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Research article

A COMPARISON OF UPPER-EXTREMITY REACTION FORCES BETWEEN THE YURCHENKO VAULT AND FLOOR EXERCISE

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ABSTRACT
The purpose of this study was to examine reaction forces transmitted to the upper extremities of high-level gymnasts during the round-off phase of the Yurchenko vault. A secondary purpose of this study was to compare reaction forces during the Yurchenko vault to reaction forces observed in a tumbling pass during the floor exercise. Ten high-level, female gymnasts volunteered to participate. Conditions of the independent variable were the Yurchenko vault and floor exercise; dependent variables were peak vertical and peak anterior-posterior reaction forces. Each participant performed three trials of both conditions with the trail hand contacting a force platform. Vertical and anterior-posterior reaction forces, normalized to body weight, were greater ($p < 0.05$) during the round-off phase of the Yurchenko vault (2.38) than during the floor exercise round-off (2.15). Vertical reaction forces during the round-off phase of the Yurchenko vault and floor exercise round-off are similar to reaction forces transmitted to upper extremities during other gymnastic skills and ground reaction forces transmitted to lower extremities while running and walking at various speeds. Results of this study reveal a need for further research considering methods aimed at reducing reaction forces transmitted to the upper extremities during the Yurchenko vault and floor exercise.

KEY WORDS: Gymnastics injuries, biomechanics, vaulting kinetics, ground reaction forces.

INTRODUCTION

The number of athletes participating in gymnastics has increased (Meeusen and Borms, 1992), exposing more gymnasts to the possibility of athletic injury (Kolt and Kirkby, 1999). Numerous epidemiological studies (Garrick and Requa, 1980; Meeusen and Borms, 1992; Sands et al., 1993; Snook, 1979) justify research considering injury etiology and prevention in women's gymnastics. Sands et al. (1993) reported that 9% of collegiate-level gymnastics training sessions result in injury, and collegiate-level gymnasts train with an injury 71% of the time. Various researchers have reported the following injury rates (injury rate is calculated as the total number of injuries during a specific time period divided by the number of participants, multiplied by 100) for elite- and collegiate-level, female gymnasts: a) Clark and Buckley (1980) reported 28% for a three year study; b) Garrick and Requa (1980) reported 70% for a one year study; and c) Caine et al. (1989) reported 294% for a one year study. Researchers consistently report gymnastics injury rates as comparable to injury rates of American football and wrestling (McAuley et al., 1987). Caine et al. (1989) reported that the types of injuries vary between acute sprains (19%), acute strains (17.7%), acute fractures (3.4%), and various overuse injuries (55.8%). Not only do many minor injuries occur, resulting in lost training time, but career-ending and even life-threatening injuries also occur (Stokstad, 2004).

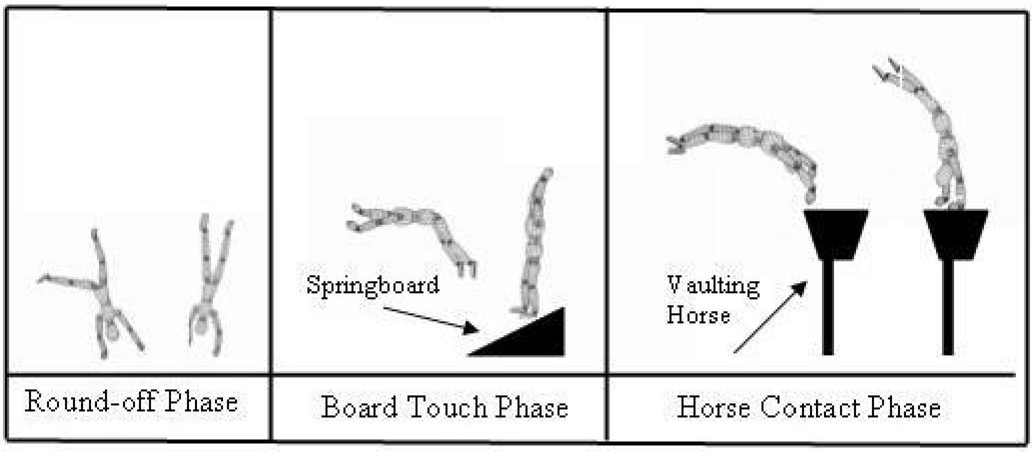

Figure 1. An illustration depicting the general motion of the initial phases of the Yurchenko vault; arrows indicate the location of the springboard and vaulting horse.

Researchers specifically associate the vault with various injuries, including upper-extremity injury (Caine et al., 1992; Lindner and Caine, 1990; Meeusen and Borms, 1992; Roy et al., 1985). Previous research implies that involved kinematics (linear and angular motion) and kinetics (internal and external forces) may be responsible for upper-extremity injuries during the vault (Caine et al., 1992; Roy et al., 1985). Vaults that transmit compression and rotational forces to the upper extremities particularly endanger the trailing upper extremity (Read, 1981).

In 1983 Natalia Yurchenko introduced the world to the Yurchenko vault, a round-off entry vault, at the World Championships in Budapest (Stokstad, 2004). The Yurchenko vault was identified as a skill containing increased difficulty, excessively high risk, and a potential for catastrophic injury. Within one year, high-risk factors motivated the United States Gymnastics Federation to ban the Yurchenko vault from all competition levels below the Olympic level (Stokstad, 2004); the National Collegiate Athletic Association also banned the Yurchenko vault (McAuley et al., 1987), but repealed the ban in 1998. Since the repeal of the ban, the number of participants performing the Yurchenko vault has increased tremendously. Despite these factors, a dearth of biomechanical research describing the kinetics of the Yurchenko vault exists.

Through the observation of reaction forces (RF) researchers accurately describe the magnitudes and loading rates of many of the external forces applied to the body (Nigg, 1985), and high RF have previously been identified as possible contributors to various gymnastics injuries (Hall, 1986; Koh et al., 1992). The primary purpose of this study was to quantify RF transmitted to the trail hand of high-level gymnasts during the round-off entry phase (the round-off just before the gymnast strikes the spring board) of the Yurchenko vault (Figure 1). Within the bounds of the present study, the trail hand was defined as the second hand to contact the competition floor; this was also the hand placed closest to the vaulting horse during the round-off.

To provide a direct comparison to another gymnastics skill that is also associated with a large number of upper-extremity injuries, RF during the round-off phase of the Yurchenko vault were compared to RF during a floor exercise round-off (the round-off immediately prior to a tumbling pass during the floor exercise). The floor exercise is also a gymnastics skill linked to a large number of upper-extremity injuries (Priest and Weise, 1981). Lindner and Caine (1990) identified the floor exercise event as the most hazardous gymnastics event and stated that round-offs performed during the floor exercise event were responsible for a large percentage of floor exercise injuries. By initially quantifying RF transmitted to the upper extremities of high-level gymnasts performing the Yurchenko vault and floor exercise, methods purporting to reduce RF transmitted to upper extremities during these skills may be better evaluated.

METHODS

Ten high-level, female gymnasts volunteered to participate in the present study. Within the bounds of the present study, a high-level gymnast was defined as any gymnast competing at level nine, ten, or elite, as ranked by the United States Gymnastics Federation. A gymnast ranked at level nine ranks in approximately the top 10% of all gymnasts competing in USA Gymnastics competitions. Level ten gymnasts rank in approximately the top 4% of all gymnasts competing in USA Gymnastics competitions. Elite gymnasts rank in the top 1% of

Table 1. Participant descriptors.

	Age (yrs)	Height (m)	Mass (kg)	Training time (hrs·wk^{-1})	Vaulting experience (yrs)
Mean (±SD)	18 (3)	1.59 (.06)	56 (6)	22 (2)	13 (4)
Range	13-21	1.50-1.68	50-67	20-24	4-17

all gymnasts competing in USA Gymnastic competitions (USA Gymnastics, 2004). Gymnasts competing at all three levels participated in this study. Each participant was training a minimum of 20 hours per week at the time data were collected and could successfully perform the Yurchenko vault prior to data collection. Eight participants were collegiate level gymnasts and two participants were competitive gymnasts, training at a local gymnastics club. All participants completed an informed consent form approved by the institution's ethics review committee. Participant descriptors are presented in Table 1.

Participants arrived at the Biomechanics Laboratory for a 1-hour data collection session. Prior to data collection participants were allowed time to execute warm-up exercises identical to those performed prior to competition. Participants then performed Yurchenko vault and floor exercise trials in a randomized order. Participant order and condition order were randomized using the random number generator function in Excel (Microsoft Corporation, Redmond, WA, USA). Each trail hand was coated with a thin layer of chalk prior to each trial to identify correct hand placement.

The vaulting and floor exercise environment were constructed of elite gymnastics equipment (American Athletic, Jefferson, IA, USA). To ensure representative data, environmental aspects were tailored to simulate the competition environment. Concerning the vaulting environment, a padded safety zone surrounded the springboard and safety mats surrounded the vaulting area to assure participant safety during warm-ups and data collection. A 40 X 60-cm force platform (Bertec, Colombus, OH, USA) was mounted at the end of the vault runway, flush to the runway surface. The floor exercise area was created to match tumbling parameters representative of the floor exercise event. Participants performed tumbling skills on a padded surface raised flush with the force platform. The force platform was mounted near the end of the tumbling area and was calibrated prior to all data collection sessions. All trials were performed in these settings.

A 152 X 305 X 3.8-cm 'Sting' mat (American Athletic, Jefferson, IA, USA) was placed over the force platform to create a representative environment during both conditions (Figure 2). The 'sting' mat is used in training and competition environments, and is specifically used while performing the round-off phase of the Yurchenko vault and round-offs during the floor exercise. The mat also effectively disguised the force platform during data collection trials. It is unlikely that peak RF magnitudes were substantially affected by placing the mat over the force platform (see discussion). Researchers ensured that the mat did not move during data collection using two methods. First, chalk was used to indicate the location of the force platform beneath the mat; following each trial, chalk markings ensured that the mat location, in comparison to the force platform, was congruent to that of the previous trial. Second, all trials were reviewed using a video camera (Panasonic AG 1880, Seacaucus, NJ, USA; video sampling rate was set at 60 Hz with a shutter speed of 400 Hz). The video camera was placed 5 m from the force platform and viewed the sagittal plane of motion. No mat movement was noted during video reviews.

Figure 2. A photograph showing the vaulting area; the 'Sting' mat is the thin, blue mat in front of the spring board. The force platform was located directly under the 'Sting' mat, indicated by the white rectangle in the center of the 'Sting' mat.

RF data were acquired and stored using DataPac III software (Laguna Hills, CA, USA). A single researcher collected RF data throughout the data collection process at a sampling rate of 500 Hz using a microcomputer with a CIO-DAS 16/330 analog to digital converter (Computer Boards Inc., Middleboro, MA, USA). Before participants contacted the force platform, a 3-s data collection period was manually initiated for each trial.

Sampling of the RF data began when a threshold value of 50 N was attained. Three acceptable trials were observed under both round-off conditions. Yurchenko vault trials were deemed acceptable when: (a) the approach was completed in < 4 s; (b) the entire trail hand was placed completely on the force platform, as determined by chalk markings and video; and (c) the Yurchenko vault was completed in a representative motion. Floor exercise round-offs were deemed acceptable when: (a) the approach was completed in < 2.5 s; (b) the entire trail hand was placed completely on the force platform, as determined by chalk markings and video; and (c) the remainder of the tumbling pass was simulated by completing the tumbling pass with two back handsprings. The time intervals of 4 s and 2.5 s were selected after timing numerous vaults and floor exercise tumbling passes in a competition environment. Trials under both conditions were ultimately deemed representative by a veteran collegiate vaulting coach and participants were encouraged to make each trial representative. The same video camera that was used to discern mat movement was also used to review questionable vaulting motion or hand placement.

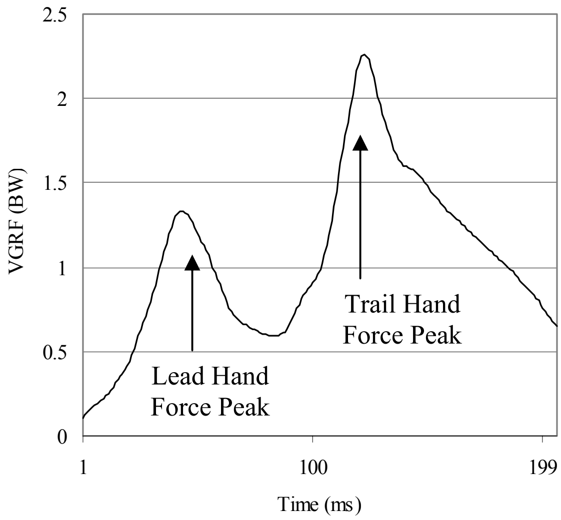

Figure 3. A bi-modal force trace depicting vertical reaction forces (VGRF), normalized to body weight (BW), transmitted to the trail hand and the lead hand during the round-off phase of the Yurchenko vault; this exemplifies instances when the trail hand and the lead hand contacted the force platform.

Peak vertical and anterior-posterior RF values during three acceptable trials were averaged. Medial-lateral RF during pilot studies were negligible and only anterior-posterior and vertical RF were considered during the present study. All RF values were normalized to body weight (BW). The rate of change of force was calculated between 10% and 90% of the time between initial contact and peak force, excluding the most initial and later portions of the loading period. A linear regression model was fitted to the data points and the slope of this regression line defined average loading rate, as was used by Markolf et al. (1990).

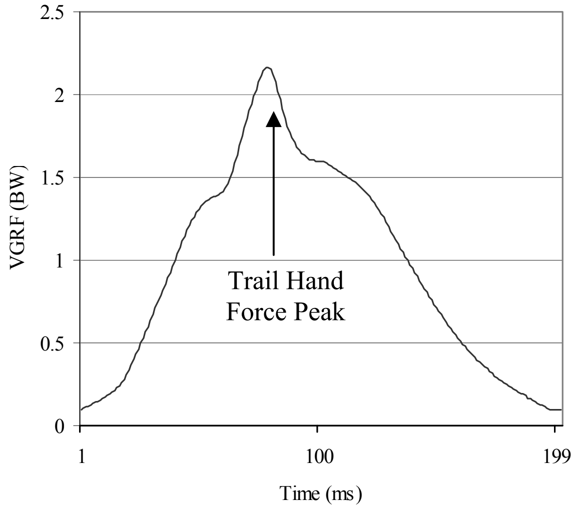

Figure 4. A force trace, containing only one peak and normalized to body weight (BW), depicting vertical reaction forces (VGRF) transmitted to the trail hand during the round-off phase of the Yurchenko vault; this exemplifies instances when only the trail hand contacted the force platform.

Requiring participants to place the trail hand not only directly, but solely on the force platform proved to be extremely difficult. During approximately two-thirds of all recorded trials the lead hand and trail hand contacted the force platform (the lead hand always contacted the force platform first), resulting in a bi-modal force trace (Figure 3). Bi-modal force traces varied from trials in which only the trail hand contacted the force platform (Figure 4). Although the bi-modal nature of the force traces did not affect peak RF measurements, the bi-modal nature prevented the calculation of average loading rate for any trial in which both hands contacted the force platform.

This study incorporated a within-subject design where every participant completed each condition. Statistical analyses included one independent variable comprised of two conditions. The conditions were (a) the round-off phase of the Yurchenko vault and (b) the floor exercise round-off. Conditions were used to manipulate two dependent variables: peak vertical and peak anterior-posterior RF. A multivariate statistic, Hotelling T^2, was used to determine the influence the two conditions of the independent variable had on peak vertical and anterior-posterior RF, as a group. Next, a paired t test was used to examine the effect each of the two conditions had on peak vertical and anterior-posterior RF individually. The probability of a Type I error was set at the 0.05 level for all observations and was adjusted using the Bonferonni Technique. Due to the aforementioned difficulty of calculating loading rate for many of the trials, only descriptive statistics were employed to analyze loading rate; 13 Yurchenko vault trials and 14 floor exercise trials were included in the loading rate analysis.

RESULTS

The multivariate analysis indicated that the conditions of the independent variable did have a significant effect on peak RF transmitted to upper extremities (T^2 = 555.0; F = 144.9; $p < 0.001$). Univariate analyses showed that vertical and anterior-posterior RF transmitted to the upper extremities were greater during the round-off phase of the Yurchenko vault than during the floor exercise round-off (Table 2). Mean peak vertical RF values during the round-off phase of the Yurchenko vault were 11% greater than during the floor exercise round-off. Mean peak anterior-posterior RF during the round-off phase of the Yurchenko vault were 30% greater than during the floor exercise round-off. Peak posterior RF (opposite to the direction of progression) were greater than anterior RF for each participant. Normalized to BW, the mean loading rate during the round-off phase of the Yurchenko vault and floor exercise round-off was 28.57 ± 6.67 and 19.15 ± 4.64 $BW·s^{-1}$, respectively.

DISCUSSION

The primary purpose of the present study was to observe RF transmitted to the upper extremities of high-level gymnasts during the round-off phase of the Yurchenko vault. A secondary purpose of this study was to compare the upper-extremity kinetics of the Yurchenko vault round-off phase to the upper-extremity kinetics of a floor exercise round-off. Results of the present study indicated that high-level gymnasts exhibit greater peak vertical and anterior-posterior RF during the round-off phase of the Yurchenko vault than during the floor exercise round-off.

Differences in RF magnitudes may have been due to differences of approach distance. Gymnasts performing the Yurchenko vault are allowed an approach distance of approximately 20 m. Gymnasts performing a tumbling pass, beginning with a round-off, during the floor exercise are limited to approach distances of approximately 7 m. Shorter approach distances during the floor exercise indicate less opportunity to accelerate, resulting in lower velocities at the time of the round-off. Equally important, may be the difference in the final portion of each skill. Gymnasts performing the floor exercise are required to stay within the limits of the floor exercise area and penalized for leaving established bounds. Conversely, gymnasts performing the Yurchenko vault have no such limits and are encouraged to vault as far and high as possible. This may also contribute to different approach velocities between the Yurchenko vault and floor exercise. Due to the small area (< 1 m^2) viewed by our video camera, approach velocities during the Yurchenko vault and floor exercise could not be calculated; this is a limitation of the study. Within the literature, horizontal velocity observed during the Yurchenko vault approach exists, but nothing has been reported describing the horizontal velocity during the floor exercise round-off approach. For these reasons a quantitative comparison of approach velocities was implausible. No other known study has observed RF transmitted to upper extremities during the Yurchenko vault. However, two groups of researchers examined RF transmitted to the upper extremities during the round-off or other comparable gymnastic skills

Table 2. Reaction forces, normalized to body weight, transmitted to the upper extremities of high-level gymnasts during the round-off phase of the Yurchenko vault and floor exercise round-off. (A/P = anterior-posterior). Data are means (±SD).

	Yurchenko Vault	Floor Exercise	p-value	Effect Size	Observed Power
Vertical reaction force	2.38 (.26) *	2.15 (.32)	.030	.64	.94
A/P reaction force	.78 (.12) †	.60 (.09)	.001	.84	1.00
Vertical reaction force range	2.11-3.00	1.67-2.60			
A/P reaction force range	.58-.94	.50-.72			

*Significantly different from floor exercise condition
†Significantly different from floor exercise condition

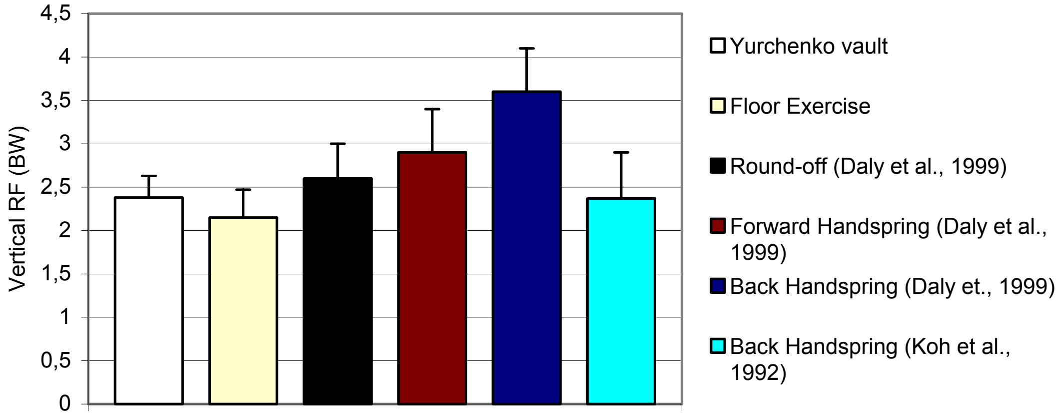

Figure 5. Peak vertical reaction forces (RF), normalized to body weight (BW), transmitted to the upper extremities during the round-off phase of the Yurchenko vault and floor exercise compared to previously observed round-offs, back handsprings, and forward handsprings.

(Daly et al., 1999; Koh et al., 1992). Despite differences between the Yurchenko vault and skills observed by Daly et al. (1999) and Koh et al. (1992), it is still worthwhile to compare results from the present study to results of the previously mentioned studies (Figure 5).

Daly et al. (1999) observed vertical and horizontal ground RF transmitted to the upper extremities of nine male gymnasts performing the round-off by fitting a force platform in a section of the spring floor used during the floor exercise. Mean peak vertical (2.60 ± 0.40 BW) and horizontal (0.70 ± 0.20 BW) ground RF, observed by Daly et al. (1999) during the round-off, are similar to vertical (2.38 ± 0.26 BW) and anterior-posterior (0.78 ± 0.12 BW) RF observed during the round-off phase of the Yurchenko vault. Ground RF observed by Daly et al. (1999) are also similar to peak vertical (2.15 ± 0.32 BW) and anterior-posterior (0.60 ± 0.09 BW) RF observed during the floor exercise round-off.

Koh et al. (1992) measured RF with a force platform under a 6-mm rubberized mat. RF observed by Koh et al. (1992) were defined slightly differently than those observed in the present study, but still merit comparison. Koh et al. (1992) defined a compressive force relatively as the component of the RF acting along the long axis of the forearm and the valgus/varus force as the component of the RF acting perpendicular to the long axis of the forearm. Mean peak compressive RF observed during a back handspring (2.37 ± 0.53 BW) are similar to mean peak vertical RF observed during the round-off phase of the Yurchenko vault (2.38 ± 0.26 BW) and floor exercise round-off (2.15 ± 0.32 BW). Mean peak valgus RF (0.18 ± 0.11 BW), observed by Koh et al. (1992) appear to be less than anterior-posterior RF observed during the present study. This may be explained by the slight difference in force vector direction definitions. Koh et al. (1992) stated that RF at the hand producing large compression forces create valgus moments at the elbow joint and may contribute to upper-extremity injuries. This certainly appears to apply during Yurchenko vault and floor exercise round-offs.

Researchers (Daly et al., 1999; Markolf et al., 1990) observed the magnitude and loading rate of RF transmitted to upper extremities during the pommel horse, an activity commonly linked to upper-extremity injury (Mandlebaum et al., 1989). Vertical RF observed during the present study were greater than RF observed during the pommel horse, as reported by Daly et al. (1.50 ± 0.30 BW) and Markolf et al. (1.6 BW). Mean loading rates during the pommel horse ranged from 5.2 BW·s^{-1} to 10.6 BW·s^{-1} (Markolf et al.,1990); the mean loading rates during the round-off phase of the Yurchenko vault (29.13 ± 7.97 BW·s^{-1}) and floor exercise round-off (20.41 ± 4.65 BW·s^{-1}) were much greater. Loading rates of these magnitudes are great for extremities that do not normally experience compression.

Although lower- and upper-extremity, weight-bearing activities are not easily compared, it is worthwhile to note that peak vertical RF during the round-off phase of the Yurchenko vault are similar to peak vertical ground reaction forces transmitted to the lower extremities while running and walking (Figure 6). Unlike lower extremities, upper extremities are poorly designed for weight bearing activities (Tuttle, 1969). Vertical ground reaction forces transmitted to the lower extremities are attenuated through several anatomical structures: a) large bones and muscles of the lower extremities, b) arches of the foot, and c) calcaneal fat pad. Shock is attenuated through the relatively large bones of the foot and shank, including the tibia and fibula. In comparison, a vertical RF transmitted to the wrist is

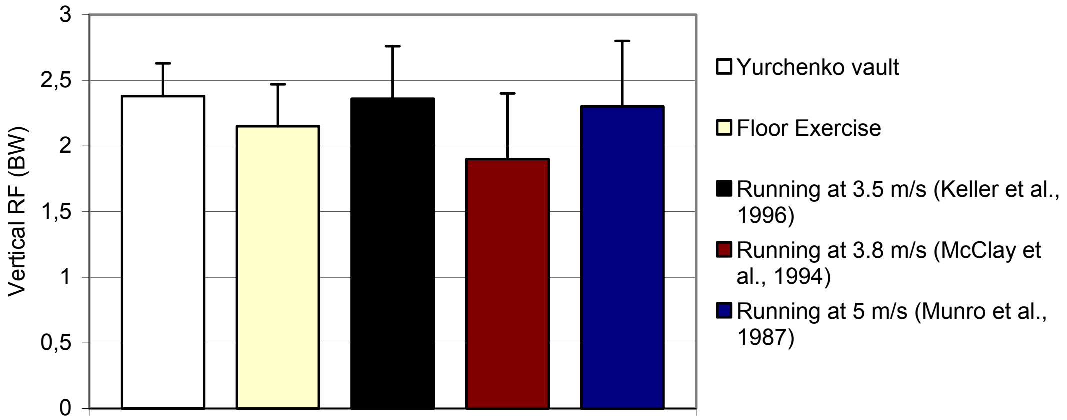

Figure 6. Peak vertical reaction forces (RF), normalized to body weight (BW), transmitted to the upper extremities during the round-off phase of the Yurchenko vault and floor exercise round-off compared to ground reaction forces transmitted to the lower extremities while running at various speeds.

attenuated only through minimal soft tissue, small carpal bones, and then to the radius and ulna, which are much smaller than the bones of the shank (Markolf et al., 1990). A second factor aiding in shock absorption is the complex system of ligament, muscle, and bone that make up the arches of the foot. These arches dissipate force before it is transferred across the ankle joint to the lower leg (Grabiner, 1989). Also, a special fat pad under the heel that has been shown to be approximately 20 mm thick protects the heel from impact generated shocks (Valiant, 1990). Well-cushioned running shoes, worn during most lower-extremity, weight-bearing activities also protect lower extremities from shock created by ground reaction forces (Wright et al., 1998).

The risk for injury in circumstances where upper extremities are absorbing vertical RF similar to those absorbed by lower extremities is apparent (Markolf et al., 1990). Forces observed in the present study create a situation similar to running on the hands. Similarities between observed forces transmitted to lower and upper extremities signal a warning flag for all upper-extremity weight bearing activities involving increased RF, including the Yurchenko vault and floor exercise.

The RF observed during the present study are great enough to cause upper-extremity injury. Researchers have previously identified force magnitudes capable of causing various upper-extremity injuries, including fractures of the distal radius (Frykman, 1967; Myers et al., 1993; Spadaro et al., 1994). A fracture of the distal radius is an injury common to gymnastics (DiFiori et al., 2002). In fact, two gymnasts performing at the institution where the present study was conducted suffered distal radial fractures while performing the Yurchenko vault prior to data collection. A comparison of the force magnitudes capable of fracturing the distal radius and forces observed during the present study is presented in Figure 7. Note that the vertical RF observed during the present study are comparable to fracture forces reported in aforementioned studies.

It was recognized that by placing the ‘Sting’ mat between the upper-extremities and force platform, only the ground reaction forces transmitted directly to the mat were measured. It was assumed that ground reaction forces applied directly to the mat were similar to RF transmitted to the upper-extremity. Özgüven and Berme (1988) studied this issue in detail by measuring the differences between ground reaction forces transmitted from a force platform to a 10-cm safety mat and the RF transmitted from the same 10-cm mat to the gymnast. No detectable differences in magnitude were found. McNitt-Gray et al. (2001) also addressed this issue by measuring the RF transmitted to gymnasts through 12-cm landing mats. McNitt-Gray et al. (2001) found that the difference between ground reaction forces transmitted to the mat and the RF transmitted from the mat to the gymnast were less than 5%. Other researchers (Arampatzi et al. 2002; McNitt-Gray, 1991) have shown that stiffness properties of a gymnastics mat have no effect on the peak magnitude of RF transmitted to the gymnast. Additionally, Nigg (1985) stated that any gymnastics safety mat < 40-cm in thickness would not affect the

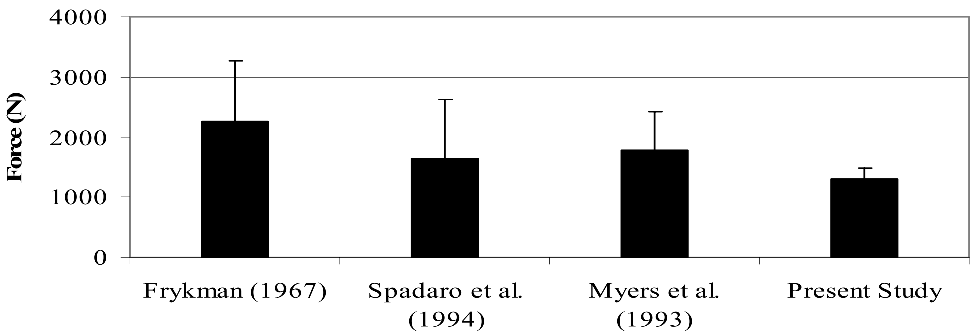

Figure 7. A comparison of the mean axial force necessary to fracture the distal radius and Yurchenko vault vertical reaction forces observed during the present study. Note the comparable nature of values observed during the present study and values reported by Spadaro et al. (1994) and Myers et al. (1993).

maximal peak RF recorded by a force platform located under the mat. Also, various safety mats have been placed over force platforms while measuring kinetic variables during gymnastic skills in previous studies (Daly et al., 1999; Hall, 1986; Koh et al., 1992). For these reasons, it was assumed that the 'sting' mat did not substantially affect measured peak RF magnitudes. It was recognized that the placement of the 'sting' mat over the force platform likely decreased the measured loading rate yet, because of the within-subject design of the study, descriptive comparisons were presumably not affected. Also noteworthy is the detail that, despite the difference in 'sting' mat and force platform dimensions, it is unlikely that, due to the compliant nature of the 'sting' mat, a non-negligible portion of the force applied to the mat by the gymnast was applied to the ground rather than the force platform.

It is admittedly difficult to link injury solely to RF during activity; although the concept is intuitive, a relationship between high forces and injury has been difficult to prove (Nigg and Bobbert, 1990). Although high RF are known to exist during the round-off phase of the Yurchenko vault, it is difficult to link high RF during the Yurchenko vault solely to upper-extremity injury. Kinematic variables, such as hyper-extension of the wrist or hyper-pronation of the proximal radioulnar joint, may also be responsible for injuries suffered during the Yurchenko vault. Injury may also be caused in other phases of the Yurchenko vault not examined during this study. Further research observing the upper-extremity kinetics involved in the round-off phase and other phases of the Yurchenko vault is necessary to identify specific etiology of Yurchenko vault injury. The inability of the present study to accurately portray the loading rate of RF transmitted to the trail hand is also a limiting factor. A methodology allowing the accurate description of loading rates during the Yurchenko vault should be developed. Future research identifying methods (technique changes or safety equipment implementation) to decrease peak RF and loading rates during the Yurchenko vault and floor exercise may also prove to be beneficial.

CONCLUSIONS

The present study quantified RF transmitted to the upper extremities of high-level gymnasts performing the Yurchenko vault and floor exercise. Results indicated that high-level gymnasts experience greater peak vertical and anterior-posterior RF during the round-off phase of the Yurchenko vault than during the floor exercise; both skills exhibited relatively high RF. The study reveals a need for further research considering methods to reduce RF transmitted to the upper extremities during the Yurchenko vault, floor exercise, and any other athletic skill where high RF are transmitted to the upper extremities. Data collected during the present study will serve as a baseline for future research considering the reduction of RF transmitted to the upper extremities in gymnastics.

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KEY POINTS

- Despite high difficulty and increased risk, a dearth of information exists concerning reaction forces transmitted to upper-extremities of high-level gymnasts performing the Yurchenko vault.
- Reaction forces experienced by high-level gymnasts performing the Yurchenko vault are relatively high; aforementioned forces are comparable to forces transmitted to lower-extremities during various activities and may be responsible for upper-extremity injury.
- Reaction forces observed during this study will serve as a baseline in the evaluation of methods purporting to reduce forces transmitted to upper-extremities during the Yurchenko vault.

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