TRAINING LOAD IN PRE-PUBERTAL FEMALE ARTISTIC GYMNASTICS

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Abstract

An understanding of the multiple factors affecting young gymnasts is required to assist in optimizing performance and injury prevention. We aimed to determine the effects of participation level (international and national level gymnasts), apparatus (beam and floor) and training phase (pre-competition and competition) on estimates of training load in 25 female artistic gymnasts (mean age 9.5, SD = 1.6 years, training age 1.9, SD = 0.7 years). Video analysis was used to determine frequency of observed gymnastic-specific movements involving estimates of ankle and wrist impacts, landings, balance-related skills, and rotations. To further estimate training load, 16 gymnasts performed sport-specific skills, on a portable force platform. Results from a series of ANOVAs showed training load differences between the two groups. Compared with national level gymnasts, international gymnasts demonstrated increased hours of training, and a greater frequency of observed impacts (independent of time). Differences were also observed between the two phases of periodised training in both participation levels however, international gymnasts followed a more refined training program. No between group differences were evident for ground reaction forces on the beam and floor. Periodisation and training load should be monitored objectively to assist in ensuring the longevity of athletes and ideally minimising injury risk.

Keywords: *gymnastics, pre-puberty, training load, periodisation, ground reaction force.*

INTRODUCTION

Female artistic gymnastics is a dynamic sport, habitually exposing young gymnasts to training programs higher in volume and intensity, than other sports for children of similar age. Intensive training at a young age may create complications for female gymnasts. Literature suggests a training load threshold exists in which gymnasts training more than 15 to 18 $hrs.wk^{-1}$ before and during puberty may experience decreased growth, resulting in reduced final adult stature (Theintz, Howald, Weiss, & Sizonenko, 1993). Training load in gymnastics is typically quantified by assessing weekly hours of gymnastics specific training. More research is needed to determine the type and magnitude of gymnastic-specific loading relative to non-elite or national level gymnasts.

In addition to reporting training load through weekly exposure, many gymnastics skills have been analysed to determine the specific impact loading on the skeleton. Ground reaction forces to both the upper and lower extremity have previously been recorded. The majority of these skills are advanced level skills and place forces of 13 to 14 times body weight on the skeleton (Brown et al., 1996; Panzer, 1987). Few intermediate skills have been assessed, with forces varying from two to four times body weight for the wrists (Daly, Rich, Klein, & Bass, 1999; Davidson, Mahar, Chalmers, &

Wilson, 2005; Koh, Grabiner, & Weiker, 1992) and 10 times bodyweight for the ankles (Daly et al., 1999).

Video analysis used to record the frequency of gymnastic-specific movements is another method used to quantify gymnastics loading. Gymnastic-specific movements including static, swing and impact movements have been used to quantify the frequency of gymnastics loading during different phases of training, for male international level gymnasts (Daly et al., 1999). To the best of our knowledge, similar techniques have not been conducted with female artistic gymnasts.

Phases of training, also known as periodised training typically consist of three phases; preparation, competition and transition (Bompa & Carrera, 2005). Gymnastics coaches are encouraged to follow periodised training programs for all aspects of the sport in order to prevent and minimise the risk of injury, optimise peak performance, and ensure adequate preparation and recovery (Brooks, 2003).

Impact forces and injury risk increase as a gymnast progresses through the competitive levels (Caine & Nassar, 2005). However, by following a periodised training program, ensuring gymnasts have adequate skill and strength requirements and by monitoring overall loading the risk of injury should decrease. As with any sport, injury resulting from gymnastics participation is inevitable. Within female artistic gymnastics, the floor apparatus is associated with the highest injury risk (Caine, Bass, & Daly, 2003; Kirialanis et al., 2002; Verhagen, Mechelen, Baxter-Jones, & Maffulli, 2000), followed by the balance beam (Caine, Cochrane, Caine, & Zemper, 1989; Petrone & Ricciardelli, 1987).

The present study uses a multidisciplinary approach, combining several sub-disciplines of sports science to understand more about gymnastics loading on pre-pubertal female artistic gymnasts. The primary goal of the study was to compare differences in frequency of observed gymnastic-specific movement patterns, independent of time, between two levels of gymnastics participation during the pre-competition and competition training phases. The secondary goal was to estimate ground reaction forces at the wrist and ankle associated with selected fundamental gymnastics skills and to determine if differences exist between high (international) and low (national) skilled gymnasts.

METHODS

Participants

Twenty-five pre-pubertal girls aged 7-13 years were recruited for this study. Participants comprised of an international levels training squad (*n* = 12) training an average of 26.42 $hrs.wk^{-1}$ (SD = 3.86 $hrs.wk^{-1}$) and an age-matched national levels squad (*n* = 13) training 13.85 $hrs.wk^{-1}$ (SD = 2.64 $hrs.wk^{-1}$). Participants were injury-free and had a minimum training age of one year in the sport of women's artistic gymnastics. Ethical approval was obtained from the University's Human Research Ethics Committee. Participants were volunteers from whom written parental consent and participant assent were obtained.

Procedures

Anthropometric Assessments

Anthropometric measures were recorded to assist in the description of participants. Gymnasts wore leotards during collection of anthropometric data. Body mass was recorded using digital scales (A & D Personal Precision Scale UC321) accurate to ± 0.05 kg. Standing and sitting height was measured using a stadiometer (Surgical & Medical Products, Melbourne, Australia) accurate to ± 0.001 metre. The measurement was taken as the maximum distance from the floor or bench to the vertex of the skull when the head was in the Frankfort Plane. Measures of standing height and body mass were used to calculate body mass index [weight (kg) / $height^2$ (m)].

Questionnaires

Parents and guardians of gymnasts completed a survey profiling their daughters' gymnastics specific and total physical activity. For descriptive purposes, parents also estimated the pubertal stage of development of their daughter using a pictorial representation of Tanner's five stage model of pubertal maturation (Duke, Litt, & Gross, 1980; Schmitz et al., 2004; Tanner, 1968).

Video Analysis

Four separate training sessions of gymnasts from the national and international levels groups were recorded using two JVC digital video cameras (GR-DVL820EA). Two recorded sessions occurred in the competition phase of the periodised training program and two in the pre-competition phase. To quantify training load the frequency of gymnastic-specific elements during floor and beam training was retrospectively recorded through video analysis of individual gymnasts during training. The gymnastic-specific elements of wrist and ankle impacts were denoted by any rebound contact with the floor or beam for less than one second. For example, a cartwheel was identified as two wrist and two ankle impacts. The remaining elements observed during sessions included: balance (any pose or hold maintained for greater than three seconds), landing (contact with the floor or beam for three seconds), and rotation (movement around any of the three body axes). The frequency of these elements during time-matched beam and floor sessions was recorded for both the international and national gymnasts.

Ground Reaction Forces

To further estimate training load, a uni-axial Kistler Quattro Jump portable force platform (9290AD, Kistler Instruments Corp., Amherst, NY) sampling at 500 Hz was used to quantify the impact of loading through wrists and ankles during selected gymnastic skills performed on floor and beam apparatus. A random sub-sample of gymnasts from the international (n = 8) and national (n = 8) levels groups were selected to perform skills on the force platform. Floor skills performed on the platform included: a jump full turn, split leap, round-off, back flip and handspring. Beam skills performed on the force platform included: straight jump, split jump, handstand, backward walkover and cartwheel. When performing beam skills a 0.1 m wide balance beam guide was created using magnesium carbonate chalk on matting placed over the force platform. Only skills that were deemed by an accredited and experienced gymnastics coach to be satisfactory on the actual apparatus were accepted for analysis. Skills performed on the force platform were selected based on the ability of gymnasts from both groups to execute the skills safely and successfully. During training, international gymnasts were not limited to performing fundamental skills and would therefore be performing skills with higher ground reaction forces than those selected for analysis.

The force platform setup was surrounded with safety matting to maximise gymnasts' safety and simulate a typical training environment. A pilot reliability study showed the effect of the matting on the force output was consistent during both static (R^2 = 0.915) and dynamic (R^2 = 0.965) trials producing systematic attenuation of forces across all conditions. Therefore, the matting responded in a uniform fashion for all gymnasts, without affecting force output.

Statistical Analysis

Following tests for normal distribution, a series of independent t-tests or non-parametric equivalent tests were applied to detect any baseline differences between gymnastics groups. Similar tests were used to compare results from dependent variables in the two levels of participation and across the two phases of the periodised training program. Force plate data were analysed the same way. For descriptive purposes effect size and 95% confidence intervals were calculated.

A three-way (3 x 2) ANOVA was used to compare differences in observed loads for two participation levels (international and national), two training phases (pre-competition and competition), and two apparatus (beam and floor). Specifically, loads consisted of wrist and ankle impacts, balance, landings, and rotations. Following Pearson's correlation, multiple linear regression analyses were used to assess the contribution of independent variables (participation level, training phase and apparatus) to the observed variability in the dependent variables. Statistical significance was set at an alpha level of $p \leq 0.05$. Statistical analyses used SPSS, (version 17.0, SPSS Inc, Chicago, Ill.).

RESULTS

Independent *t*-tests showed the two levels of gymnastics participation compared favourably for age, mass, standing and sitting height, body mass index, and training age (Table 1). Non-parametric data of pubertal status were assessed using Mann-Whitney *U* test. No differences occurred between the international and national groups for proxy reports of pubic hair and breast development. Total weekly hours of gymnastics training was the only variable showing significant difference between groups.

Table 1. *Descriptive characteristics for international and national level female artistic gymnasts*

	International Gymnasts *Mean (SD)*	National Gymnasts *Mean (SD)*	*p* Value
Age (yr)	9.25 (1.86)	9.77 (1.24)	0.426
Mass (kg)	27.66 (4.83)	30.46 (5.23)	0.179
Standing Height (cm)	130 (10)	135 (8)	0.158
Sitting Height (cm)	69 (4)	71 (4)	0.139
Body Mass Index (kg.m^2)	16.12 (1.04)	16.45 (1.08)	0.446
Training Age (yr)	1.92 (0.79)	1.85 (0.69)	0.814
Gymnastic Training (hr.wk^{-1})	26.42 (3.86)	13.85 (2.64)	<0.0001*
Pubertal Status (Tanner stage 1 to 5)	1[a]	1[a]	1.000

[a] Median values reported following Mann-Whitney *U* test
* Denotes significant difference

Gymnastic-Specific Movement Patterns

The overall trend for ankle impacts and balance related skills was to increase from pre-competition to competition for both groups of gymnasts. International gymnasts were exposed to fewer impacts, landings and rotations during competition than pre-competition, whereas the national gymnasts were exposed to more. Overall, when comparing the two groups of gymnasts for the same duration, international gymnasts had higher frequencies of observed gymnastic-specific movements (Table 2).

Table 2. *Frequency of accumulated gymnastic-specific movement patterns observed within a 30 minute training session during the pre-competition and competition phases on the beam and floor apparatus*

	International Level Gymnasts				National Level Gymnasts			
	Beam		Floor		Beam		Floor	
	Pre-comp	Comp	Pre-comp	Comp	Pre-comp	Comp	Pre-comp	Comp
Wrist Impact [abc]	93.08 (29.14)	63.50 (22.10)	86.75 (14.77)	60.79 (22.48)	37.73 (15.99)	57.77 (19.92)	30.38 (10.89)	35.27 (13.63)
Ankle Impact [abc]	143.79 (34.58)	87.92 (22.19)	108.85 (30.19)	106.83 (31.55)	79.92 (18.58)	90.91 (24.64)	54.88 (17.51)	65.55 (12.98)
Landing [abc]	10.95 (6.34)	8.54 (4.95)	21.20 (5.42)	13.83 (4.90)	9.29 (5.51)	7.77 (3.60)	13.15 (9.32)	16.50 (5.29)
Balance [abc]	8.47 (6.47)	26.63 (16.34)	0	11.00 (8.33)	6.83 (7.09)	3.90 (1.41)	1.40 (0.55)	2.21 (1.05)
Rotation [a]	92.13 (25.04)	83.33 (21.25)	107.80 (18.59)	81.92 (13.21)	42.62 (17.50)	64.50 (22.67)	52.46 (16.68)	60.18 (22.13)

Data presented as mean (standard deviation)
[a] denotes main effect for group – international vs national ($p<0.05$)
[b] denotes main effect for apparatus – beam vs floor ($p<0.05$)
[c] denotes main effect for training phase – pre-competition vs competition ($p<0.05$)

Participation level demonstrated the strongest main effect with all dependent variables reaching significance. Main effects for apparatus and training phase were also present for all dependent variables, with the exception of rotation (Table 2). Interaction effects from the three-way ANOVA for all dependent variables are shown in Table 3. A participation level x training phase interaction effect showed the strongest two-way relationship, with all dependent variables achieving significance. Two three-way interactions were observed for ankle impacts [$F(1, 180) = 18.925$, $p < 0.0001$] and landings [$F(1, 173) = 4.831$, $p = 0.006$].

Linear regression analyses were conducted following significant Pearson's correlation coefficient effects. Regression analyses revealed the strongest predictor ($R^2_{adj} = 51.1\%$) of observed variability in rotations was participation level [$F(1, 94) = 100.453$, $p < 0.0001$]. During data entry, international gymnasts were assigned the value "1" and national gymnasts "2". Consequently, the rotation regression equation [$y = (-38.426 * \text{participation level}) + 129.002$] represented a negative relationship between participation level and rotations. Specifically, international gymnasts executed a higher frequency of rotations compared with national gymnasts.

Table 3. *Female artistic gymnastics, interaction effects for a three-way ANOVA*

	Interaction Effects			
Dependent Variables	Participation Level x Apparatus	Participation Level x Phase	Apparatus x Phase	Participation Level x Phase x Apparatus
Wrist Impact	0.069	<0.0001*	0.313	0.101
Ankle Impact	0.033*	<0.0001*	0.001*	<0.0001*
Landing	0.409	0.001*	0.979	0.006*
Balance	0.001*	<0.0001*	0.490	-
Rotation	0.454	<0.0001*	0.008*	0.802

* Denotes significant difference

Explained variance in dependent variables was weak to moderate, ranging from 34% to 51%. Therefore, other factors in addition to participation level, apparatus and training phase must have influenced the dependent variables.

Ground Reaction Forces

Mean peak ground reaction forces (PGRF) are reported relative to body weight and displayed in Table 4. Independent *t*-tests revealed no differences between the estimates of ankle and wrist forces in international and national gymnasts for any of the selected skills. The floor apparatus routinely exposed gymnasts to greater forces relative to body weight than the beam. Similarly, the lower extremities were exposed to greater PGRF than the upper extremities, across both apparatus. On the beam, the split jump exposed the ankles of gymnasts to the highest PGRF (international gymnasts M = 4.51, SD = 1.09 times body weight; national gymnasts M = 5.50, SD = 1.20 times body weight). The ankle impact associated with the round-off demonstrated the highest PGRF on the floor for the international (M = 8.06, SD = 1.33 times body weight) and national (M = 8.46, SD = 2.04 times body weight) level gymnasts.

Training Load

Training load differences were evident between participation level, hours of training and the frequency of observed gymnastic-specific skills. For gymnastic-specific movement patterns, international level gymnasts generally recorded higher frequency of observed movements within a standardized 30 minute training period. Participation level also had a major influence on all gymnastic-specific skills and training phase. Ankle impacts were the most sensitive measure of gymnastic-specific movements. Frequency of ankle impacts varied according to participation level, apparatus and training phase.

Overall training load is higher for international than national level gymnasts. International gymnasts are exposed to ground reaction forces up to 14 times body weight (Panzer, 1987) and train 26 $hrs.wk^{-1}$. Female national gymnasts are typically exposed to forces up to 10 times body weight (Daly et al., 1999) and train 14 $hrs.wk^{-1}$. In addition to increased loading through exposure time and ground reaction forces, international level gymnasts performed more gymnastic-specific movement patterns than national gymnasts, within a matched time period. Therefore, when total hours of participation, frequency of movement patterns and ground reaction forces are considered, loading was substantially greater for international level gymnasts.

There was an absence of between group differences for measured ground reaction forces. These results differ from previous studies who reported higher vertical ground reaction forces among highly skilled gymnasts compared with recreational athletes/non-gymnasts (McNitt-Gray, 1991; Sabick, Goetz, Pfeiffer, Debeliso & Shea, 2006), although tasks were not gymnastics specific.

Table 4. *Peak ground reaction forces, relative to body weight, applied to the wrists and ankles for specific fundamental beam and floor gymnastics skills*

	International *Mean (SD)*	National *Mean (SD)*	Effect Size	Δ 95% CI	P Value
Beam Skills					
Straight Jump (ankles)	4.51 (1.09)	5.50 (1.20)	0.86	-0.988 -2.21 – 0.24	0.106
Split Jump (ankles)	5.89 (1.04)	5.59 (1.29)	0.26	0.296 -0.96 – 1.55	0.620
Handstand (wrists)	1.30 (0.20)	1.30 (0.14)	0	0.001 -0.18 – 0.18	0.988
Handstand (ankles)	1.66 (0.25)	1.82 (0.27)	0.61	-0.154 -0.43 – 0.13	0.260
Cartwheel (wrists)	1.04 (0.13)	1.17 (0.20)	0.77	-0.135 -0.32 – 0.05	0.135
Cartwheel (ankles)	2.04 (0.26)	2.31 (0.41)	0.79	-0.276 -0.65 – 0.09	0.132
Backward Walkover (wrists)	1.55 (0.34)	1.33 (0.25)	0.74	0.226 -0.97 – 0.55	0.155
Backward Walkover (ankles)	1.86 (0.24)	2.03 (0.18)	0.80	-0.172 -0.40 – 0.06	0.131
Floor Skills					
Back Flip (wrists)	4.10 (0.36)	3.99 (0.72)	0.19	0.109 -0.52 – 0.74	0.714
Back Flip (ankles)	5.87 (1.13)	6.09 (1.25)	0.18	-0.128 -0.60 – 1.17	0.739
Handspring (wrists)	2.41 (0.76)	2.37 (0.67)	0.06	0.045 -0.73 – 0.82	0.902
Handspring (ankles)	7.88 (1.46)	8.25 (2.53)	0.18	-0.370 -2.59 – 1.85	0.726
Round off (wrists)	2.19 (0.38)	1.99 (0.40)	0.51	0.204 -0.21 – 0.62	0.132
Round off (ankles)	8.06 (1.33)	8.46 (2.04)	0.23	-0.398 -2.24 – 1.45	0.651
Split Leap (takeoff)	3.41 (0.46)	3.30 (0.52)	0.22	0.108 -0.42 – 0.64	0.670
Split Leap (landing)	4.65 (0.93)	4.08 (0.50)	0.76	0.561 -0.24 – 1.36	0.156
Jump Full Turn (ankles)	5.03 (0.78)	4.79 (0.88)	0.29	0.238 -0.65 – 1.13	0.576

Training Load - Frequency

Of the three independent variables (participation level, apparatus, and training phase), participation level appeared to have the strongest influence on observed variability in skills involving rotations and wrist impacts. These dependent variables may be strongly associated with participation level due to the more refined skill demands required for success as participation level increases. For example, more skilled gymnasts perform a greater number of wrist impacts by combining discrete skills into a serial sequence (tumbling row) and single rotations progress to double rotations. The increased impact loads associated with international level gymnasts, occurred independent of hours of participation.

Ankle impacts and landings revealed three way interactions. Among international level gymnasts, observations of fewer ankle impacts on beam during the competition phase than the pre-competition phase could be synonymous with more “whole” versus “part” practice. Training for international level gymnasts involved a relatively high demand for connective dance elements, combined with more serial skills. The skill quality contrast may partially explain the interaction for participation and training phase in observations of lower limb skills. Furthermore, the absence of apparatus-based differences in ankle impacts for national level gymnasts may suggest a more limited skill base to practice and perfect during the two training phases.

In contrast, observed landing frequencies increased for both apparatus between the two phases of training for international level gymnasts. Observed frequencies almost doubled on beam compared with floor and perhaps partially explain previous reports of high injury rates on the beam (Caine et al., 1989) and with landings (Kirialanis et al., 2002), at least with the international level gymnasts. Increased landings were also observed between the pre-competition and competition phases of training for national level gymnasts. However, trends differed as the increases in the competition phase were greater on floor than beam. Additional landings occurred during competition for both groups which could be attributed to the injury preventative strategy of landing in foam pits in the pre-competition phase of training when skills are still being refined. During this study, landings into the foam pit were disregarded due to a lack of impact and control during contact. Participation level and apparatus interactive effects of greater landings on beam for international than national level gymnasts may be attributed to an advanced capacity for flight-based skills on the beam and perhaps a greater need to practice more advanced skills and dismounts repetitively, even during the competition phase.

Training Load – Ground Reaction Forces

No differences in ground reaction force relative to body weight were observed between high (international) and low (national) skilled gymnasts. It is possible forces relative to body weight observed in the present study, may have differed between groups if skills could have been assessed during a sequence of skills or movements, such as a tumbling row. Instead, skills were assessed in isolation. Furthermore, between group differences may have emerged if dismounts from the beam (approximately 0.9 – 1.2 m high) were assessed (McNitt-Gray, 1991).

The ground reaction forces reported in the present study compared favourably with previous reports on male gymnasts (Daly et al., 1999). Vertical ground reaction forces at the wrist (Daly et al., 1999) ranged from 1.5 to 3.6 times body weight for male gymnasts compared with 2.0 to 4.1 times body weight on the floor apparatus in the present study. Similarly, the ankle was exposed to higher ground reaction forces than the wrist, four to ten times body weight for the young male gymnast (Daly et al., 1999) and three to eight times body weight in the female gymnasts from the current study. The forces recorded on the floor for the present study should be similar to the results of the previous study (Daly et al., 1999) as three of the same skills were analysed. Additionally, participants were approximately the same age, height and mass. Impacts within the present study on young female gymnasts were substantial and frequent and may have consequences for enhancing musculoskeletal growth (Daly et al., 1999) and, or, contribute to reported injuries (Seegmiller & McCaw, 2003).

Training Load – Periodised Training

Periodised training was defined from the results of the present study by the recognised variation in training volume (observed frequency of gymnastic-specific movements) between phases. The two groups of gymnasts demonstrated discernable differences in periodised training for the pre-competition and competition training phases. However, periodised training was more evident in international level gymnasts than national level gymnasts. Specifically, international level gymnasts decreased their observed gymnastic-specific movement patterns from the pre-competition to competition phase, whereas national level gymnasts increased their movement patterns. This may be due to the general increased duration of training for international level gymnasts who subsequently distribute skill practice across a greater volume of time.

Future Research

The present study provides sufficient results to justify further studies involving the entire periodised year. Although, to capture specific training phases such as transition or tapering before competition, an international group may be required. Comparisons between participation groups could also be further enhanced by the expansion of the present research to prospective injury monitoring and analysis of sequential activity involving more apparatus.

A limitation of the current study was the ability to include only the two most injurious apparatus across two phases of the periodised year. As training load on the vault and uneven bars was not reported, total training load has been under reported. Furthermore, response variables such as heart rate and RPE were not assessed simultaneously with training load.

A more extensive range of gymnastics skills, ability to capture skills in sequence or as a dismount from an apparatus may be required to demonstrate between group differences for ground reaction forces. Skill quality from an accredited judge was not assessed in conjunction with quantitative impact forces. Future studies could benefit from the addition of quality assessment and joint kinematic data concurrent with ground reaction force measurements in which skills are performed in sequence or tumbling series.

CONCLUSION

Independent of time, differences exist in estimates of training load for international and national level gymnasts performing on floor and beam apparatus. These between group differences existed in different phases of the periodised year and across apparatus. International level gymnasts were exposed to a higher frequency of impacts than national level gymnasts across both apparatus throughout the periodised program. This effect was even more pronounced with the greater hours of exposure and higher impact forces to "loading" opportunities.

Ground reaction forces associated with national level gymnastics skills were lower than those previously reported for international level gymnastics skills. Between group differences were not evident in performing fundamental gymnastics skills for higher and less skilled gymnasts.

Coaches must be aware that as the frequency and magnitude of impacts increase, there is a greater need to implement and follow a periodised training program. Such a program should ensure the longevity of athletes and minimise the risk of injury.

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