investigated: impact peak force magnitude (N and BW), time to impact peak (s), impulse (BWs) and average loading rate (between the impact and peak) ($BWs^{-1}$). Similarly to Markolf`s investigation on the kinetics analysis of pommel horse exercises (Markolf et al., 1990) the force data were split in two groups: one included data with impact peaks of magnitude less than 0.7 BW (LI group), defined as low intensity load; the other included data with impact peaks greater than 0.7 BW (HI group), defied as high intensity load. Data analyses were performed with the software SPSS (Version 18.0, SPSS, Inc. Chicago, IL, USA). Differences in force characteristics between HI and LI were assessed with an independent t test (α=0.05). Pearson correlation was used to determine the relationship of the loading rate with the impact peak, the time to peak and the impulse for both load intensities.

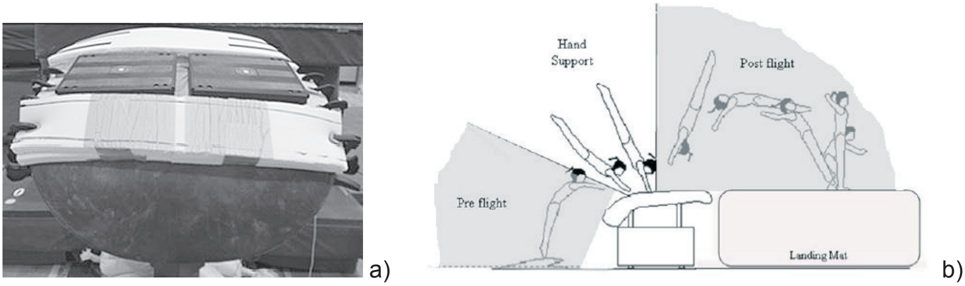

Figure 1: a) Two portable force platforms fixed on the table vault; b) Forward handspring vault.

RESULTS: The descriptive statistics relative to the impact peak magnitude, time to impact peak, impulse and average loading rate for Low and High intensity load, respectively are presented in Table 1.

Table 1
Forward Handspring vault Vertical Force characteristic

		N	Mean (StDev)	Range
Impact Peak (BW)	Low Load	27	.44 (.14)	[0.15-0.73]
	High Load	21	1.32 (.30)	[0.80-1.08]
Impact Peak (N)	Low Load	27	240.5 (72.3)	[92.6-377.5]
	High Load	21	743.8 (192.7)	[365.6-1059.7]
Time to Impact Peak (s)	Low Load	27	.007 (.003)	[002 - 0.014]
	High Load	21	.016 (.007)	[0.06 - 0.030]
Impulse (BWs)*	Low Load	27	.10 (.014)	[0.05-0.12]
	High Load	21	.11 (.018)	[0.06-0.14]
Loading Rate (BWs^{-1})*	Low Load	27	74.9 (44.9)	[22.2-207.7]
	High Load	21	98.9 (37.9)	[49.1-216.1]

* Independent t test sign (p<.05)

The impulse showed a statistically significant difference between HI and LI groups ($t(46)$ = -2.09, p =0.042). The average loading rates did not exhibit a significant difference between LI and HI groups. However, it should be noted that the t-test approached significance at the .05 level (*t(46)* = 1.96, p =.056). For the LI load, the average loading rate resulted significantly correlated with the magnitude of the impact peak (r = 0.557, p = 0.002) and with the time to peak (r = -0.638, p < 0.01). The average loading rate for the HI load resulted in a statistically significant correlation with the time to peak force(r = -0.783, p < 0.01).

DISCUSSION: The objective of this study was to investigate the effects of low and high intensity vertical impact forces on the average loading rate during the forward handspring on the vault performed by female gymnasts. Major findings indicated that the magnitude of the peak force generated at the instant of impact with the table had a mean value of 743.8 ± 192.7 N for the HI group. This load is smaller than the fracture loads of 1917 ± 640N and 1580 ± 600N measured on women cadavers by Frykman (1967) and Myers (1993) cited in DeGoede (2003). However it should be noted that the maximum load recorded in the present study (1059.7 N) is very close to these fracture thresholds and no injuries occurred. The impact peak force occurred within 50 ms period after hand contact (maximum time to peak force recorded 30 ms). In this short time muscle activity is adjusted in reaction to impact forces. This is comparable to the pre-activation that occurs during running where the lower limbs muscles are pre-activated before the heel strike to minimize the impact shock. Thus, the first spike in the time-force curve must be considered an anticipated event in which the gymnast must activate muscles before the impact (Boyer and Nigg, 2004; McNeal et al., 2007) A potential injury mechanism may be considered when athletes fail to pre-activate their upper extremity muscles. It can be suggested that the impact with the table represents a stress that generates shock waves and vibrations that must be absorbed by the upper extremities. When muscle is unprepared for receiving impact forces, then bone and joint suffer the insult of the impact (Harris, 2002).

The only comparable impact force data for the upper limb during gymnastics manoeuvres were found in the investigation conducted by Marfolk et al. (1990) on the hip circle exercise on the pommel horse. Although the comparison of their data with the forward handspring vault is limited by the nature of the movements, it is possible to identify interesting contradictory differences in the peak magnitude, time of the impact peak force and loading rate. Even if they are both explosive skills, in the hip circle exercise upper extremities are involved in a cyclic and alternate movement similar to a walk; in the handspring vault upper extremities are involved in a ballistic and bilateral movement more similar to a jump. Comparing the magnitude of the impact peak force and the loading rate of the forward handspring (impact peak = 1.32 ± 0.30 BW; loading rate = 98.9 ± 37.9 BWs^{-1}) with that ones generated during the hip circle on the pommel horse (impact peak = 1.01 ± 0.33 BW; 129.0 ± 43.5 BWs^{-1}) it can be noted that the higher loading rate on the pommel horse is associated with a lower impact peak. Contrary to the assumption that high impact forces generate high loading rate (McNitt-Gray, 1991), this comparison shows that for impact peak above 0.7 BW impact forces high in magnitude may not result in a high loading rate. Results from the forward handspring analysis further confirmed the different interactions between the magnitude of the impact force and the loading rate at different load intensities. For LI loads the loading rate is positively correlated ad influenced by the impact peak (r = 0.55l p = 0.002), whereas for HI loads the loading rate is not statistically correlated with the impact peak, moreover it shows a negative but non-significant correlation (r = -0.177; p>.05). On the other hand, a short time to peak appeared to be more likely the factor that contributed to generate high loading rate and thus can be identified as injury risk-related factor at any load intensity.

CONCLUSION: Direct measurement of the forces during a forward handspring vault was used to investigate the interaction between the vertical impact forces and the loading rate considered a major factor of injury. The data showed that upper extremities are subjected to impact forces very close to what is considered the fracture load. This suggested that two major interventions need to be adopted to modulate the magnitude of the impact peak force, the cushioning characteristics of the vault table surface and the kinematics of the body at the impact with the apparatus. Results from this study also demonstrated that in order to improve the understanding of the development of injuries in upper extremities during explosive actions further investigations on the factors that determine the time to impact peak are necessary.

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