FOREARM LOADING AND SYMMETRY DURING ARTISTICS GYMNASTICS VAULT TRAINING SESSIONS.

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Vaulting places considerable load on the upper limbs which can be associated with pain and injury. This study aims to use forearm-mounted IMUs to quantify forearm segmental loading and symmetry when performing foundation to advanced-level vaults. Twelve artistic gymnasts (female, n= 6; male, n= 6) wore bilateral forearm-mounted IMUs while completing their vault training sessions. The peak resultant acceleration (PRA) for the leading and non-leading forearms during hand contact was calculated. Descriptive statistics (median and IQR) and symmetry index scores (SI%) were calculated between the lead and non-lead forearms. High asymmetrical loading during vault contact was identified for some Yurchenko (SI%= 3.7-37.6%), Handspring (SI%= 7.7-21.0%) and Tsukahara vaults (SI%= 2.0-28.8%). Limb asymmetries varied between skills and gymnasts, highlighting that individual screening is needed to identify gymnasts with higher injury risk.

KEYWORDS: IMU, asymmetry, accelerometer, gymnastics.

INTRODUCTION: Vaulting is a unique sporting movement as gymnasts actively land and push-off using both their hands, therefore, the upper limbs play a crucial role in determining the success and overall score of the vault (Penitente and Sands, 2015). A quick and forceful push-off from the vault is needed to increase the height, distance, and time of the second-flight phase (Farana and Vaverka, 2012; Fernandes, Carrara, Serrão, Amadio and Mochizuki, 2016). An enhanced second-flight phase allows gymnasts to complete more twists and somersaults prior to landing, thereby increasing the difficulty and overall score of the vault (Farana and Vaverka, 2012; Hao, Li, Yu and Wu, 2014). However, to achieve this the upper limbs are placed under considerable loading, which raises injury risk concerns (Amaral, Claessens, Ferreirinha and Santos, 2011; DiFiori, Caine and Malina, 2006).

Repetitive high magnitude loading of the upper limbs is a major extrinsic risk factor for injury, especially during the growth and developmental years of young gymnasts (DiFiori, et al., 2006; Penitente, Sands and McNeal, 2011). As a result, certain vaults have been associated with wrist pain in female gymnasts. For example, during Tsukahara vaults the wrist tends to hyperextend and move into ulnar deviation during vault contact (DiFiori, et al., 2006).

Asymmetrical loading between upper limbs can also increase the risk for overuse injuries, specifically if one limb is continually exposed to higher loading (Lilley, Bradshaw and Rice, 2007; Zifchock, Davis and Hamill, 2006). When vaulting, gymnasts will train skills using their preferred (or leading) limb only to achieve performance consistency. This could overload one limb, leaving the contralateral limb weaker and less able to absorb the high forces associated with performing vault skills (Lilley, et al., 2007). Clinical definitions of functional imbalance are not well-established in gymnasts; however, it has been suggested that limb loading asymmetries of greater than 10% may place gymnasts (or limbs) at a greater risk for injury (Lilley, et al., 2007).

The primary aim of this study was to use forearm-mounted IMUs to investigate the magnitude and symmetry of forearm segmental loading experienced when performing a mixture of foundation, intermediate and advanced-level vaults during a training session. It was hypothesised that vaulting would expose gymnasts to asymmetrical forearm loading.

METHODS: Participants: Twelve advanced-level competitive gymnasts (male, n= 6; female, n= 6) were recruited to participate in this study (age= 16.1 ± 2.5 years, body mass= 52.2 ± 8.5

kg, stature= 159.2 ± 9.4 cm, training age= 9.8 ± 2.8 years, weekly training hours= 29.3 ± 2.3 h/week, gymnastics level= National Level 9-Senior International). Participants were excluded from participating if they were injured or ill at the time of data collection or if they did not provide informed consent.

Procedure: Data collection took place during scheduled vault training in each gymnast's local training centres. In this study, peak acceleration was used as a proxy measure for peak force or loading at the forearm. The relationship between force and acceleration is highlighted in Newton's second Law of Motion; $F=ma$, where F is the net force (N), m is the mass of the object (kg) and a is the acceleration of the object (m/s^2). Two IMUs (Blue Thunder, 3-axis, ±16 g, 1000 Hz; IMeasureU, Auckland, New Zealand) were placed bilaterally on each forearm (intersection of the third and last distal quarters of the dorsal aspect of the forearm). IMUs were secured in position using a combination of double-sided toupee tape (Creative hair products, Melbourne, Australia), Fixomull (BSN Medical, Hamburg, Germany) and sports strapping tape (Elastoplast, Hamburg, Germany). All female gymnasts performed Yurchenko entry style vaults, which involves two hand contacts; the round-off entry and vault contact. Both hand contacts were analysed. The male gymnasts performed Handspring and Tsukahara or Kasamatsu entry vaults, which only involve one hand contact (vault contact). Gymnasts only performed the vault skills instructed by their coach, meaning that gymnasts each performed several different vaults.

IMU data were simultaneously collected using an iPad (Mini 3; Apple, California, USA) and the IMeasureU Research Application (IMeasureU, Auckland, New Zealand). A video camera (Canon XF205; Canon, Tokyo, Japan) captured footage of the data collection session. To synchronise the IMU signals and the video footage, participants tapped each IMU three times within the video frame at the beginning of the data collection sessions, then the offset between the timing of the taps from the video and IMUs was calculated and used to synchronise the IMU and video footage.

Data analysis and statistical analysis: Video footage from each testing session was coded for the IMU sensor taps at the beginning of the testing session, and each hand contact with the ground or vault using Kinovea software (0.8.15; Kinovea, Bordeaux, France). Ground (for Yurchenko vaults only) and vault contacts were defined as occurring from one frame prior to visually identifying the hand touching the ground or vault, to one frame after contact ended. A custom Python script (v2.7.15; Python Software Foundation, Delaware, USA) was used to apply a filter to the raw IMU signal (fourth-order zero-lag Butterworth filter with 85 Hz cut-off frequency; Campbell, Bradshaw, Ball, Hunter and Spratford, 2020), calculate the resultant acceleration, then export the peak resultant acceleration (PRA) during ground and vault contact. All PRA results were grouped according to the lead or non-lead forearm depending on the gymnast's technique. The lead arm was determined by observing the gymnast perform a round-off on the floor (the arm which contacted the ground first was defined as the lead arm). For all hand contacts, a symmetry index (SI%) was calculated to assess functional symmetry using the following equation adapted from Zifchock, et al. (2006); $SI\% = (PRA_L – PRA_{NL})/(0.5 \times (PRA_L + PRA_{NL})*100)$, where PRA_L refers to the lead forearm and PRA_{NL} to the non-lead forearm. Due to the exploratory nature of this study, and to maintain individual variability of participant performance, the recorded vault data were not collapsed to produce a single mean for each gymnast or vault. Therefore, the data violates normality and independence assumptions, meaning only non-parametric descriptive statistics could be conducted. Median and inter-quartile range (IQR) were calculated using Prism software (v8.0.1; GraphPad Software, San Diego, USA).

RESULTS AND DISCUSSION: Descriptive statistics and the SI% scores for the lead and non-lead forearm during all vaults are displayed in Figure 1. Female gymnasts experienced less forearm loading during the round-off entry hand contact for both the lead and non-lead forearm than during the vault contact phase for the Yurchenko Tuck and Yurchenko Layout skills. Significant asymmetry was present during the round-off entry and the vault contact for the Yurchenko Tuck vault (SI%= 18.3% and 23.9%, respectively) and the vault contact during the Yurchenko Pike vault (SI%= 37.5%; Figure 1). This is an interesting finding, as the vault contact for the Yurchenko vaults theoretically should be symmetrical in loading, whereby both hands should contact the vault at the same time and push-off the vault using the same movement. However, these results highlight that even though a movement might appear symmetrical, the loading experienced can still be asymmetrical. Exell, Robinson and Irwin (2016) reported similar findings for forward handspring skills on floor. The hand contact during a forward handspring appears symmetrical, however it was reported that all gymnasts demonstrated asymmetrical loading that appeared to be related to the leading limb. Additionally, pilot research from Campbell, Bradshaw, Ball, Hunter and Spratford (2019) stated that the upper limbs during forward and backward handsprings, and the lower limbs during tuck jump landings also experienced significant levels of asymmetrical loading. This highlights that even during "symmetrical" gymnastics skills, one limb could still be experiencing much higher loading which is likely not detectable through simple visual observation by a coach.

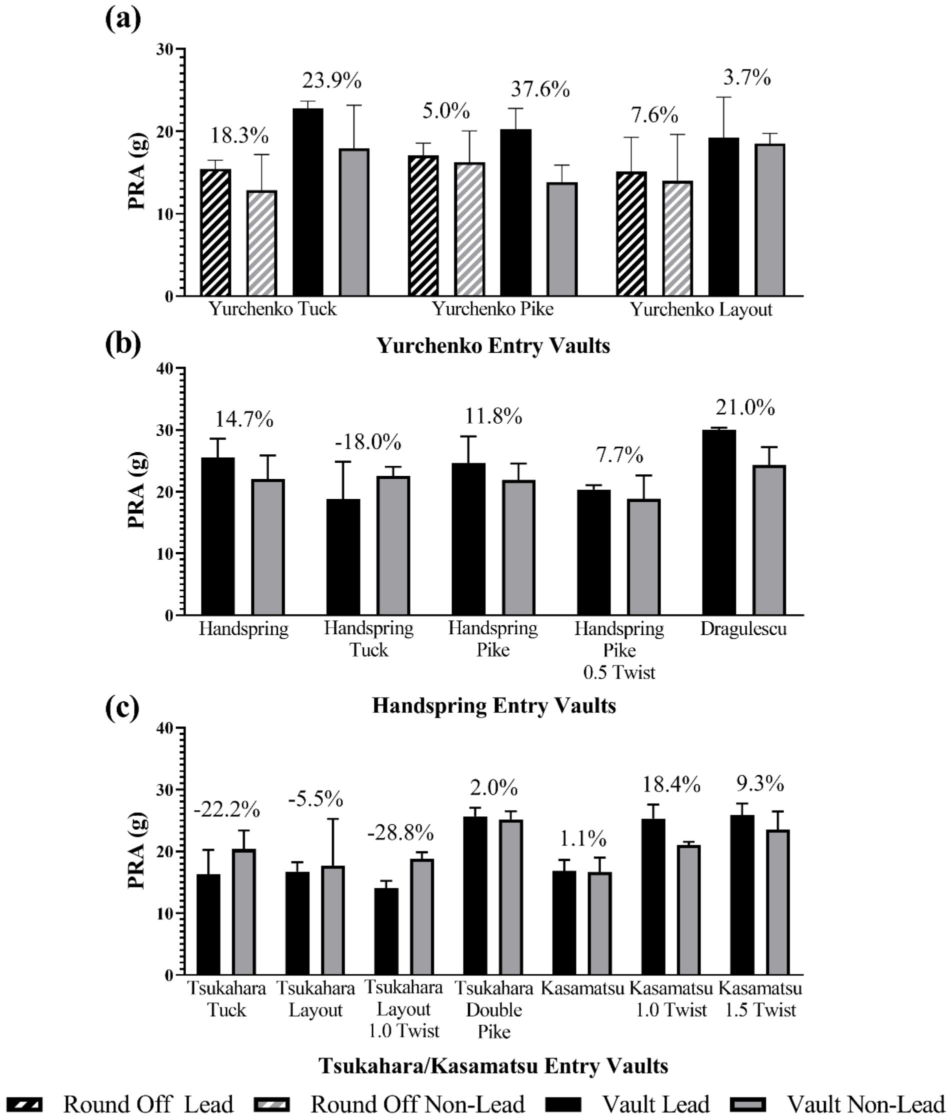

Figure 1: Descriptive statistics (median and IQR) for lead and non-lead PRA during (a) Yurchenko entry vaults performed by female gymnasts, (b) Handspring entry and (c) Tsukahara/Kasamatsu entry vaults performed by male gymnasts. The striped bars are the hand contact during the Yurchenko round-off entry, and the solid bars are for the vault hand contact. Lead limb is displayed in black, and non-lead limb in grey. SI% scores between the lead and non-lead limbs are presented above the corresponding hand contacts.

Male gymnasts experienced varied forearm loading during Handspring vaults. Specifically, the leading forearm experienced higher loading during the Handspring, Handspring Pike, Handspring Pike 0.5 Twist and Dragulescu vaults, but for the Handspring Tuck, the non-lead forearm experienced greater loading (Figure 1). It should be noted that, except for the Handspring Pike 0.5 Twist, all other Handspring style vaults had SI% scores of greater than 10% (Figure 1). Similar to Yurchenko vaults, Handspring style vaults involve a hand contact phase that appears symmetrical, yet the loading experienced was asymmetrical. During Tsukahara vaults, generally greater loading was experienced in the non-lead forearm (except for the Tsukahara Double Pike), while for Kasamatsu vaults the opposite was observed, with the lead forearm experiencing greater loading (except the Kasamatsu vault which demonstrated a relatively even loading pattern; Figure 1). This could be due to the technical differences between the Tsukahara and Kasamatsu vaults. Both vaults have the same entry and first-flight phase (prior to vault contact), however differ in the second-flight phase. During Tsukahara vaults that involve twisting around the longitudinal axis (i.e. Tsukahara Layout 1.0 Twist), prior to vault contact the gymnast will be twisting in one direction, but after the vault contact the gymnast will change the twist direction in the second-flight phase prior to landing. In contrast, during Kasamatsu vaults (all vaults involve twisting around the longitudinal axis), a gymnast will continue to twist in the same direction in the second-flight phase as they were prior to vault contact. To change the twisting direction in the second-flight phase, the arms during vault contact must push-off in different directions, which could explain the different loading trends that were observed between Tsukahara and Kasamatsu vaults. Limitations of this study include the capacity of the IMUs (±16 g) and that data collection took place in each gymnast's training centre. All equipment was up to competition regulation standards to best allow for consistency between participants.

CONCLUSION: Advanced-level artistic gymnast's experience significant forearm loading asymmetries when performing some Yurchenko, Handspring and Tsukahara entry style vaults. The vault contact for the Yurchenko and Handspring vaults involve both hands simultaneously contacting and pushing-off the vault, however, the loading experienced in this study was asymmetrical. Forearm asymmetry varied between skills and gymnasts, highlighting that individual screening should be a priority to identify gymnasts and limbs that may be at a higher risk for injury. Overall, IMUs can be used within a gymnastics training environment to provide a proxy measure of limb loading and symmetry in training.

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