

# Ground Reaction Forces Among Gymnasts and Recreational Athletes in Drop Landings

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**Objective:** To compare vertical ground reaction forces among gymnasts and recreational athletes during drop landings from 30-, 60-, and 90-cm heights.

**Design and Setting:** Two subject groups, intercollegiate gymnasts and college-aged recreational athletes, participated in this study. Subjects completed 10 landing trials onto a force platform at each height.

**Subjects:** Ten female competitive gymnasts (height = 1.57 ± 0.02 m, mass = 55.4 ± 7.3 kg) and 10 female recreational athletes (height = 1.63 ± 0.06 m, mass = 59.6 ± 4.9 kg) volunteered for this study.

**Measurements:** Measurements of first peak-force magnitude (F1), time to F1 (T1), impulse to F1, second peak-force magnitude (F2), time to F2 (T2), and impulse to F2 were compiled to describe the ground reaction force profile for each trial at 30-, 60-, and 90-cm platform heights. A 2 × 3 (group × height)

mixed-factors analysis of variance was calculated for each of the 6 variables.

**Results:** The group-by-height interaction was significant for F1, F2, and impulse to F2. Tukey post hoc analyses revealed significantly higher values for the gymnasts than for the recreational athletes at 60- and 90-cm heights for F1 and F2 magnitudes. Differences between groups for T1, T2, impulse to F1, and impulse to F2 were not statistically significant at any height.

**Conclusions:** Drop landings performed by female gymnasts at 60- and 90-cm heights exhibited higher vertical ground reaction forces than drop landings performed by female recreational athletes. High ground reaction forces experienced by gymnasts during landings may contribute to the incidence of lower extremity injuries.

**Key Words:** impact force, biomechanics, injury

Most injuries to gymnasts affect the lower extremity.<sup>1-13</sup> Garrick and Requa<sup>2</sup> found the ankle to be the most frequent site of trauma. However, Weiker<sup>13</sup> noted the most injuries to the knee, followed by the ankle. Petrone and Ricciardelli<sup>8</sup> observed a trend toward lower extremity injury, with the ankle and knee as the most frequent sites.

According to the 2002-2003 NCAA Sports Medicine Handbook,<sup>6</sup> gymnastics ranks second behind spring football for practice injury rate for all sports, with 6.2 injuries per 1000 athlete-exposures. For severity of practice injuries resulting in 7+ days of time loss, women's gymnastics again ranked second behind spring football. In a 5-year prospective study of collegiate women's gymnastic injuries, Sands et al<sup>10</sup> found that lower extremity injuries accounted for 49.51% of 509 new injuries. Low back injuries accounted for an additional 15.52%. As for the type of injury sustained, repetitive stress syndrome injuries were the most prevalent. In another prospective study of 50 highly competitive female gymnasts, the lower extremity injury rate was 63.7%. An additional 12.2% of injuries affected the low back.<sup>1</sup>

Landings are common in gymnastics and are a time in which many injuries occur.<sup>9,12</sup> Gymnasts often land with minimal flexion at the hip, knee, and ankle, which is normally a primary means of attenuating energy during landings.<sup>9,14</sup> These observations have raised questions as to whether landings by gymnasts are significantly different than landings of

other athletes when measured quantitatively, whether these differences influence the occurrence of injury, and whether interventions such as training programs in landing techniques can reduce injury occurrence. These questions have not been adequately addressed for female gymnasts.

To begin answering these questions, ground reaction force (GRF) data from landings must be studied so that differences in landing forces, if any, can be identified. The goals of our study were to (1) observe whether gymnasts exhibited higher GRFs than recreational athletes in drop landings, possibly predisposing gymnasts to lower extremity injury, (2) increase subject group size over previous studies, and (3) increase the number of trial repetitions, thereby increasing the reliability of data obtained. We compared the variables of the first (F1) and second (F2) peak vertical-force magnitudes, time to F1 (T1) and F2 magnitudes (T2), and F1 and F2 impulse between gymnasts and recreational athletes from drop landings at 30-, 60-, and 90-cm heights. The drop-landing protocol was selected because it offered a well-controlled experimental approach to investigating differences in landing forces.<sup>15</sup> The 30-, 60-, and 90-cm heights were selected for an incremental progression that encompassed heights similar to those used in other studies with different athletic populations.<sup>14-17</sup> We hypothesized that gymnasts would exhibit higher F1 and F2 magnitudes, shorter T2, and greater impulse to F2 than recreational athletes at each height.

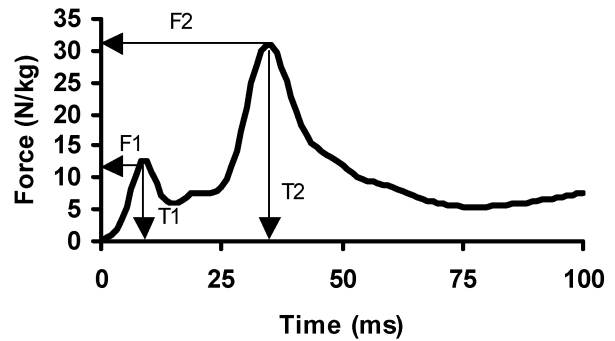
## METHODS

Twenty female students between 18 and 23 years of age volunteered as participants and provided informed consent as approved by the institutional review board, which also approved the study. A questionnaire was completed by each participant to quantify sport involvement, years and level of gymnastics experience, age, and injury history. All participants were free of injury or physical impairment at the time of data collection. Ten competitive gymnasts (height =  $1.57 \pm 0.02$  m, mass =  $55.4 \pm 7.3$  kg), all members of a National Collegiate Athletic Association Division I collegiate gymnastics team, had at least 8 years of gymnastics experience, with an average of  $12.6 \pm 2.8$  years. Ten recreational athletes (height =  $1.63 \pm 0.06$  m, mass =  $59.6 \pm 4.9$  kg) had previous involvement in organized sport or training programs that included jumping activities such as basketball, volleyball, and track but not competitive gymnastics. Recreational athletes were intentionally selected for height and weight characteristics similar to the gymnasts. Previous participation in plyometric or jump-landing technique instruction was not assessed.

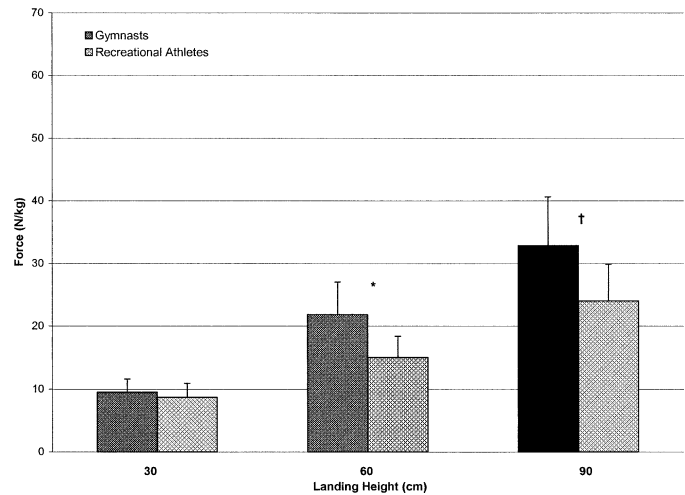
Landings were performed barefoot from 30, 60, and 90 cm with the trial height order randomized for each subject. Before data collection, subjects were allowed to practice the landing protocol 3 times at each height to familiarize themselves with the procedure. To collect landing data, we used a protocol similar to that of Devita and Skelly.<sup>14</sup> Wearing shorts and a sport bra, the subject stood on an adjustable platform located 21 cm from the back edge of the force plate. The toes of the left foot were extended over the edge of the platform, and the right leg was held over the force platform by slight flexion at the hip. Arms were held in 90 degrees of shoulder flexion in the sagittal plane. When stationary, the subject shifted forward to begin the drop landing. Each subject was instructed to land using her natural landing style with the right foot completely on the force plate, the left foot parallel to the right foot but off the force plate, and arms maintaining position.<sup>15,16,18</sup> Separate 1.6-cm rubber pads, similar to those used by Self and Paine,<sup>15</sup> were securely taped over the force plate and floor to provide a nonslip, visually identical landing surface. The rubber pads on the force plate, although a necessary safety precaution, are a limitation to our study and preclude use of our data for normative values.

Vertical GRF data were collected using a force platform (model OR6-5-6, Advanced Mechanical Technology, Inc, Watertown, MA), which was installed flush with the floor to ensure a safe landing surface. Using an amplified signal, we sampled data for each trial at 960 Hz using an analog-digital board (DT 2821, Data-Translation, Marlboro, MA) installed in a laboratory computer. Landing data were graphed on the computer monitor for each trial.

After completion of 10 trials from each height, force data were scaled to force in N/kg to account for differences in body mass among subjects, and 6 variables (F1, F2, T1, T2, and F1 and F2 impulse) describing the vertical GRF profile were compiled using laboratory software (Figure 1). The F1 and F2 magnitudes were assumed to be the peak vertical forces at toe contact and heel contact, respectively, and T1 and T2 indicated the times at which F1 and F2 occurred.<sup>18</sup> Impulse to F1 and F2 was calculated as the area under the GRF curve and reported in N/kg-s. For each subject, a 10-trial mean was calculated for each of the 6 vertical GRF variables at each of the 3 heights.



**Figure 1.** Representative ground reaction force curve. F1 indicates first peak vertical-force magnitude; F2, second peak vertical-force magnitude; T1, time to first peak vertical-force magnitude; and T2, time to second peak vertical-force magnitude.



**Figure 2.** F1 magnitude mean values ( $P = .001$ ) for each group at each height. \*Indicates significant difference between groups at 60 cm; †, significant difference between groups at 90 cm.

The 10-trial mean value of each subject for each variable was entered into a mixed-factor  $2 \times 3$  analysis of variance (between-subjects factor: group; within-subjects factor: height) for statistical analysis ( $\alpha = .05$ ). When appropriate, a Tukey post hoc analysis was performed to identify the source of a significant F ratio.

## RESULTS

No significant difference in F1 was noted between gymnasts ( $9.46 \pm 2.13$  N/kg) and recreational athletes ( $8.70 \pm 2.21$  N/kg) at the 30-cm height (critical  $Q = 2.97$ ,  $df = 18$ ) (Figure 2). However, F1 values at 60 cm ( $21.82 \pm 5.17$  N/kg) and 90 cm ( $32.84 \pm 7.81$  N/kg) were significantly higher for the gymnasts than for the recreational athletes at 60 ( $15.02 \pm 3.37$  N/kg) and 90 cm ( $24.00 \pm 5.85$  N/kg). No significant differences were seen between study groups at any height for time to F1 or F2 or F1 or F2 impulse (Tables 1 and 2).

The F2 magnitude between gymnasts ( $27.06 \pm 6.88$  N/kg) and recreational athletes ( $21.51 \pm 4.88$  N/kg) at the 30-cm height (critical  $Q = 2.97$ ,  $df = 18$ ) was not significantly different (Figure 3). However, F2 values for gymnasts at 60 cm ( $40.27 \pm 8.29$  N/kg) and 90 cm ( $56.00 \pm 10.75$  N/kg) were significantly higher than for the recreational athletes at 60 cm ( $26.98 \pm 6.28$  N/kg) and 90 cm ( $37.44 \pm 10.02$  N/kg). Within

**Table 1. Time to First (F<sub>1</sub>) and Second (F<sub>2</sub>) Peak Vertical Force for Gymnasts and Recreational Athletes at Each Height\***

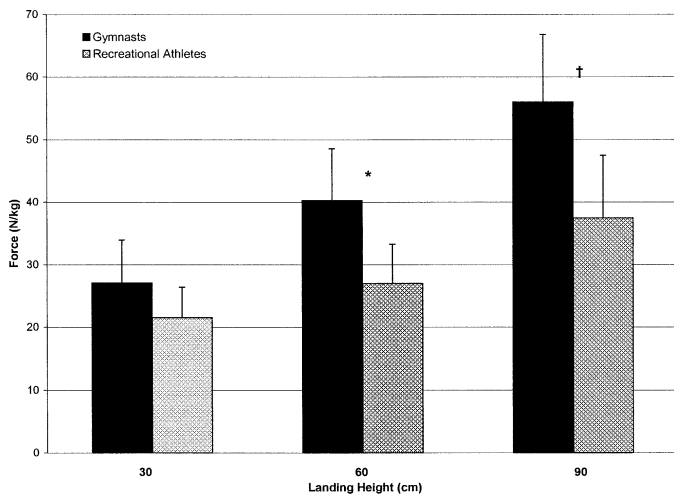
Group	Time to F <sub>1</sub> (s)			Time to F <sub>2</sub> (s)		
	30 cm	60 cm	90 cm	30 cm	60 cm	90 cm
<b>Gymnasts</b>						
Mean	0.016	0.011	0.010	0.057	0.045	0.038
SD	0.007	0.003	0.003	0.014	0.008	0.006
<b>Recreational athletes</b>						
Mean	0.018	0.012	0.010	0.065	0.050	0.042
SD	0.004	0.002	0.002	0.010	0.006	0.005

\*No significant differences were found between groups for time to F<sub>1</sub> or F<sub>2</sub> at any height condition.

**Table 2. F<sub>1</sub> and F<sub>2</sub> Impulse for Gymnasts and Recreational Athletes at Each Height\***

Group	F <sub>1</sub> Impulse (N/kg-s)			F <sub>2</sub> Impulse (N/kg-s)		
	30 cm	60 cm	90 cm	30 cm	60 cm	90 cm
<b>Gymnasts</b>						
Mean	0.071	0.075	0.084	0.612	0.735	0.778
SD	0.033	0.015	0.019	0.123	0.100	0.092
<b>Recreational athletes</b>						
Mean	0.074	0.067	0.076	0.673	0.678	0.727
SD	0.024	0.016	0.017	0.112	0.097	0.094

\*No significant differences were found between groups for F<sub>1</sub> or F<sub>2</sub> impulse at any height condition.



**Figure 3. F<sub>2</sub> magnitude mean values ( $P = .002$ ) for each group at each height. \*Indicates significant difference between groups at 60 cm; †, significant difference between groups at 90 cm.**

each group, F<sub>2</sub> increased significantly (critical  $Q = 3.47$ ,  $df = 36$ ) as height increased (gymnasts = 27.06 N/kg, 40.27 N/kg, 56.00 N/kg, and recreational athletes = 21.51 N/kg, 26.98 N/kg, 37.44 N/kg, at 30, 60, and 90 cm, respectively).

## DISCUSSION

Studies of GRFs in gymnasts during landings have been limited. McNitt-Gray<sup>16</sup> found no significant difference in the magnitude of vertical GRF, time to peak, or impulse charac-

teristics between male gymnasts and recreational athletes as they landed from different heights. However, with only 6 subjects per group and only 1 trial per subject at each height, the statistical power was low.<sup>19</sup> Additionally, use of a single trial as representative of general performance is questionable because variability is inherent in all human performance.<sup>20</sup>

In our study, at 60 and 90 cm, gymnasts demonstrated significantly higher F<sub>1</sub> and F<sub>2</sub> magnitudes than the recreational athletes. At 60 cm, gymnasts had 31% higher F<sub>1</sub> magnitudes and 33% higher F<sub>2</sub> magnitudes than the recreational athletes. At 90 cm, gymnasts had 27% higher F<sub>1</sub> magnitudes and 34% higher F<sub>2</sub> magnitudes than the recreational athletes. The mean gymnast F<sub>1</sub> and F<sub>2</sub> magnitude values at 60 cm were similar to those observed by Devita and Skelly<sup>14</sup> in stiff landings from 59 cm. The significant differences we observed in F<sub>1</sub> and F<sub>2</sub> magnitudes between gymnasts and recreational athletes at 60 and 90 cm partially support our hypothesis that gymnasts would exhibit higher F<sub>1</sub> and F<sub>2</sub> magnitudes than recreational athletes at 30-, 60-, and 90-cm heights.

The lack of a significant difference between groups for both F<sub>1</sub> and F<sub>2</sub> at the 30-cm height may be due to the height itself. Ayalon and Ben-Sira<sup>21</sup> noted that subjects appeared to be more careless in landing technique at 40 cm. McNair and Prapavesis<sup>17</sup> collected normative GRF data for 234 male and female competitive and recreational athletes at 33 cm. They used a 33-cm height to avoid causing lower limb injuries during data collection and so that subjects with previous lower limb injuries could tolerate the landing. They found no significant differences between groups. Self and Paine<sup>15</sup> compared GRF values for male recreational athletes at 30.48 cm using 4 landing techniques: (1) knees bent, natural landing; (2) knees stiff, natural landing; (3) knees stiff, absorb through plantar flexors; and (4) knees stiff, landing on heels. A knees-stiff landing on the heels produced significantly higher GRF values than the other 3 techniques, but GRFs for the other 3 landing techniques did not differ. Because the 30-cm height is so low, the lack of differences between groups at 30 cm was not extraordinary, even though it was not anticipated.

The results for T<sub>1</sub>, T<sub>2</sub>, and F<sub>1</sub> and F<sub>2</sub> impulse were not statistically significant between groups in our study at any height. These findings are consistent with those of McNitt-Gray,<sup>16</sup> who found no significant differences between male gymnasts and recreational athletes for these variables. However, with the larger group sizes and by including females in our study, we hypothesized that T<sub>2</sub> would be shorter and F<sub>2</sub> impulse would be greater in the gymnasts. An inverse relationship generally exists between the magnitude of peak vertical forces and time to peak magnitudes.<sup>19</sup> We expected that landings with greater F<sub>1</sub> and F<sub>2</sub> magnitudes would exhibit shorter T<sub>1</sub> and T<sub>2</sub> values, thereby affecting the F<sub>1</sub> and F<sub>2</sub> impulse as well. However, the only direct relationship between peak magnitudes and time to peak magnitudes was seen across the height condition. As the height increased, so did the F<sub>1</sub> and F<sub>2</sub> values. Corresponding T<sub>1</sub> and T<sub>2</sub> values indicated shorter times to peak magnitudes, as would be expected.

Although there were no significant differences in T<sub>1</sub> and T<sub>2</sub> or F<sub>1</sub> and F<sub>2</sub> impulse between the groups at any height, these unusual results can be explained as follows. The F<sub>1</sub> and F<sub>2</sub> magnitudes were higher for gymnasts than recreational athletes at 60 and 90 cm. However, differences between groups for T<sub>1</sub> and T<sub>2</sub> were not statistically significant, indicating similar landing contact patterns and landing phase durations. The F<sub>1</sub> and F<sub>2</sub> impulses are calculated from a combination of peak-

force magnitude and time to peak force. Although the F1 and F2 magnitudes were significantly greater for the gymnasts, compared with the recreational athletes, the slightly shorter times of T1 and T2 for the gymnasts resulted in similar impulse values to the 2 peak forces for the groups.

## CONCLUSIONS

We found it noteworthy that although both groups received the same landing instructions, gymnasts exposed themselves to higher GRFs at 60 and 90 cm than did recreational athletes. Given the higher GRF loads experienced by gymnasts during landings in our study, we suggest that repetitive exposure to high loads is one of the contributing factors to injury.

Furthermore, our results support the idea that not all athletes land with the same GRF magnitude, even when landing from the same height. By comparing GRF data of gymnasts with those of recreational athletes in a noncompetitive setting, we found that gymnasts land with higher impact forces than recreational athletes, raising concerns for repetitive stress injuries because of high-impact loading.

High-impact loads may be reduced if athletes in general, and gymnasts specifically, are instructed and trained in landing technique, thereby minimizing the injury risk from repetitive high vertical-impact forces on the lower extremity.<sup>20</sup> Instruction in landing technique has been shown to reduce landing impact loads in child and adolescent recreational athletes and gymnasts.<sup>17,22–24</sup> However, whether similar instruction would have the same effect with an older population of experienced athletes is unknown because their landing patterns may be more ingrained and less subject to change. It has been suggested that individuals can lower GRF values by performing landings using toe-heel contact patterns<sup>20,25</sup> or controlled landings without heel contact by increasing joint flexion,<sup>18</sup> but these ideas have not been sufficiently tested within a gymnast population to support a general recommendation.

In light of our findings, it seems necessary to perform a kinematic analysis to evaluate differences in lower extremity joint patterns between the 2 groups. Investigating the effects of training programs on landing behavior might also be useful in preventing lower extremity injuries.

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