INFLUENCE OF SHORT-TERM GROWTH ON MECHANCIAL RISK INDICATORS IN FEMALE GYMNASTS

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Female gymnasts have increased vulnerability to chronic injuries during heightened growth. The study aimed to further understanding of the influence of growth rate and morphological growth rate on mechanical risk indicators over a 12 month period. Biomechanical measurements were taken during the performance of handstand and forward walkover skills at three time points. Bicristal to biacromial ratio measurements informed the division of the gymnasts into ‘high’ and ‘low’ growth groups. Greater mean mechanical risk indicator differences were found when the cohort was divided according to morphological growth rate. Large effects (η_P^2>.14) were found between time points for 88% of mechanical risk indicators. The importance of the shape and size of growth, along with the value of longitudinal monitoring of gymnasts was subsequently emphasised.

KEY WORDS: morphology, growth rate, injury screening

INTRODUCTION: The instigation of training as young as five years of age is customary for female artistic gymnasts. Chronic and strenuous performance-induced demands, which occur simultaneously to the underlying process of growth have been acknowledged to heighten the injury susceptibility of the young gymnasts’ (Caine and Maffulli, 2005). Associations of growth with chronic back pain (CBP) and chronic spinal injuries (CSI) have contributed to the accepted vulnerability of young gymnasts throughout the growth period; however, exploration of the influence of growth on female gymnasts’ injury susceptibility is yet to undergo rigorous scientific study. Biomechanical variables such as lordotic posture (Bugg *et al.*, 2011) and instability (Pajek and Pajek, 2009), are established risk indicators for CBP and CSI. Subsequently, extended biomechanical insights into the factors which influence the respective variables are important for the development of etiological understanding along with effective CBP and CSI prevention strategies.
In accordance with Tanner (1962), the quantification of growth in children and adolescence should be inclusive of both size and shape. Such qualities are commonly neglected, for example the measurement of growth through use of height. However, the bicristal to biacromial ratio is one growth measure which suffices Tanner’s recommendation. An additional feature of many growth-based studies is the use of cross-sectional data, for example, Siatras *et al*. (2009); within such research, the dynamic nature of growth is disregarded. Extended insight into the influence of longer term monitoring of growth measurements on mechanical risk factors may offer valuable insight for musculoskeletal screening practice within vulnerable populations. The aim of this study was to subsequently develop understanding of the influence of changes in the rate of growth, along with morphological growth rate, on mechanical risk indicators across a 12 month longitudinal testing period within young female gymnasts. The purpose for undertaking the research was to inform musculoskeletal screening protocols, with focus on injury prevention techniques. It was hypothesised that morphological growth rate (shape and size) would advance biomechanical understanding of CBP and CSI risk, in comparison with growth rate (size). In addition, the gymnasts with heightened growth were predicted to be of increased risk to CBP and CSI development; finally, longitudinal data were hypothesised to influence mechanical risk indicators.

METHODS: Participants: A longitudinal approach was taken, for which, biomechanical data were collected from eight healthy female artistic gymnasts at an initial testing point (time point a), and at subsequent 7.1 ± 1.2 month (time point b) and 12.4 ± 0.5 month intervals (time point c). At time point a, the gymnasts were aged between 9 and 15 years (12.0 ± 2.3 years) with height and mass of 1.43 ± 0.15 m and 41.55 ± 12.79 kg. The height and mass of the gymnasts was 1.48 ± 0.13 m and 45.90 ± 12.85 kg at time point b (*n*=7) and 1.47 ± 0.13 m and 45.82 ± 13.57 kg at time point c (*n*=8). Ethical approval was gained from Cardiff Metropolitan University; at each collection point, parental consent and participant consent/assent were obtained.

Data collection: A maximum of 20 quasi-static handstand and 20 dynamic forward walkover skills were performed in each of the repeated testing sessions by each gymnast. A Cartesian Optoelectronic Dynamic Anthropometer (CODA Charnwood Dynamics, Ltd.) motion analysis system was used for the collection of three-dimensional coordinate data (sample rate: 100Hz) of markers located on each limb and the trunk, with emphasis on the lumbar spine. Simultaneous ground reaction force data were obtained using a Kistler 9287BA force plate (sample rate: 1000Hz). Anthropometric measurements were acquired for each gymnast using an image-based approach presented by Gittoes *et al*. (2009), while mass data were measured during quiet standing using a force plate.

Data processing and analysis: All data were input into Visual 3D software (C-motion, Rockville, MD, USA), in which gymnast-specific customised models were created. The period of hand balance was of interest in each skill (the time in when neither foot was in contact with the floor). The hand balance phase of the handstand skill was considered to be initiated at foot release from the floor and terminated when the centre of mass exceeded the anterior-posterior base of support. For the forward walkover, the entire hand-balance phase was analysed. Determined in accordance with residual analysis calculations, coordinate and ground reaction force data were filtered using a second order Butterworth filter at 10Hz and 120Hz respectively. For each trial, lordotic posture, which was determined by the sagittal plane angle between a L1 to L3 lumbar segment and L3 to L5 segment, and anterior-posterior centre of pressure were calculated. General stability (dynamic postural stability index, DPSI) and lumbo-pelvic stability (dynamic lumbo-pelvic stability index, DLPSI) were defined using ground reaction force and lumbo-pelvic angles respectively and calculated using the approach outlined by Wilkstrom *et al.* (2005). The risk indicators were selected to represent important exposure factors identified from an extensive critique of existing literature. Bicristal to biacromial breath ratio data were derived from inertia image data for each gymnast at each time point.

Post-processing, the gymnasts were divided into 'high' and 'low' growth groups according to the rate of growth of the ratio measure (disregarding directional change; *n*=4 in both groups), and separately for morphological growth rate (*n*=3 in low growth (negative ratio) group and *n*=5 in the high growth (positive ratio) group). Gymnast-specific data were averaged across time points to subtract the influence of time, from which, the relative difference between the high and low growth groups were calculated for each grouping approach. The calculation of relative difference between low and high growth groups was determined using the formula ((low growth – high growth)/(1 – high growth)). A factorial repeated measures analysis of variance was applied to examine the short-term longitudinal influence of grouping on mechanical risk indicators. Statistical analyses were performed using IBM SPSS Statistics 20.

RESULTS: Across the mechanical risk indicators for both skills, greater differences between the high and low groups were evident when divided according to morphological growth rate as oppose to growth rate. Subsequently, the responses of the morphological growth rate groups were further explored across the three time points and are summarised in Table 1. Overall, the high growth group demonstrated greater risk than the low growth group in the handstand skill, with typically lower anterior-posterior and lumbo-pelvic stability, in addition to increased lordotic posture (mean differences of 9.50 mm, 3.71 and 3.23° respectively). However, with the exception of lumbo-pelvic stability, the forward walkover produced opposing outcomes.

No significant difference (p>.05) between time or group were identified for any of the mechanical risk indicators; however, each mechanical risk indicator showed a large effect (η_P^2>.14) for time or group, or both (Table 2).

Table 1
Mean ± SD for sagittal lumbar lordosis (posture), general stability (DPSI), anterior-posterior stability (AP CoP) and lumbo-pelvic stability (DLPSI) across the three time points (a, b and c) for high and low morphological growth rate (MGR) groups

	Time Point A		Time Point B		Time Point C	
	High MGR	Low MGR	High MGR	Low MGR	High MGR	Low MGR
Handstand						
Posture (°)	-1.62 ± 6.12	3.23 ± 3.44	-4.54 ± 7.72	-1.63 ± 4.34	-3.48 ± 5.98	-1.56 ± 9.25
DPSI	16.84 ± 14.99	26.05 ± 15.68	26.65 ± 18.07	26.24 ± 15.73	37.37 ± 25.55	35.53 ± 17.07
AP CoP (mm)	74.44 ± 23.88	67.90 ± 13.98	53.78 ± 5.63	64.49 ± 21.82	55.43 ± 14.35	79.77 ± 24.44
DLPSI	14.88 ± 7.04	7.53 ± 2.38	12.13 ± 6.67	8.74 ± 2.34	11.63 ± 5.57	11.25 ± 5.48
Forward Walkover						
Posture (°)	-15.01 ± 11.40	-15.31 ± 10.31	-19.81 ± 2.05	-14.02 ± 3.15	-7.96 ± 7.63	-11.89 ± 4.65
DPSI	42.37 ± 22.39	45.01 ± 19.47	45.86 ± 16.80	55.41 ± 22.53	52.37 ± 22.10	59.91 ± 29.59
AP CoP (mm)	100.26 ± 31.31	78.91 ± 24.77	141.93 ± 89.17	72.30 ± 32.40	81.94 ± 44.05	70.75 ± 2.62
DLPSI	16.64 ± 4.04	13.41 ± 3.13	16.32 ± 6.02	14.73 ± 2.23	12.63 ± 3.30	27.71 ± 14.67

Overall, time was shown to have a greater influence on the mechanical risk indicators (88% large effects) over the morphological growth rate groupings (50% large effects). Large effect sizes (between .157 and .209) were reported for anterior-posterior general stability and lumbo-pelvic stability between the high and low growth groups for both the handstand and forward walkover.

Table 2
Significance (sig) and partial eta squared (η_P^2) factorial-repeated measures ANOVA outputs for time and group for each mechanical risk indicator

		Time (sig)	Time (η_P^2)	Group (sig)	Group (η_P^2)
Handstands	Posture	.515	.233	.428	.108
	DPSI	.249	.427	.856	.006
	AP CoP	.274	.404	.332	.157
	DLPSI	.931	.028	.269	.198
Forward Walkovers	Posture	.108	.590	.865	.005
	DPSI	.132	.555	.671	.032
	AP CoP	.523	.228	.288	.185
	DLPSI	.333	.356	.256	.208

Shaded values indicate large effect sizes (>.14) in accordance with Cohen (1988)

DISCUSSION: The physical process of growth is recognised to increase the susceptibility of female gymnasts to CBP and CSI. In an attempt to develop understanding for injury screening and prevention purposes, the study aimed to explore the influence of short-term changes in the rate of growth and morphological growth on mechanical risk indicators across a 12 month time period within young female gymnasts. Each hypothesis was accepted with the exception of the finding that the low morphological growth group showed increased risk in the forward walkover skill. The division of the cohort in accordance with morphological growth rate typically heightened mean differences between the high and low growth groups, when compared to the growth rate grouping approach. The findings are subsequently supportive of Tanner's (1962) emphasis on the inclusion of size and shape for the measurement of growth. The negative morphological growth ratio (low growth) indicated that the gymnasts' shoulders were broadening at an increased rate to the hips; conversely, those gymnasts with a positive morphological growth rate (high growth) showed similar ratio trends to the general population (Siatras *et al.*, 2009). Morphological growth grouping was shown to have large effects for specific mechanical risk indicators, with lumbo-pelvic stability being the only variable in the handstand skill with an effect size of <.228 for time. Consequently, the inclusion of the morphological measure in musculoskeletal screening approaches may be advocated. Gymnasts' morphological growth profiles may subsequently offer valuable insight

into their predisposition to CBP and CSI through use of a simplistic methodology that is readily employable by practitioners. The high morphological growth rate group were explicitly found to have greater biomechanical risk for the handstand skill (for all mechanical risk indicators other than general stability), yet the biomechanical risk of the group for all variables apart from posture was lower than the low growth group when measured in the forward walkover skill. These findings indicate scope for practitioners to be able to counteract the morphological growth changes by focusing on quasi-static skill posture and stability development in gymnasts' who exhibit high morphological growth and the enhancement of dynamic skill posture and stability for those with a low morphological growth rate.
The study further demonstrated the importance of short-term longitudinal collections on gaining insight into mechanical risk indicators in the respective cohort. The influence of time on the majority of mechanical risk indicators identified in the current study challenges the protocols used in current pre-season screening approaches, which employ single event measures ('snap-shots') (Batt *et al*., 2004). Consequently, the study findings advocate the use of longitudinal measurements throughout the period of growth in vulnerable female gymnast samples, as a result of the dynamic alterations of body proportions and the subsequent influence of injury susceptibility. The grouping approach used offered valuable insight into the mechanical impact of growth; however, further interrogation of individual responses, in addition to supplementary risk indicator analysis, is anticipated to extend understanding of the implications of growth on CBP and CSI risk in female gymnasts.

CONCLUSION: The rate of change of morphological growth has emerged as a notable screening measure for ensuring effective insights into differing mechanical risk indicators between young, vulnerable female gymnasts. The need for consideration of gymnasts' size and shape in the monitoring of CBP and CSI susceptibility has been demonstrated, thus, the integration of the bicristal to biacromial ratio into current screening approaches used by applied sports practitioners is advocated. The longitudinal monitoring of growth in young gymnasts was further highlighted as a potentially important screening mechanism for CBP and CSI. The study findings are anticipated to be of use to coaches and sport science practitioners who are subsequently focused on the development of injury screening protocols in attempt to identify those gymnasts at increased risk of CBP and CSI.

REFERENCES:
Batt, M.E., Jaques, R. & Stone, M. (2004). Preparticipation examination (screening): practical issues as determined by sport: a United Kingdom perspective. *Clinical Journal of Sport* Medicine, 14(3), 178-182.

Bugg, W.G., Lewis, M., Juette, A., Cahir, J.G. & Toms, A.P. (2011). Lumbar lordosis and pars interarticularis fractures: a case-control study. *Skeletal Radiology*, 41(7), 817-22.

Caine, D.J. & Maffulli, N. (2005). Epidemiology of children's individual sports injuries. *Epidemiology of Pediatric Sports Injuries. Individual Sports, Basel: Medicine and Sport Science, Karger,* 48, 1-7.

Cohen, J. (1988). *Statistical power analysis for the behavioural sciences* (2nd ed.). New Jersey: Lawrence Erlbaum.

Gittoes, M.J.R., Bezodis, I.N. & Wilson, C. (2009). An image-based approach to obtaining anthropometric measurements for inertia modeling. *Journal of Applied Biomechanics*, 25(3), 265-270.

Pajek, M. B. & Pajek, J. (2009). Low back pain and the possible role of pilates in artistic gymnastics. *Science of Gymnastics Journal*, 1(1), 55-61.

Siatras, T., Skaperda, M. & Mameletzi, D. (2009). Anthropometric characteristics and delayed growth in young artistic gymnasts. *Medical Problems of Performing Artists*, 25(2), 91.

Tanner, J.M. (1962). *Growth at Adolescence* (2nd ed.). London: Blackwell Scientific Publications Ltd.
Wilkstrom, E.A., Tillman, M. D., Smith, A.N. & Borsa, P.A. (2005). A new force-plate technology measure of dynamic postural stability: the dynamic postural stability index. *Journal of Athletic Training*, 40(4), 305-309.

Acknowledgement
This research was funded by Cardiff Metropolitan University and Sport Wales.