Science of Gymnastics Journal

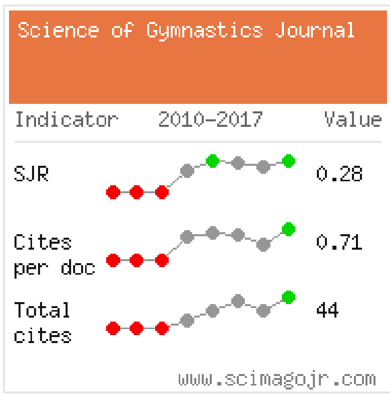
vol. 11, num. 2, year 2019

Published by Department of Gymnastics, Faculty of Sport, University of Ljubljana ISSN 1855-7171

Science of Gymnastics Journal (ScGYM®)

Science of Gymnastics Journal (ScGYM®) (abrevated for citation is SCI GYMNASTICS J) is an international journal that provide a wide range of scientific information specific to gymnastics. The journal is publishing both empirical and theoretical contributions related to gymnastics from the natural, social and human sciences. It is aimed at enhancing gymnastics knowledge (theoretical and practical) based on research and scientific methodology. We welcome articles concerned with performance analysis, judges' analysis, biomechanical analysis of gymnastics elements, medical analysis in gymnastics, pedagogical analysis related to gymnastics, biographies of important gymnastics personalities and other historical analysis, social aspects of gymnastics, motor learning and motor control in gymnastics, methodology of learning gymnastics elements, etc. Manuscripts based on quality research and comprehensive research reviews will also be considered for publication. The journal welcomes papers from all types of research paradigms.

Science of Gymnastics Journal is indexed in
Web of Science (ESCI data base, since 2015), EBSCOhost SPORTDiscus, SCOPUS, COBISS (IZUM), SIRC (Canada), ERIHPLUS, OPEN. J-GATE, GET CITED, ELECTRONIC JOURNALS INDEX, SCIRUS, NEW JOUR, GOOGLE SCHOLAR, PRO QUEST and INDEX COPERNICUS.
ScGYM® (ISSN 1855-7171) is an international online journal published three times a year (February, June, October).



Front page design: Sandi Radovan, Slovenia.

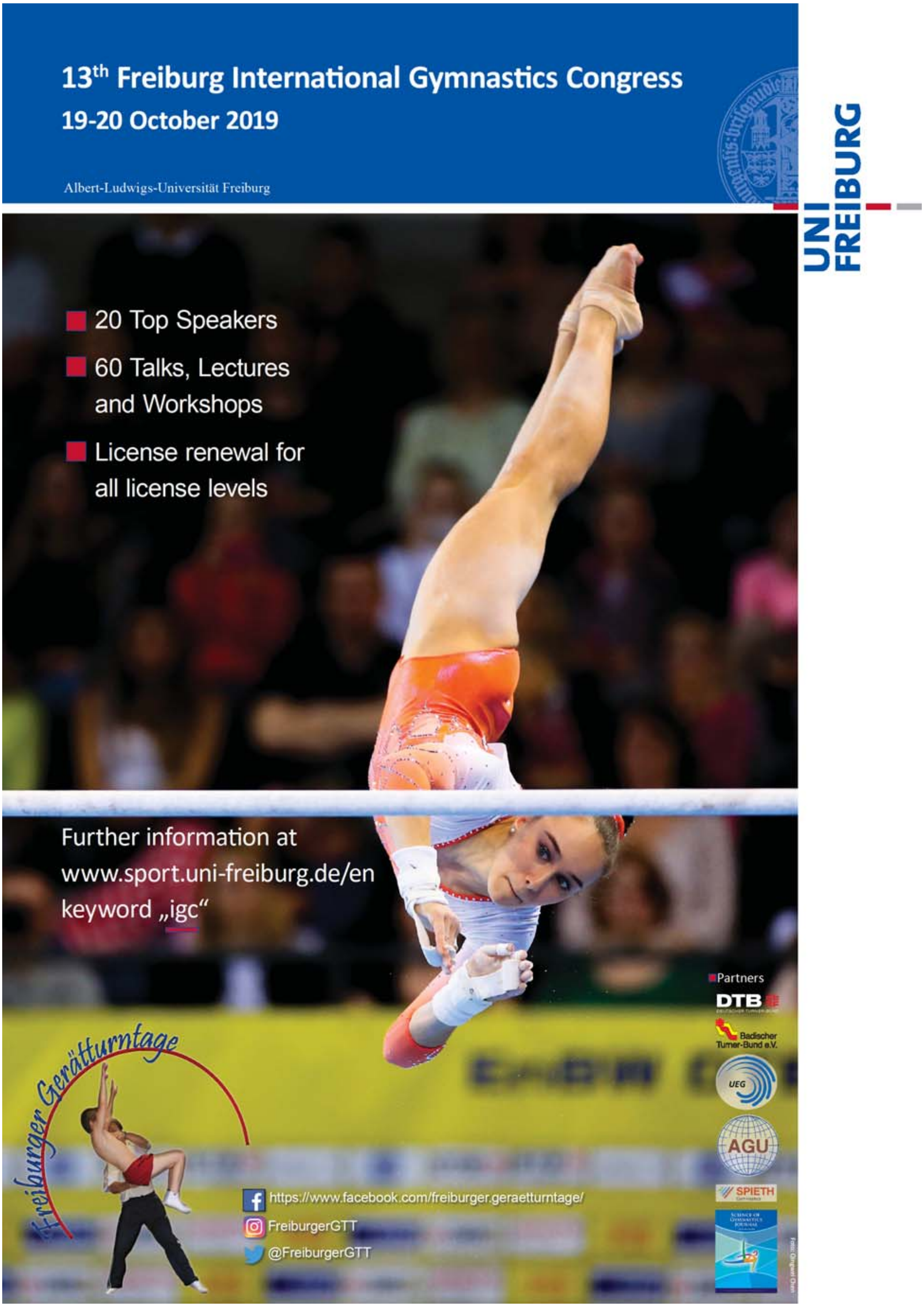
Editorial Office Address
Science of Gymnastics Journal
Faculty of Sport, Department of Gymnastics
Gortanova 22, SI-1000 Ljubljana, Slovenia
Telephone: +386 (0)1 520 7765
Fax: +386 (0)1 520 7750
E-mail: scgym@fsp.uni-lj.si
Home page: http://www.scienceofgymnastics.com

Science of Gymnastics Journal is supported by Foundation for financing sport organisations in Slovenia, Slovenian Research Agency and International Gymnastics Federation.

Fundacija za šport

Slovenian Research Agency

CONTENTS


13th Freiburg International Gymnastics Congress
19-20 October 2019
Albert-Ludwigs-Universität Freiburg
UNI FREIBURG
20 Top Speakers
60 Talks, Lectures and Workshops
License renewal for all license levels
Further information at www.sport.uni-freiburg.de/en keyword „igc“
Freiburger Gerätturntage
https://www.facebook.com/freiburger.geraetturntage/
FreiburgerGTT
@FreiburgerGTT
Partners
DTB
Badischer Turner-Bund e.V.
UEG
AGU
SPIETH

EDITORIAL

Dear friends,

The European Union has changed its approach toward scientific publications and we have to respect the new guidelines. The most important guideline is that all scientific articles have to be openly accessible. While our journal already has open access to articles, we will try to number articles by digital object identifier (DOI) by the end of the year. It will be slightly more work, but generally we will still be able to publish three issues per year.

At the end of May new journal evaluations have been published in SCOPUS. Unfortunately, our citation has been placed slightly lower than last year, but our SNIP indicator has risen and thus our journal is now in the second quarter of journals. An excellent result!

In this issue, we have again ten articles by authors from Brazil, Portugal, Canada, Greece, Denmark (for the first time), Bulgaria (for the first time), Great Britain, Japan, Croatia, Germany, the USA, the Czech Republic and Slovakia. There is a variety of research fields and it is good to see that there is a lot of productive international cooperation among researchers. Among articles on gymnastics disciplines, most are dealing with the man and the women artistic gymnastics; we are proud that for the first time we have an article from TEAMGYM, a discipline that is gaining momentum in Europe.

Anton Gajdoš prepared another article related to the history of gymnastics, refreshing our information on Albert Azarjan, an excellent Armenian (ex Soviet Union) gymnast.

Please be welcome to Freiburg to 13th International Gymnastics Congress.

Just to remind you, if you quote the Journal, its abbreviation on the Web of Knowledge is SCI GYMN J.

I wish you pleasant reading and a lot of inspiration for new research projects and articles,

Ivan Čuk
Editor-in-Chief

MOTOR PERFORMANCE OF BRAZILIAN FEMALE ARTISTIC GYMNASTS: INSIGHTS VIA MULTILEVEL ANALYSIS

Sarita Bacciotti [1,2,], Adam D.G., Baxter-Jones[4], Adroaldo Gaya[5], José Maia[1]

[1] Faculty of Sport, University of Porto, Portugal
[2] Physical Education Course, Federal University of Mato Grosso do Sul, Campo Grande, Brazil
[3]CAPES Foundation, Ministry of Education of Brazil, Brasília—DF, Brazil
[4] College of Kinesiology, University of Saskatchewan, Canada
[5] Department of Physical Education, Federal University of Rio Grande do Sul, Porto Alegre, Brazil.

Original article

Abstract

The aim of this research was to investigate individual and club-level variables that explain individual differences in gymnasts´ motor performance (MP). The sample was comprised of 249 female gymnasts (68 elite; 181 non-elite), aged between 9 and 20 years, split into four age categories: 9-10 years (n=98); 11-12 years (n=72); 13-15 years (n=64), and 16 and above (n=15). Gymnasts were from 26 Brazilian clubs, from six different states. The Talent Opportunity Program physical ability total test score was used to assess gymnasts' MP, based on a battery of seven tests: handstand hold, cast, rope climb, press handstand, leg flexibility, leg lift, and 20 meter sprint. Anthropometric, body composition, biological maturation, and training history data were also collected, as were club dimensions, infrastructures, competitions, manpower, and availability of selection/talent programs. Data were analyzed using a multilevel modelling approach. Individual gymnast' characteristics explained 39% of physical ability score variance from which 32% was related to the independent effects of age, competitive level, fat free mass, occurrence of menarche, and trainings hours per week (p<0.05). Club characteristics explained 61% of gymnasts' total variance in physical ability score; 96% of this amount was related to club dimension, manpower, and talent program. These results reinforce the relevant role of the contextual effects and highlight the need to invest in club infrastructures: ideally in coaches' expertise and effective selection programs. Such investments should enable the enhancement and development of a gymnast's careers during their lifetime involvement in training and competition.

Keywords: *physical fitness, performance, gym club.*

INTRODUCTION

Elite women artistic gymnasts (WAG) differ from their peers in their: physique aesthetics, explosive power and specialized skills, and their technical perfection in each of the elements (Bradshaw, Hume, & Aisbett, 2011). Although gymnast's high performance levels may express different genetic endowments (Morucci, Punzi, Innocenti, Gulisano, Ceroti, & Pacini, 2014), it is also acknowledged that performance is related to training conditions, continuous competition engagement, and coaching excellence (Côté, 1999).

It has always been challenging to assess gymnasts' motor performance (MP), apart from specialized skill-oriented tasks (Marina, Jemni, & Rodriguèz, 2013). A gymnast's physical attributes (Bajin, 1987; Vandorpe, Vandendriessche, Vaeyens, Pion, Lefevre, Philippaerts et al., 2011) interact with, and reflect, motor components (Sands, 2011), with the greatest emphasis's placed on strength and explosive power, flexibility and artistry (Bale & Goodway, 1990). The putative MP measurements are made difficult by having a complex set of parameters such as technical skills, muscular contractions and speed of stretch (Monèm, 2011). However, test batteries to assess MP have been developed to identify specific gymnastics motor profiles (Albuquerque & Farinatti, 2007), and to identify giftedness amongst gymnasts (Bajin, 1987; USA-Gymnastics, 2014). The new 2014 Talent Opportunity Program (TOP) offers a comprehensive test battery for gymnastics and it has been suggested that the resulting scores (TOPS total score - TTS) could be used in talent identification programs (USA-Gymnastics, 2014).

Since gymnasts spend considerable amounts of their sport life time training in their clubs, it is likely club infrastructures, competition schedules, number and quality of coaches, as well as selection programs may affect their MP. For example, manager/coach, pay/salary and training conditions ((Kayani, Zia, & Abbas, 2012), human resources in achieving organizational objectives, the relationship between human resources and sports performance ((Mihaela, Veronica, & Dana, 2014), and the joint effects of individual and group level covariates (Hill, Stoeber, Brown, & Appleton, 2014; (Petitta, Jiang, & Palange, 2015) have all been shown to be related to a gymnasts performance.

The aim of this research was to investigate individual and club-level variables that explain individual differences in gymnasts´ motor performance (MP).

METHODS

The sample comprises 249 female gymnasts [68 elite (EG); 181 non-elite (NEG)] aged 9-20 years. They were separated into four age categories according to the Brazilian Gymnastics Federation competition rules (CBG, 2015): 9-10 years (n=98); 11-12 years (n=72); 13-15 years (n=64), and ≥16 yeas (n=15). Gymnast were classified as EG or NEG using the following criteria: NEG are those who participated in regional or state championships, or competed at the national championship but were classified below the 10th position (all-around classification); EG are those who either participated in national championship and had been classified between the 1st and the 10th position in the final ranking (all-around classification), or who had participated in international championships. Gymnasts were selected from 26 Brazilian gymnastics clubs, representing ~60% of all clubs in a state. Clubs were selected based on their participation and classification in the 2014 Official Brazilian Championships. All gymnasts included in the study (Table 1) were identified by their coaches and were part of the main team in each club. The study protocol was approved by the ethics committee of Dom Bosco Catholic University (CAAE 42967215.9.0000.5162), as well as by the technical director of all the Gymnastics Clubs. Written consent forms were obtained from parents or legal guardians of gymnasts, as well as assent from all gymnasts.

The Talent Opportunity Program physical ability testing score (TTS), (USA-Gymnastics, 2014) was calculated from a battery of seven MP test: handstand hold; cast; rope climb; press handstand; leg flexibility; leg lift; and 20 meter sprint. Each of the 7 test scores was scored between 0-10 points, except leg flexibility which was scored between 0-12 points. The upper limit of the TTS is 72 points, and a higher score indicates better MP.

All anthropometric measurements were made according to standardized protocols (Ross, & Marfell-Jones, 1991). Height and sitting height were measured to the nearest 0.1cm using a portable stadiometer (Sanny Stadiometer, SP, BR) with the head positioned in the Frankfurt plane. Body mass (Kg) was measured with a portable bio-impedance scale (Tanita SC 240 Body Composition Analyser scale, IL, USA) with a 0.1kg precision. Leg length was calculated as the difference between standing height and sitting height. All measurements were performed at the beginning of each training session.

Body composition was estimated from regression equations provided by the manufacturer of the bio-impedance Tanita SC 240 scale (Tanita SC 240 Body Composition Analyser scale, IL, USA) which were unavailable to researchers. In the present study, fat mass (Kg), free fat mass (Kg), and percent fat (%Fat) were considered.

Biological maturity was obtained using data from menarche occurrence (yes or no) as well as from predicting age from (maturity offset) the attainment of peak height velocity (PHV) using a anthropometric variables (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002). In girls, the predictive equation is: Maturity Offset=-9.376 + 0.0001882 * leg length and sitting height interaction + 0.0022 * age and leg length interaction + 0.005841 * age and sitting height interaction - 0.002658 * age and weight interaction + 0.07693 * weight by height ratio. A positive (+) maturity offset indicates the number of years the participant is beyond PHV, whereas a negative (-) maturity offset represents the number of years the participant is prior to the attainment of PHV.

Athletes answered questions regarding their onset of training, training years, onset of competition, as well as the number of training hours per week. These answers were cross-checked with their parental as well as coaches' reports. When inaccuracies were found, we relied on the information provided by the coach.

Information about all gymnastic clubs was obtained via questionnaire which was developed in accordance with an expert panel of gymnastics coaches and researchers from Brazilian and Portuguese clubs and Sport Sciences colleges. It was centered on 5 domains: (1) club dimensions; (2) infrastructures; (3) competition; (4) manpower; (5) selection/talent programs. Club managers or persons with similar functions answered all questions.

Club dimensions (CD) recorded information about the total number of women artistic gymnasts (WAG) practicing at the club. A dummy coding schema was used to categorize the responses: CD=0 if up to 50 gymnasts (reference category); CD=1 if between 51 to 150 athletes; CD=2, if 150+ gymnasts. Further, the number of gymnasts per team was assessed (GPT). GPT=0 if gymnasts ≤6 (reference category); GPT=1 if 7 to 10 gymnasts; and GPT=2, if >10 gymnasts.

Infrastructures included questions about the exclusive use of the club for gymnastics, availability of complete sets of WAG apparatuses and Pit (foams' pool for security used in the end of or under gym apparatuses) in the gym. These variables were binary coded 1=yes or 0= no.

In this domain questions were related to WAG lifetime (LT) in the club. This was coded in the following way: LT=0 if up to 4 years (reference category), LT=1 if 5 to 10 years, and LT=2 if ≥11 years. Participation in international competitions was also recorded, binary coded as 1=yes or 0=no.

Manpower included questions about the amount of WAG coaches (C): C=0 if <=to 4 coaches, and C=1 if >4 coaches. Further, coaches experience (CE) was also recorded in years, in competitive WAG:

CE= 0 if <=4 years, CE=1 if >4 but <10 years, CE=2 if ≥10 years but < 20 and CE = 3 if ≥20 years.

In this domain questions were asked about the way the gymnasts' search/selection was made, because most selections are made external or internal to the club. As such our reference variable (0) was if selection (S) made externally in groups of children interested to participate in gymnastics: S=1 if external from club but from children already participating in gymnastics; S=2 if internal to the club, and S=3 if different from the previous. A second question was about the systematic use of tests in selection, coded as 0 (reference category, meaning "no") and 1 (yes, they use).

Exploratory and descriptive statistics were performed in SPSS 20.0. Mean differences between EG versus NEG, in each age group, were calculated in STATA 14, using a t-test with a Satterthwaite's approximation for degrees of freedom, since in most cases the variances were not equal between the groups. Alpha was set at p=0.01. Mean differences for relative (%) data were performed in WinPep software (Abramson, 2004).

Since our data was clustered, i.e., gymnasts (level-1) nested within clubs (level-2), we used a hierarchical multilevel model and data were analyzed using Supermix v.1 software (Hedeker, D, Gibbons, R, du Toit, M, & Cheng, Y, 2008). A sequence of nested models was developed and tested as is common in multilevel modelling (Hox, 2010). We started with a simple model and then added predictors, i.e., we increased the model complexity. Simpler models are contained in more complex models, i.e., they are nested within. Deviance is the usual statistic that describes the goodness of fit of a model. More complex models in terms of explanatory power as well as in number of parameters, i.e., with more predictors, are expected to have lower values of Deviance. Differences in Deviances follow a Chi-Square distribution with degrees of freedom equal to the difference in the number of parameters of both models (Hox, 2010). Further, the relevancy of individual and club-level predictors to explain TTS variance was assessed with a pseudo-R^2 (which is similar, in a way, to the R^2 of multiple linear regression), and is defined as the proportional reduction in variance resulting from a comparison of a new model with a previous one (Hedeker et al., 2008). Modeling was performed in a sequential fashion as is usual when using any statistical model to explain any outcome variable – in our case TTS. First a Null model (M0) was estimated to compute the intraclass correlation, i.e., the variance accounted for by clubs' effects on gymnasts' TTS – the main issue here is to answer the fundamental question: are clubs important in explaining gymnasts´ TTS scores? Then, in Model 1 (M1) we only included gymnasts' TTS predictors. Finally, in Model 2 (M2), we added club predictors. This is, in fact, our most complex model in terms of explanatory power and also in the number of parameters to be estimated.

RESULTS

Gymnasts' descriptive statistics (means ± standard deviations and percentages) are shown in Table 1. As expected, the EG had significantly higher TTS's (p<0.01). However, there were no differences in size, maturation or body composition between gymnasts at any age group (p>0.01) apart from significantly more NEG 13-15 year old's attaining menarche (p<0.01). There were also no differences in the age of training onset or training years between the groups (p>0.01), however the GE, 11-12 and 13-15 year old's performed significantly more training hours per week (p<0.01).

Table 1
*Descriptive statistics by level of gymnastics (*non-elite *-NEG and elite-EG) and age group.*

	9-10 yrs n=98		11-12 yrs n=72		13-15yrs n=64		> 15 yrs n=15	
Competitive Level	NEG n=84	EG n=14	NEG n=45	EG n=27	NEG n=41	EG n=23	NEG n=11	GE n=4
Age (yrs)	9.49±0.50	9.86±0.36	11.51±0.51	11.52±0.51	13.76±0.73	13.57±0.66	17.00±0.78	17.50±1.92
TTS	26.68±13.11*	45.07±13.60	25.47 ±13.90*	48.11±13.99	34.96±15.54*	53.52±10.10	30,63±13,44	52,66±7,68
Weight (kg)	29.03±3.88	30.84±4.19	37.59±7.37	35.20±6.97	47.37±7.65	43.54±4.95	53.78±5.11	52.40±4.06
Height (cm)	134.69±6.22	135.76±5.91	146.12±7.16	142.64±6.60	154.23±6.98	150.84±4.76	159.33±4.28	159.18±4.97
Free Ft Mass (kg)	24.17±2.92	25.30±3.03	30.37±4.34	28.66±3.98	36.53±4.60	34.37±2.99	42.72±2.54	40.96±1.75
Maturity Offset	-2.71±0.49	-2.37±0.47	-1.07±0.60	-1.28±0.60	0.61±0.79	0.29±0.57	2.76±0.50	3.00±1.27
Menarche occurrence	3 (3.60%)	-	5 (11.10%)	3 (11.10%)	30 (73.20%)*	7 (30.40%)	11(100%)	4(100%)
Training onset (yrs)	5.84±1.53	5.07±1.33	6.55±2.05	5.82±1.27	6.40±2.01	6.00±1.41	8.09±2.38	5.50±1.91
Training years (yrs)	3.89±1.91	5.11±1.60	5.13±2.19	5.92±1.75	7.43±2.32	7.91±1.56	9.27±2.80	11.75±4.71
Training hours ($h \cdot w^{-1}$)	20.66±7.03	24.39±4.35	19.40±8.88*	28.20±3.09	21.7±8.8*	30.13±4.21	24.00±8.31	27.75±3.50
Competition onset (yrs)	7.52±1.51	6.85±1.19	8.05±1.69	7.59±1.21	8.24±1.54	7.61±1.23	9.27±1.90	8.25±0.50

*p<0.01

Table 2
Variable domains and their results at the club level.

Club dimension	
Total Number of Gymnasts - WAG[1]	
Up to 50 gymnasts	23.00%
51 - 150 gymnasts	38.50%
Over 150 gymnasts	38.50%
Number of Gymnasts per team	
Less than 6 gymnasts	34.60%
7 - 10 gymnasts	42.30%
More than 11 gymnasts	23.10%
I*nfrastructures*	
Exclusive place for gymnastics	
No	7.70%
Yes	92.30%
Complete Apparatuses of WAG and Pit[2] in the gym	
No	30.80%
Yes	69.20%
Competition	
Lifetime of WAG in the club	
Up to 4 years	11.50%
5 to 10 years	15.40%
Over 11 years	73.10%
Gymnasts with participation in International Competitions	
No	50.00%
Yes	50.00%
Manpower	
Amount of WAG coaches in teams	
Up to 4 coaches	92.30%
5 to 10 coaches	7.70%
Coach time experience in competitive WAG	
Up to 4 years	15.40%
5 to 10 years	34.60%
11 to 20 years	26.90%
More than 20 years	23.10%
Talent programs	
The way in which the selection of gymnasts is performed.	
Externally (evaluating girls still no exercise practitioners)	7.70%
Externally (evaluating girls who already practice or practiced gymnastics)	15.40%
Internal form (evaluating girls already practicing gymnastics at the club)	53.80%
Another (not identified way).	23.10%
Use of tests in gymnasts selection	
No	15.40%
Yes	84.60%

WAG[1] = Women's Artistic Gymnastics, Pit[2]=security place for training

Table 3
Results summary of hierarchical linear modeling.

Parameters	Null Model			Model 1			Model 2		
	Estimates	SE	p	Estimates	SE(1)	p	Estimates	SE	p
Fixed Effects									
Gymnasts Level									
Intercept	34.80	2.72	<0.01	27.70	1.85	<0.01	42.02	6.77	<0.01
Age Categories				4.17	1.31	<0.01	4.07	1.33	<0.01
Competitive Level				11.16	2.28	<0.01	11.98	2.25	<0.01
Free Fat Mass (kg)				-0.34	0.13	<0.01	-0.36	0.13	<0.01
Menarche occurrence				11.57	4.43	<0.01	11.54	4.38	<0.01
Training hours/per week ($h \cdot w^{-1}$)				1.12	0.13	<0.01	1.22	0.13	<0.01
Age Cat(2)-by-Comp Level(3) Interaction				-2.21	1.59	>0.01	-3.01	1.58	>0.01
Menarche occurrence-by-Age Cat Interaction				-4.46	2.13	>0.01	-4.47	2.12	>0.01
Club Level									
Club dimension									
Total WAG: 51 -150							-7.15	3.31	>0.01
Total WAG: over 150							3.94	2.75	>0.01
Gymnasts per team: 7 - 10 gymnasts							-4.16	2.21	>0.01
Gymnasts per team: More than 11 gymnasts							-9.32	2.60	<0.01
Manpower									
Number of WAG coaches in teams							-7.99	4.06	>0.01
Coach time experience									
5 to 10 yrs							0.31	3.38	>0.01
11 to 20 yrs3							7.40	3.61	>0.01
More than 20 yrs							4.25	3.11	>0.01
Talent/Selection programs									
Selection externally (already practitioners)							-21.55	6.22	<0.01
Selection internally at the club							-12.11	4.73	<0.01
Another selection process (not identified)							-12.12	4.83	<0.01
Use of tests in gymnasts selection							7.41	2.84	<0.01
Random effects									
Intercept	177.32			39.43			7.20		
Residual	115.95			79.19			79.38		
Deviance (number of parameters)	1951.44 (3)			1802.53 (10)			1775.28 (22)		

SE(1)= Standard Error, Age Cat(2)= Age Categories, Comp Level(3)= Competitive Level, WAG(4)=Women´s Artistic Gymnastics.

Clubs' descriptive statistics are shown in Table 2. Nearly 80% of clubs had more than 50 gymnasts and at least 4 coaches with between 5 and 20 years of experience. A third of the clubs had 6 gymnasts in a team and over a half had athletes participating in international competitions, with the majority having competed for over 11 years. Most clubs were exclusively for gymnastics and over two thirds had a pit and complete sets of apparatuses. The most frequent mode of selection into the sport was internal to the club (54%), and most clubs (85%) used tests to identify talent.

The results of the multilevel models are shown in Table 3. In the Null Model (M0), the intercept (fixed effects) represents the average TTS points (β=34.8±2.7) for all gymnasts. Variance between gymnasts and between clubs is shown in the random effects; the intraclass correlation coefficient (ICC)=0.61, implies that 61% of the total variance in gymnasts' TTS is explained by club level covariates; further, the remaining variance, 39%, is explained by differences in individual gymnasts' characteristics.

M1 fitted the data better than M0 indicated by a reduction in goodness of fit from 1951.4 to 1802.5 ($p<0.01$). The intercept of M1 (β=27.7±1.9, $p<0.01$) represents the TTS for a gymnast from the reference group (9-10 yrs old). TTS increased with increasing age category (β=4.2±1.3, $p<0.01$); further, EG gymnasts scored higher on TTS (β=11.2±2.8, $p<0.01$) when all other confounders were controlled. Gymnasts with higher free fat mass performed worst in TTS (β=-0.3±0.1, $p<0.01$). The higher the number of training hours per week the better the performance (β=1.1±0.1, $p<0.01$). Experiencing menarche was positively associated with TTS scores (β=11.6±4.4, $p<0.01$). Taken together, these gymnasts' covariates explained 32% of the 40% inter-individual TTS scores variance.

Since most clubs have similar infrastructures, as well as competition no association was found with TTS ($p>0.01$). M2, with club-level covariates added fitted the data better than M1. In M2, the intercept (β=41.6±6.85, $p<0.01$) is the TTS of a gymnast when all predictors are at zero. Gymnast level covariates remained similar to those in M1. Results from M2 showed that gymnasts from small clubs (less than 50 gymnasts) and small number of gymnasts in team classes, as well as from clubs with less than 4 coaches but with more experience time in training tend to perform better in TTS ($p<0.01$). Further, gymnasts from clubs that had selection tests and who selected gymnasts externally (no practitioners) tend to perform better in TTS ($p<0.01$). Taken together, club-level covariates explained 96% of the ~61% of the between-clubs variance.

DISCUSSION

This paper aimed to identify gymnast and club level characteristics that explained inter-individual differences in motor performance (MP) tests. The main findings indicated that a substantial amount of TTS variance (61%) was attributable to club environment and to a smaller extent (39%) the individual gymnast's characteristics.

Total TTSs score increases of ~4.2 points were observed across age categories, this is similar to a mean increase of ~3 points across 9 to 11 years old previously reported in USA gymnasts (USA-Gymnastics, 2010). Further, a previous study of Brazilian gymnasts, albeit using a different test battery (Albuquerque, & Farinatti, 2007), showed mean increments of 2.5 points among beginners and 3.7 points among elite gymnasts aged 9 to 15 years old. These results confirm the roles of both neuromuscular maturation and experience in performing strength tasks (Malina, Bar-Or, & Bouchard, 2004). In 2010, the American Gymnastics Federation reported TTS averages of 53.47, 56.43 and 59.57 points in 9, 10 and 11 yrs old gymnasts respectively, which are greater than those reported in present sample of Brazilian gymnasts. This may explain in part their higher performances. In our models a constant difference in EG and NEG TTS of ~11.2 points was evident across all age categories, favoring the EG. A similar trend was previously reported between beginners and elite Brazilian gymnasts, but again using a different test battery (Albuquerque, & Farinatti, 2007). (Vandorpe et al., 2011) also found significant differences in physical performance characteristics between non-elite and elite levels, favoring the elite group, even after controlling for age and maturation (age at peak height velocity). These consistent differences could be explained in part by the greater amount of weekly training hours performed by EG.

There was a positive effect of biological maturation on TTS of ~11.6 points, i.e., a superior MP of those who already passed through menarche. However, a statistically significant interaction between menarcheal status and age categories revealed a decrease of ~4.5 TTS points. It has consistently been shown that EG are late maturers (Baxter-Jones, Thompson, & Malina, 2002; Malina, Baxter-Jones, Armstrong, Beunen, Caine, Daly et al., 2013), and since a high frequency of NEG reached menarche prior to EG in each age category this may help explain this interaction.

As expected, the number of training hours per week was positively associated with TTS performance, on average, ~1.2 points. This is in agreement with available data (Vandorpe et al., 2011), given that weekly time in training increases with age and competition level (Malina et al., 2013). As per (Ericsson, Krampe, & Tesch-Römer, 1993) suggestion, more training hours per week provide more deliberate practice which then translates to higher levels of expertise, which is consistent with (Lidor, Tenenbaum, Ziv, & Issurin, 2016) findings.

Results from club-level covariates showed significant associations of club dimensions, manpower and talent programs with gymnasts' TTS development. Gymnasts from larger clubs (over 150 gymnasts) had better performance while those from medium clubs (51 - 150 gymnasts) had worse performance (-7.0) in the TTS. It is possible that these results may be due to the fact that larger clubs have a larger pool to select from and have better opportunities to train them. In contrast, smaller clubs work with those available, who may be less gifted. Team size was negatively associated with performance suggesting smaller teams are prone to more individualized planning, coaches' attention and training together with more systematical assessments and skills enhancement (Asqalan, 2016). In educational settings classes with more students are thought to have a negative influence in educational attainment (Case, & Deaton, 1999), whist small classes, especially in the early grades, lead to higher academic achievement (Nye, Hedges, & Konstantopoulos, 2000). Translating this to gymnastics training, where quality and repetition are very important, more individual attention allows the gymnast to develop a high degree of perfection (Asqalan, 2016).

Gymnasts belonging to clubs with more coaches had worse TTS performance (-8.4 points), at the same time more coaching experience was positively associated with TTS. (Baker, Horton, Robertson-Wilson, & Wall, 2003) highlighted that the coach is most probably one of the utmost significant keys to athlete development and performance. Additionally, more years of experience allow coaches to draw upon their vast and diverse amounts of information about their sport as well as their athletes, since more experience allows better planning, diagnose, and strategize more effectively (De Marco, & Mccullick, 1997). Since the development of expertise is a long-term process, coaches who achieved it are more efficient in detecting what athletes need to know and then find the best strategies to supply that information to them (De Marco, & Mccullick, 1997). As is to be expected, clubs with selection processes had higher TTS scores (Albuquerque, & Farinatti, 2007; Bajin, 1987; Pion, Lenoir, Vandorpe, & Segers, 2015) as did those who teams were selected externally. This is likely associated with a broader recruitment basis together with the fact that decisions are mostly based on innate characteristics that are believed to be mandatory to excel, and not so much on specific technical skills (Meyers, Van Woerkom, & Dries, 2013).

This study has limitations, specifically the sample does not represent all Brazilian gymnasts and care needs to be taken about the generalizability of the findings. However, the sample includes gymnasts from states with higher competitive levels across Brazil. Secondly, the TOPS battery is not widely implemented in Brazil and its importance and applicability in gymnasts' training control is unknown.

CONCLUSIONS

The present study showed that individual gymnast' traits explained 40% of TTS variance, from which 32% was related to the independent effects of age, competitive level, fat free mass, menarche occurrence, and trainings hours per week, i.e., older, lighter and mature gymnasts, as well as those belong to the elite group that train more hours per week perform better. Moreover, club characteristics explained 61% of gymnasts' total variance in TTS performance, and 96% of this amount is related club dimension, manpower, and talent program, reinforcing the relevant roles of contextual effects, which highlights the need to also invest in club structures, mainly in coaches' expertise as well as in effective selection programs to develop and enhance gymnasts' carriers during their lifetime involvement in serious training and competition.

ACKNOWLEDGMENT

This work was supported by CAPES Foundation, Ministry of Education of Brazil, Brasília—DF, Brazil, (11927/13-5/PhD scholarship).

REFERENCES

Abramson, Joseph H. (2004). WINPEPI (PEPI-for-Windows): computer programs for epidemiologists. *Epidemiologic Perspectives & Innovations,* 1(1), 6.

Albuquerque, Patricia Albuquerque, & Farinatti, Paulo Tarso Veras. (2007). Development and validation of a new system for talent selection in female artistic gymnastics: The PDGO Battery. *Revista Brasileira de Medicina do Esporte,* 13(3), 157-164.

Asqalan, Manar. (2016). The effect of EFL large classes on Yarmouk University Students' achievement. [Article]. *Arab World English Journal,* 7(1), 358-369.

Bajin, Boris. (1987). Talent identification program for Canadian female gymnasts. In Petiot, Bernard, Salmela, John H & Hoshizaki, T Blaine (Eds.), *World Identification Systems for Gymnastic Talent* (pp. 34-44). Montreal: Sport Psyque Editions.

Baker, Joseph, Horton, Sean, Robertson-Wilson, Jennifer, & Wall, Michael. (2003). Nurturing sport expertise: factors influencing the development of elite athlete. *J Sports Sci Med,* 2(1), 1-9.

Bale, Peter, & Goodway, Jackie. (1990). Performance variables associated with the competitive gymnast. / Variables de performance du gymnaste de competition. *Sports Medicine,* 10(3), 139-145.

Baxter-Jones, Adam D G, Thompson, Angela M, & Malina, Robert M. (2002).

Growth and maturation in elite young female athletes. *Sports Medicine and Arthroscopy Review,* 10(1), 42-49.

Bradshaw, Elizabeth Jane, Hume, Patria Anne, & Aisbett, Brad. (2011). Performance score variation between days at Australian national and Olympic women's artistic gymnastics competition. *Journal of Sports Sciences,* 30(2), 191-199.

Case, Anne, & Deaton, Angus. (1999). School inputs and educational outcomes in South Africa. [Article]. *Quarterly Journal of Economics,* 114(3), 1047-1084.

CBG. (2015). Capítulo V - Das Categorias [Chapter V - Categories] *Regulamento Geral Confederação Brasileira de Ginástica [Categories General Regulation of Gymnastics Brazilian Federation]* (pp. 6-7). Aracaju-BR: Confederação Brasileira de Ginástica.

Côté, Jean. (1999). The influence of the family in the development of talent in sport. [Article]. *Sport Psychologist,* 13(4), 395-417.

De Marco Jr, Georg M, & Mccullick, Bryan A. (1997). Developing expertise in coaching: Learning from the legends. *Journal of Physical Education, Recreation & Dance,* 68(3), 37-41.

Ericsson, K Anders, Krampe, Ralf T, & Tesch-Römer, Clemens. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review,* 100(3), 363.

Hedeker, Donald, Gibbons, Robert, du Toit, Mathilda, & Cheng, Yan. (2008). *Manual of SuperMix: mixed effects models.* Lincolnwood, IL: Scientific Software International.

Hox, Joop J. (2010). *Multilevel Analysis. Techniques and Applications* (2nd ed.). New York: Routledge.

Kayani, Jawad, Zia, M Qamar, & Abbas, Thair. (2012). What variables shape player's performance in professional teams/clubs. *Journal of Physical Education & Sport,* 12(3), 380-384.

Lidor, Ronnie, Tenenbaum, Gershon , Ziv, Gal, & Issurin, Vladimir. (2016). Achieving expertise in sport: deliberate practice, adaptation, and periodization of training. *Kinesiology Review,* 5(2), 129-141.

Malina, Robert M, Bar-Or, Oded, & Bouchard, Claude. (2004). *Growth, maturation, and physical activity* (2nd ed.). Champaign: Human Kinetics.

Malina, Robert M, Baxter-Jones, Adam D G, Armstrong, Neil, Beunen, Gaston P, Caine, Dennis, Daly, Robin M, et al. (2013). Role of intensive training in the growth and maturation of artistic gymnasts. *Sports Medicine,* 43(9), 783-802.

Marina, Michel, Jemni, Monèm, & Rodriguèz, Ferran A. (2013). Jumping performance profile of male and female gymnasts. *Journal of Sports Medicine and Physical Fitness,* 53(4), 378-386.

Meyers, M Christina, Van Woerkom, Marianne, & Dries, Nicky. (2013). Talent — Innate or acquired? Theoretical considerations and their implications for talent management. [Article]. *Human Resource Management Review,* 23, 305-321.

Mihaela, Iconomescu Teodora, Veronica, Mindrescu, & Dana, Badau. (2014). Importance of human resources in sports clubs and in sports performance management. *Gymnasium: Scientific Journal of Education, Sports & Health,* 15(2), 269-278.

Mirwald, Robert L, Baxter-Jones, Adam D G, Bailey, Donald A, & Beunen, Gaston P. (2002). An assessment of maturity from anthropometric measurements. [Article]. *Medicine and Science in Sports and Exercise,* 34(4), 689-694.

Monèm, Jemni. (2011). Specific physical and physiological assessments of gymnasts. In Jemni, Monèm (Ed.), *The science of gymnastics* (pp. 32-38). London: Routledge.

Morucci, Gabriele, Punzi, Tiziana, Innocenti, Giovanni, Gulisano, Massimo, Ceroti, Marco, & Pacini, Stefania. (2014). New frontiers in sport training: genetics and artistic gymnastics. *Journal of Strength and Conditioning Research,* 28(2), 459-466.

Nye, Barbara, Hedges, Larry V, & Konstantopoulos, Spyros. (2000). The effects of small classes on academic achievement: the results of the Tennessee class size experiment. *American Educational Research Journal,* 37(1), 123-151.

Petitta, Laura, Jiang, Lixin, & Palange, Miriam. (2015). The differential mediating roles of task, relations, and emotions collective efficacy on the link between dominance and performance: A multilevel study in sport teams. [Article]. *Group Dynamics,* 19(3), 181-199.

Pion, Johan, Lenoir, Matthieu, Vandorpe, Barbara, & Segers, Veerle. (2015). Talent in female gymnastics: a survival analysis based upon performance characteristics. *International Journal of Sports Medicine,* 36(11), 935-940.

Ross, W D, & Marfell-Jones, Michael J. (1991). Kinanthropometry. In MacDougall, J. Duncan, Wenger, Howard A. & Green, Howard J. (Eds.), *Physiological testing of the high-performance athlete* (pp. 223-308). Champaign, Ill Human Kinetics.

Sands, Willian A. (2011). Fitness model of high-level gymnasts. In Jemni, Monèm (Ed.), *The science of gymnastics* (pp. 22-25). London: Routledge.

USA-Gymnastics. (2010). TOPS History-National TOP Averages and Standard Deviation/National Best Retrieved May 2th, 2016, from https://usagym.org/PDFs/Women/TOPs/History/10topavg.pdf

USA-Gymnastics. (2014). Talent Opportunity Program - testing manual Retrieved 24th september, 2014, from https://usagym.org/pages/women/video/tops.html

Vandorpe, Barbara, Vandendriessche, Joric, Vaeyens, Roel, Pion, Johan, Lefevre, Johan, Philippaerts, Renaat, et al. (2011). Factors discriminating gymnasts by competitive level. *International Journal of Sports Medicine,* 32(8), 591-597.

Corresponding author:

Sarita Bacciotti
Physical Education Course
Federal University of Mato Grosso do Sul
Campo Grande-MS-Brazil.
E-mail: saritabacciotti@hotmail.com

THE EFFECT OF 6-WEEKS WHOLE BODY VIBRATION ON MUSCULAR PERFORMANCE ON YOUNG NON-COMPETITIVE FEMALE ARTISTIC GYMNASTS

George Dallas[1], Alkmini Savvathi[1], Konstantinos Dallas[2], Maria Maridaki[1]

[1] National and Kapodistrian University of Athens - School of Physical Education and Sport Science, Athens, Greece
[2] Athens, Greece

Original article

Abstract

The purpose of this study was to investigate the effects of a 6-week whole body vibration-intervention on muscle performance and flexibility on gymnasts. Twenty-two young non-competitive-moderate trained gymnasts that volunteered to participate in the study separated into either the vibration group or the no vibration group according to their training regime. The vibration intervention consisted of a 6-week whole-body vibration, 3 times per week and involved eccentric and concentric squatting movements on a vibration platform with the participants performing three exercises on the vibration device whereas for the no vibration group vibration platform was turned off. Five performance tests (20m running speed, sit & reach test, squat jump, counter movement jump and single leg squat (right leg and left leg) were performed at the beginning of the intervention, and after the end of 6-week intervention program. According to the results significant interaction effect between group and time was found for the running speed and Squat Jump test. On the contrary, significant main effect were found were found for time on the running speed, Squat Jump, Counter movement jump and single leg squat. Conclusively, it has been reported that Whole body vibration is an effective method to improve Squat Jump performance in young non-competitive female artistic gymnasts.

Keywords: *explosive strength, intervention, gymnastics.*

INTRODUCTION

Whole Body Vibration (WBV) exercise or vibration training is a new type of exercise that has been reported to be an effective method to improve athletic performance (Cole & Mahoney, 2010). It is considered an ergogenic aid for training and competition (Bazett-Jones, Finch, & Dugan, 2008) and is potentially a less-consuming method for increasing power output than traditional training (Marin & Rhea, 2010). The main argument for using vibration for muscle training has been based on the assumption that strength improvements can be easily achieved during a short time (Dallas et al., 2015; Tsopani et al., 2014). When a person stands on a vibration platform it generates vertical sinusoidal vibration which are transmitted directly to the tendon, which in turn leads to activation of the alpha-motoneurons and initiates muscle contractions comparable to the "tonic vibration reflex (TVR)" (Nortlund & Thorstensson, 2007). The transmission of mechanical oscillations from the vibrating platform may lead to physiological changes in muscle spindles, joint mechanoreceptors, higher brain activity and strength and power properties (Moezy, Olyaei, Hadian, Razi, Mohammad, & Faghihzadeh, 2008). TVR is the sustained contraction of a muscle due to the effect of vibration that activates muscle spindles, which are muscle receptors sensitive to stretch in the muscle. Afferent fibers send a signal to the spinal cord from the muscles spindles activating a reflex which causes the muscle to contract. TVR also causes an increase in recruitment and synchronization of motor units within the muscle via activation of muscle spindles and polysynaptic pathways (de Gail, Lance, & Neilson, 1966), which is seen as a temporary increase in the muscle activity. Furthermore, the increase in strength following WBV training may be due to elevated essential hormones, i.e. testosterone, growth hormone, and insulin-like growth factor. According to Rothmuller and Cafarelli (1995) vibration enhances the stretch reflex loop through the activation of the primary endings of the muscle spindle, which influences agonist muscle contraction while antagonists are simultaneously inhibited. Further, according to Cardinale & Bosco (2003), the acute enhancement of neuromuscular performance after vibration is probably related to an increase in the sensitivity of the stretch reflex. Furthermore, vibration appears to inhibit activation of antagonist muscles through Ia-inhibitory neurons, thus altering the intramuscular coordination patterns leading to a decreased braking force around the joints stimulated by vibration. Vibration might raise the muscle temperature due to the friction between the vibrating tissues, increase the blood flow, which could in turn enhance the extensibility of the muscle and ROM and change the pain threshold (Sands et al, 2008).

Several studies showed that WBV training resulted in improved muscle strength or muscle performance. Specifically, it has been shown that exposure to WBV increases the explosive strength of the lower limbs, flexibility with or without stretching (Dallas & Kirialanis, 2013; Dallas, Kirialanis, & Mellos, 2014a; b; Dallas et al., 2015; Tsopani et al, 2014) and sprint running (Paradisis & Zacharogiannis, 2007). The majority of these studies are referred to female and male participants aged between 22-43 years (Carson, Popple, Verschueren, & Riek, 2010) or young adults (Chen, Liu, Chuang, Chung, & Shiang, 2014) or trained individuals; volleyball and beach volley athletes (Pérez-Turpin et al., 2014) or female basketball athletes (Fernadez-Rio, Terrados, & Suman, 2012), whereas there is a strong to moderate evidence that long-term whole body vibration exercise can have positive effects regarding leg muscular performance (Annino et al., 2007; Chen et al., 2014; Fernandez-Rio et al., 2012; Dallas et al, 2017; Pérez-Turpin et al., 2014; Preatoni et al., 2012). However, there are controversial results with regards to the effect WBV on explosive strength of lower limbs with some of these studies to indicate positive effect (Fernadez-Rio et al., 2012; Pérez-Turpin et al., 2014; Preatoni et al, 2012), whereas other studies found no positive effect (Carson et al., 2010).

In addition, a number of these studies have been applied a single bout of vibration to examine acute effect of vibration (Dallas & Kirialanis, 2013; Dallas, Kirialanis, & Mellos, 2014a; b; Tsopani et al, 2014), whereas other studies examine the effect of intervention program on muscle performance (Fernandez-Rio et al, 2012; Perez-Turpin et al, 2014; Preatoni et al, 2012; Sands et al, 2006). In addition, studies that are referred to gymnastics sports have examined mainly the vibration effect on flexibility in competitive gymnasts (Dallas & Kirialanis, 2013), on young gymnasts (Dallas et al., 2014a) or high level gymnasts (Sands et al, 2006; Tsopani et al., 2014).

Studies on long-term effects of vibration training have also yielded contradictory outcomes. Significant enhancement was found in the parameters evaluated by Annino et al. (2007), whereas other studies found no significant changes (Hand, Verschuere, & Osternig, 2009).

More specifically, Paradisis and Zacharogiannis (2007) and Wyon, Guinan, and Hawkey (2010) concluded that the 6 weeks program improves sprint running and explosive power of lower limbs of healthy subjects. Perez-Turpin et al. (2014) studied 23 beach volleyball and volleyball athletes reported that implementation of 6-week WBV training increases leg strength more and leads to greater improvement in jump performance than traditional strength training. Different time protocols were also studied. Carson et al. (2010) compared a 4-week WBV training program to that without vibration. The subjects were aged 22-43 years and concluded that the non-vibration group increased the CMJ height; however, there were no significant improvements between groups. An 8 week WBV program by Chen et al. (2014) on injury-free young adults with average age of 20.3 years revealed a significant jumping improvement from 6.4 to 11.9%. Another 8 week training program (periodized) was carried out by Preatoni et al. (2012) on female softball and soccer athletes and concluded that combining conventional strength training with WBV doesn't improve the athletes' strength. The 8-week WBV training program of 22 ballerinas by Annino et al. (2007) concluded that it improves explosive strength on knee-extensor muscles although this is only short term. When comparing with and without vibration 14-week training programs of 31 female basketball athletes Fernandez-Rio et al. (2012) concluded that there were no significant improvements between the two programs even though there was strength increase. Further, a meta-analysis found that WBV has small and inconsistent acute and chronic effects on athletic performance in competitive and /or elite athletes (Hortobagyi, Lesisnski, Fernandez-del-Olmo, & Granacher, 2015).

Although, there is a lack of data concerning the improvement of muscular strength in young gymnasts, previous data by Ronnestad (2004) support that vibration may enhance measures of explosiveness. Furthermore, as Kinser and colleagues (2008) stated the combination of vibration and stretching can enhance flexibility while maintaining explosive strength in young gymnasts aged 11.3 ± 2.6 years. In addition, Rohmert et al. (1989) showed that muscles with increased muscle length or tension are most affected by vibration. Therefore, it may be advantageous to use a combination of vibration and stretching as part of the warm-up for gymnasts, thus enhancing flexibility and maintaining or improving explosive performance (Stone et al, 2006). However, despite the above noted effect of vibration devises among subjects, scientific evidence on the efficacy of long term intervention vibration program on young gymnasts is lacking. Further, to our best knowledge, there are not scientific data related to the effect of long term intervention program on gymnasts. Therefore, the purpose of this study was to investigate the effect of a 6-week whole body vibration intervention on explosive strength of lower limbs, flexibility and running speed (RS) of young moderately trained artistic gymnasts. It was hypothesized that 8-week vibration intervention program will be more effective in improving muscular performance compared to the same program without vibration.

METHODS

Twenty-two young, healthy volunteers participated in this study (age 9.70 ± 0.95 years, body mass 34.47 ± 6.94 kg, and body height 137.67 ± 8.14 cm). All individuals, the last 2 years, were participated in a scheduled training program for 3 times per week in clubs of artistic gymnastics and had no previous experience in WBV. They were randomly assigned to two groups, which included a WBV group (VG: n = 12) and a non-vibration group (NVG: n = 10). During the six-week intervention period, both groups were advised to continue with their regular habitual gymnastics training. Furthermore, participants incorporated an additional conditioning program at the end of each training session performing three exercises according to their protocol. Subjects were informed extensively about the experiment procedures and the possible risks or benefits of the project. They had no musculoskeletal injuries in the previous 6 months, and all parents provided written informed consent before participation of their children in the experimental design. The study was approved by the local institutional Review Board and all procedures were in accordance with the Helsinki declaration of 1975 as revised in 1996.Three days prior to the study, the anthropometric characteristics of subjects (age, body mass, body height) were measured and a familiarization session to get acquainted with the proper technique for the execution of the examined exercises (running speed, flexibility test, jumping tests) were performed. The vibration protocol consisted of a 6-week WBV training, which will be discussed in detailed herein. The intervention program was implemented at the end of each training session, as the technical skills training module is usually preceded. The total duration of training lasts about 60 minutes, with the most time, other than that of warm-up, devoted to the learning of simple technical exercises. Therefore, the degree of fatigue may be reduced to a minimum.

On each session, each subject performed a 3-min standardized warm-up that include running at low intensity and light callisthenic exercises. Participants in the VG were exposed to vertical sinusoidal mechanical WBV while standing on the commercially available Power Plate® Next Generation WVB platform (Power Plate North America, Northbrook, Illinois), whereas participants in NVG performed the same exercises but the WBV platform was turned off. The vibration was set at 30 Hz, which produced a peak-to-peak amplitude of 2.5 mm and an acceleration of 2.28 g. The participants were exposed for 6 weeks using different execution forms of three exercises. Every training session was supervised by the researchers. In first exercise, participants were instructed to move through the eccentric portion of the movement for two sec and the concentric portion for two sec synchronized by a metronome operating with 20 bpm to a depth of approximately 90° of knee flexion. In exercise two and three, the participants standing on one leg, flexed their knee to a depth of approximately 90° of knee flexion and instructed to move as in the first exercise. The duration of 30 sec was used in hopes to improving the performance enhancement found by Cormie et al. (2006). During all the vibration-training session, the participants wore the same gymnastics shoes to avoid bruises and to standardize the damping of the vibration caused by the footwear. The training load on the vibration platform for the two groups, for each one exercise was as follows:

Table 1
Training load for intervention protocol

Week	Series	Duration (sec)
1 - 3	1	30
4 - 6	2	30

The rest between the sets and exercises was 30 sec to provide a proper time for relaxation. As there are no scientific-based WBV programs the training program in the present study was based on similar protocols that resulted in significant changes in muscle performance (Torvinen et al, 2002a).

A battery of tests (Running speed 20 m: RS; Flexibility test: S & R test;

Jumping tests) was performed at the start baseline (pre-test), one day after the end of sixth week (Post 1) and 5-min (Post 5) and 10-min (Post 10) after the end of the intervention protocol to measure the effects of training. The participants were informed about the test procedures and were asked to perform all these tests at maximum intensity. Before each test, the participants had one uninventive familiarization trial. Testing for each subject was completed in the same order during each testing period. All subjects participated in supervised training three days per week during the six-week training sessions. For all test items the Interclass reliability coefficients was estimated to be 0.91 – 0.96.

In the first day of performance testing, the participants, after completion of the standardized 3-min warm-up, performed two maximal 20 m RS with subjects started from a crouched position. The sprint was performed in a gymnastic hall at a constant temperature of 22° C. The time was obtained using the Brower timing systems (Brower, USA). A rest period of 5 minutes was given between each trial.

Flexibility was measured using the sit and reach test using a Flex-Tester box (Cranlea, UK). Participant, sitting barefoot on the floor with legs out straight ahead, were instructed to lean forward slowly as far as possible, toward a graduated ruler held on the box from -25 to +25, without bending their knees and held at the greatest stretch for 2 sec. The investigator has to be sure that there are no jerky movement on the part of the participant and that their fingertips remain at the same level and the legs flat. The score is recorded as the distance before or beyond the toes. The test was repeated twice with a rest period of 10 sec (15), and the best score was recorded.

Jumping performance was measured using the squat jump (SJ), the counter movement jump (CMJ) and single leg squat (right leg (RL) and left leg (LL). Vertical jump tests were conducted on a switch mat connected to a digital timer (accuracy±0.001s, Ergojump, Psion XP, MA.GI.CA. Rome, Italy), which recorded the flight time (t_f) of each single jump. The height of rise of the centre of mass in all jump tests was determined by the flight time and used in order to analyze the explosive strength characteristics of the leg muscles as reported elsewhere (Bosco et al., 1998). Prior to testing, the participants underwent one or two familiarization trials to ensure the proper performance technique for these three different jumps.

The squat jump (SJ) started from a semi-squatting position with the knee flexed approximately at 90° that was maintained for 2 sec before jumping vertically. During SJ, the participants kept their trunk in an upright position and their hands on hips. The participants were instructed to perform two maximal trials with a rest period of 30 sec and the best jump was considered for further statistical analysis. For the counter movement jump (CMJ) the participants were instructed to perform a maximal vertical jump starting from upright position, with hands positioned at the hips to assess the lower-limb explosive performance capacity. The same regime as previous for SJ was followed. During CMJ, the participants kept their trunk in an upright position and their hands on hips. The participants were instructed to perform two maximal trials with a rest period of 30 sec and the best jump was considered for further statistical analysis. SJ involved the participants assuming a 90° knee bend position holding for two seconds, and jumping. The CMJ began in an upright position, had no pause, and was one, fluid, jumping movement. Depth for the eccentric portion of the CMJ was self-selected. The single leg squat (right and left), was performing under instructions that were given for the SJ test.

The SPSS version 24 was used for the statistical analysis. The arithmetic mean, standard deviation, and range were calculated for each variable and trial. To explore the impact of time (pre, post1, post5, post10) and group (VG, NVG) on the dependent variables, a two-way (group x time) ANOVA with repeated measures on the second factor was used for the statistical analysis. Sphericity was checked using Mauchly's test, and the Greenhouse-Geisser's correction on degrees of freedom was applied when necessary. Levene's test of equality of error variances was used to check the assumption of homogeneity of variances. In cases where interaction between time and group was detected, the simple effects were investigated, and Bonferonni's correction was used. In the absence of interaction, the main effects of the two factors (time and group) on the dependent variables were investigated. All statistical significances were tested at $\alpha = 0.05$.

RESULTS

The statistical analyses revealed that the interaction effect between time and group was statistically insignificant for RS ($F_{(3, 60)} = 0.947$, $p > 0.05$). On the contrary, significant main effect was found for time ($F_{(3, 60)} = 3.558$, $p < 0.019$, $\eta^2 = 0{,}151$), but the post hoc analysis revealed no significant differences among the factor's levels. Furthermore, no significant main effect was found for group ($F_{(1, 20)} = 4.222$, $p > 0.05$). The mean values of the examined parameters are presented in table 1. Regarding S & R, the statistical analysis demonstrated no significant interaction effect between the two factors ($F_{(3, 60)} = 0.070$, $p > 0.05$) and also no significant main effect for time ($F_{(3, 60)} = 0.777$, $p > 0.05$) and group ($F_{(1, 20)} = 0.112$, $p > 0.05$). The SJ results indicated a significant interaction effect between the two factors ($F_{(3, 60)} = 3.911$, $p < 0.042$, $\eta^2 = 0.164$). The post hoc analysis showed that squat jump significantly increased after 6 weeks vibration training, either it was measured immediately after the vibration (Mean difference = 3.417 cm, $p < 0.05$, 95% CI = 1.430–5.403 cm), or 5 (Mean difference = 3.417 cm, $p < 0.05$, 95% CI = 1.292–5.540 cm) and 10 min later (Mean difference = 3.000 cm, $p < 0.05$, 95% CI = - 1.103–4.896 cm). There was no significant interaction effect between time and group for CMJ ($F_{(3, 60)} = 1.477$, $p > 0.05$). While the analysis revealed a statistically significant main effect for time ($F_{(3, 60)} = 4.163$, $p < 0.024$, $\eta^2 = 0.172$), the post hoc analysis did not indicate any significant difference among the four levels. The main effect for group was not significant ($F_{(1, 20)} = 0.536$, $p > 0.05$). Regarding the RL there was not found significant interaction ($F_{(3, 60)} = 0.471$, $p > 0.05$) or main effect for group ($F_{(1, 20)} = 0.972$, $p > 0.05$). On the contrary, it was found significant main effect for time ($F_{(3, 60)} = 4.918$, $p < 0.004$, $\eta^2 = 0{,}197$). The post hoc analysis did not indicate significant difference in the RL high among the four levels. As concerns the LL, the interaction effect between the two factors was found no significant ($F_{(3, 60)} = 1.143$, $p > 0.05$). The main effect for group was also insignificant ($F_{(1, 20)} = 0.537$, $p > 0.05$), but the main effect for time was found statistically significant ($F_{(3, 60)} = 5.334$, $p < 0.008$). It was indicated by the post hoc analysis that the LL height was greater after 5 min of the vibration intervention, compared with the LL height measured before the 6 weeks vibration training.

DISCUSION

The primary findings of this study was that 6-week strength training produced significant improvement on VG in RS, and SJ performance of non-competitive young female artistic gymnasts, whereas non-significant improvement was found at all examined parameters on NVG. To date, quantity in WBV protocol and quantity to outcome relationship has not been established (Rehn, Lidstrom, Skoglund, & Lindstrom, 2007). Studies, with or without a successful outcome, use a number of different frequencies, durations and amplitudes using a progressive protocol thus increasing the intensity of the frequency and/or duration and/or amplitude of the WBV protocol (Cole & Mahoney, 2010).

Although non-significant main effect was found for group, VG showed greater improvement (4.41%) on running speed (RS) compared to NVG (1.64%) after the end of the vibration protocol. These results are in accordance with data of Paradisis and Zacharogiannis (2007) who concluded that there is a 2.10% improvement in the time of 60m sprinting. The non-significant differences between two groups in our study verify previous results of Roberts, Hunter, Hopkins, & Feland (2009) who state that there were no observed differences in the 30 m sprint times in collegiate athletes. Conversely, our results opposed to those of Cole and Mahoney (2010) who found that WBV training may have had a small detrimental effect on speed during a 40m-dash test. However, other data failed to provide evidence that acute WBV stimulus positively affects sprint performance (Cochrane, 2013; Roberts et al, 2009). It has been observed that WBV training induces tonic vibration reflection; a higher activation of the muscular spindles and motor neurons which decreases the Electromagnetic delay (EMD) and increases the motor units. The neurological theory of muscular coordination could be a reason for this fast improvement in performance; motor neurons in one practical group of muscles and joints are prepared and there are improvements: in motor units coordination and integration, in synergist muscles co-contraction, and in antagonist muscles inhibition (Cardinale & Wakeling, 2005).

Table 2
Mean values and standard deviations on various measurements.

	Pre		Post 0	
	VG	NVG	VG	NVG
RS (sec)	4.26 ± 0.17	4.32 ± 0.32	4.08 ± 0.26↑	4.25 ± 0.22
S & R (cm)	28.00 ± 4.99	27.20 ± 4.73	27.67 ± 5.10	27.20 ± 4.80
SJ (cm)	18.75 ± 2.73	20.20 ± 3.01	22.17 ± 3.32↑	21.00 ± 2.71
CMJ (cm)	21.69 ± 2.00	21.94 ± 2.73	23.74 ± 3.60↑	22.66 ± 2.83
RL (cm)	10.41 ± 1.50	9.70 ± 3.16	12.17 ± 2.65↑	10.80 ± 2.61
LL (cm)	9.41 ± 1.97	9.50 ± 2.27	11.16 ± 2.82↑	10.10 ± 2.28
	Post 5		Post 10	
	VG	NVG	VG	NVG
RS (sec)	3.97 ± 0.26↑	4.22 ± 0.22	4.07 ± 0.27	4.26 ± 0.27
S & R (cm)	28.17 ± 5.00	27.70 ± 4.44	28.67 ± 4.83	27.80 ± 4.42
SJ (cm)	22.17 ± 3.40↑	21.10 ± 3.14	21.75 ± 3.52↑	21.20 ± 3.08
CMJ (cm)	23.81 ± 3.54↑	22.42 ± 3.03	23.37 ± 3.22	22.11 ± 2.99
RL (cm)	12.25 ± 2.89↑	10.90 ± 2.88	11.33 ± 2.46	10.80 ± 3.01
LL (cm)	11.33 ± 2.42↑	10.20 ± 2.25	10.91 ± 2.64	10.20 ± 3.08

↑ denote significant difference compared to baseline (pre) values ($p < .05$)

In Sit & Reach test (S & R), VG showed a slight mean decrease by -0.33 cm (1.21%) immediately after the end of 6-weeks vibration, whereas NVG remain unchangeable, that means WBV training may not be reflected in improvements in flexibility. This finding is in accordance with data of Cole and Mahoney (2010), which revealed no significant effect of WBV on flexibility of the hamstrings and lower back after 5-weeks of WBV training. However, our results opposed to those of Marshall and Wyon (2012) who found a significant large increase by 30% in ROM in young trained dancers without increasing thigh and calf circumferences after a 4-week vibration protocol and those of Sands et al. (2006) who a significant improvement, after 4-week vibration training on young high trained male gymnasts, on one split side performance. However, the improvement by 4.17% that appeared in our study 10 min after the end of the vibration protocol in VG was greater compared to that of NVG (2.80%), which suggest that the vibration exposure may have activated the Ia inhibitory interneurones of the antagonist muscle. It is mentioned that these discrepancies on the aforementioned results may be attributed to the different vibration protocols that were applied, the status and the chronological age of the subjects.

Results showed that a 6-week Whole Body Vibration induced, immediately after of the end of vibration protocol, a significant percentage improvement by 18.81% on squat jump (SJ) on VG which is significant greater from those of NVG (3.96%). The improvement that showed VG support previous findings which revealed that WBV increases explosive strength of lower limbs (Fernadez-Rio et al., 2012). Furthermore, the percentage improvements of VG 5 and 10 min after the end of vibration protocol (18.81% and 16.00%, respectively) are much greater from those of NVG (4.45% and 4.95%, respectively). In the present study the applied protocol of 6-weeks had a positive effect on counter movement jump (CMJ) performance. It was found that VG showed greater improvements (9.45%) than NVG (0.96%). This improvement by 9.45% support previous findings of Wyon et al. (2010) that found a beneficial effect of vertical jump height after 6-week vibration intervention in moderately trained undergraduate female dance students. Furthermore, results of our study are in congruence with those of other authors that founded an increase by 1.49% - 9.0% after several weeks of WBV training (Annino et al., 2007; Armstrong, Grinnell, & Warren, 2010; Bazett-Jones et al, 2008; Cole & Mahoney, 2010; Hand et al, 2009). Furthermore, the percentage improvements of VG 5 and 10 min after the end of vibration protocol (9.77% and 7.70%, respectively) are much greater from those of NVG (3.36% and 0.77%, respectively). Suggested neuromuscular improvement mechanisms are: increased corticomotor excitability and decreased short-interval intracortical inhibition, increased muscle activity due to dampening of the vibrational oscillations (Boyer & Nigg, 2007), increased motor unit activity (Pollock, Woledge, Martin, & Newham, 2012).

Significant greater improvements were found in right leg (RL) and left leg (LL) on VG immediately after the end of vibration protocol (16.91% and 18.57%, respectively) compared to NVG (11.34% and 6.31%, respectively). These results confirm findings of Shin, Lee, & Song. (2015) who found a considerably larger increase on SLJ in unilateral vibratory stimulation group (UVSG: 21% for the weak leg [WL]) and 12% for the strong leg [SL]) in comparison to the NVG (1.86% and 1.98% for the WL and SL, respectively). Further, the bilateral deficit (BLD) of 4.41% found in our study, support data of Costa, Moreira, Cavalcanti, Krinski, and Aoki (2015) who reported a strength reduction of 11%, meaning a BLD, after a resistance training protocol that consisted of 3 sets of leg extensions using a load of 50% 1RM. The bilateral deficit is α phenomenon where the sum of force produced by each leg individually is greater than the force produced by both legs combined in bilateral movement and is due to neural inhibition during bilateral tasks. WBV induces a non-voluntary muscle contraction i.e. TVR, activating α-motor neurons and increasing the sensitivity of primary ending of the muscle spindles thus stimulating the Ia afferent fiber of the muscle spindle. Moreover, more muscles are recruited via the muscle spindles and neuron bundles. According to Henneman’s size principle, as contraction strength increases, motor units are recruited from smallest to largest. According to Swearingen et al. (2011), small type I muscles are recruited before large type II, and with more large type II muscles, muscle strength and movement improve. According to the above, even slight WBV training can significantly affected muscle recruitment required for the single leg jump. Although knowledge the neurological and physiological mechanism of WBV training is limited there has been numerous research into the mechanisms through which WBV training affects performance. Our study sample was fairly small and thus the results of the WBV should be interpreted with caution. Furthermore, although there were no reported injuries during the period of our study, care should be taken vibration training is believed to be stressful for this particular age group. Additional studies are required with longer interventions in order to verify whether WBV training as a complement to resistance training produces specific benefits. The results of our study, however, may encourage trainers to include WBV sessions in their training programs so as to increase leg strength and jump height.

Certain limitations do not allow the generalization of this study. The results refer to a specific category of athletes and a specific level of technical training. The intervention protocol was applied after the end of each workout, with the potential for the resulting fatigue to affect the end result. To carry out a study by applying the intervention protocol at the beginning of the training sessions and at athletes of competitive level would give different results.

CONCLUSIONS

The findings of this study demonstrate that the implementation of 6-week WBV training in non-competitive young female artistic gymnasts improve leg strength more and leads to greater improvement in jump performance than traditional strength training (NVG).

REFERENCES

Annino, G., Padua, E., Castagna, C., di Slavo, V., Minichella, S., Tsarpela, O., Manzi, V., & D'Ottavio, S. (2007). Effect of whole-body vibration training on lower limb performance in selected high-level ballet students. *Journal of Strength and Conditioning Research, 21*, 1072-1076.

Armstrong, W.J., Grinnell, D.C., & Warren, G.S. (2010). The acute effect of whole-body vibration on the vertical jump height. *Journal of Strength and Conditioning Research, 24*, 2835-2839.

Bazett-Jones, D.M., Finch, H.W., & Dugan, E.L. (2008). Comparing the effects of various whole-body vibration accelerations on counter-movement jump performance. *Journal of Sports Science and Medicine, 7*, 144-150.

Bosco, C., Cardinale, M., Tsarpela, O., Colli, R., Tihanyi, J., von Duvillard, S.P., & Viru, A. (1998). The influence of whole body vibration on jumping performance, *Biology of Sport*, *15*, 157-164.

Boyer, K.A., & Nigg, M. (2007). Changes in muscle activity in response to different impact forces affect soft tissue compartment mechanical properties. *Journal of Biomechanics and Engineering, 129*, 594-602.

Cardinale, M., & Bosco, C. (2003). The use of vibration as an exercise intervention. *Exercise and Sport Science Review*, 31, 3-7

Cardinale, M., & Wakeling, J. (2005). Whole body vibration exercise: are vibrations good for you? *British Journal of Sports Medicine, 39,* 585-589.

Carson, R.G., Popple, A.E., Verschueren, S.M.P., & Riek, S. (2010). Superimposed vibration confers no additional benefit compared with resistance training alone. *Scandinavian Journal of Medicine and Science in Sports*, *20*, 827-833.

Chen, C.H., Liu, C., Chuang, L.R., Chung, P.H., & Shiang, T.Y. (2014). Chronic effects of whole-body vibration on jumping performance and body balance using different frequencies and amplitudes with identical acceleration load. *Journal of Science and Medicine in Sport, 17,* 107-112.

Cochrane, D.J. (2013). The effect of acute vibration exercise on short-distance sprinting and reactive agility. *Journal of Sports Science and Medicine*, *12*, 497-501.

Cole, K.J., & Mahoney, S.E. (2010). Effect of five weeks of Whole Body Vibration training on speed, power, and *flexibility. Clinical Kinesiology, 64*, 1-7.

Cormie, P., Deane, R.S., Triplett, N.T., & McBride, J.M. (2006). Acute effects of whole-body vibration on muscle activity, strength, and power. *Journal of Strength and Conditioning Research, 20*(2), 257-261

Costa, E.C., Moreira, A., Cavalcanti, B., Krinski, K., & Aoki, M.S. (2015). Effect of unilateral and bilateral resistance exercise on maximal voluntary strength, total volume of load lifted, and perceptual and metabolic responses. *Biology of Sport, 32,* 35-40.

Dallas, G., & Kirialanis, P. (2013). The effect of two different conditions of whole-body vibration on flexibility and jumping performance on artistic gymnasts. *Science of Gymnastics Journal, 5*, 67-77.

Dallas, G., Kirialanis, P., and Mellos, V. (2014a). The acute effect of Whole-Body Vibration on flexibility and explosive strength of young gymnasts. *Biology of Sport, 31*, 233-237.

Dallas, G., Paradisis, G., Kirialanis, P., Mellos, V., Argitaki, P., & Smirniotou A. (2015). The acute effect of different training load of whole body vibration on flexibility and explosive strength of lower limbs on divers. *Biology of Sport, 32*, 235-241.

Dallas, G., Tsiganos, G., Tsolakis, Ch., Tsopani, D., Di Cagno, A., & Smirniotou, A. (2014b). The acute effect of different stretching methods on flexibility and jumping performance in competitive artistic gymnasts. *Journal of Sport Medicine and Physical Fittness, 54,* 683-690.

Dallas, G., Mavidis, A., Kirialanis, P., Papouliakos, S. (2017). The effect of 8-weeks of whole body vibration training on static balance and explosive strength of lower limbs on physical education students. *Acta Gymnica, 47*(4): 153-160.

De Gail, P., Lance, J.W., & Neilson, P.D. (1966). Differential effects on tonic and phasic reflex mechanisms produced by vibration of muscles in man. *Journal of Neurolology and Neurosurgery Psychiatry, 29*, 1–11.

Fernandez-Rio, J., Terrados, N., & Suman, O. (2012). Long-term effects of whole-body vibration training in high-level female basketball players. *Journal of Sports Medicine and Physical Fitness, 52,* 18-26.

Hand, J., Verschuere, S., & Osternig, L. (2009). A Comparison of Whole-Body Vibration and Resistance Training on Total Work in the Rotator Cuff. *Journal of Athletic Training*, *44*, 469-474.

Hortobagyi, T., Lesisnski, M., Fernandez-del-Olmo, M, & Granacher, U. (2015). Small and inconsistent effects of whole body vibration on athletic performance: a systematic review and meta-analysis. *European Journal of Applied Physiology*, *115,* 1605-1625.

Marin, P.J., Rhea,& M.R. (2010). Effects of Vibration Training on Muscle Strength: A Meta-Analysis. *Journal of Strength and Conditioning Research, 24,* 548-556.

Marshall, L.C., & Wyon, M.A. (2012). The effect of whole-body vibration on jump height and active range of movement in female dancers. *Journal of Strength and Conditioning Research, 26,* 789-793.

Moezy, A., Olyaei, G., Hadian, M., Razi, M., & Faghihzadeh, S. (2008). A comparative study of whole body vibration training and conventional training on knee proprioception and postural stability after anterior cruciate ligament reconstruction. *British Journal of Sport Medicine, 42*, 373-378

Nordlund, M.M., & Thorstensson, A. (2007). Strength training effects of whole body vibration? *Scandinavian Journal of Medicine and Science in Sport,17*, 12-17

Paradisis, G., & Zacharogiannis, E. (2007). Effects of whole-body vibration training on sprint running kinematics and explosive strength performance. *Journal of Sport Science and Medicine, 6*, 44-49.

Pérez-Turpin, J.A., Zmijewski, P., Jimenez-Olmedo, J.M., Jové-Tossi, M.A., Martínez-Carbonell, A., Suárez-Llorca, C., & Andreu-Cabrera, E. (2014). Effects of whole-body-vibration on strength and jumping performance in volleyball and each volleyball players. *Biology of Sport, 31*, 239-245.

Pollock, R.D., Woledge, R.C., Martin, F.C., & Newham, D.J. (2012). Effects of whole body vibration on motor unit recruitment and threshold. *Journal of Applied Physiology, 112*, 388-395.

Preatoni, E., Colombo, A., Verga, M., Galvani, C., Faina, M., Rodano, R., Preatoni, E., & Cardinale, M. (2012). The effects of whole body vibration in isolation or combined with strength training in female athletes. *Journal of Strength and Conditioning Research, 26*, 2495-2506.

Rehn, B., Lidstrom, J., Skoglund, J., & Lindstrom, B. (2007). Effects on leg muscular performance from whole-body vibration exercise: A systematic review. *Scandinavian Journal of Medicine and Science in Sports, 17*, 2-11.

Roberts, B., Hunter, I., Hopkins, T.Y., & Feland, B. (2009). The short-term effect of whole-body-vibration training on sprint start performance in collegiate athletes. *International Journal of Exercise and Science, 2*, 264-267.

Rohmert, W., Wos, H., Norlander, S., & Helbig, R. (1989). Effects of vibration on arm and shoulder muscles in three body postures. *European Journal of Applied Physiology and Occupation Physiology, 59*, 243-248.

Ronnestad, B.R. (2004). Comparing the performance-enhancing effects of squats on a vibration plate with conventional squats in recreational resistance-trained men. *Journal of Strength and Conditioning Research, 18*(4), 839-845

Rothmuller, C., & Cafarelli, E. (1995). Effect of vibration on antagonist muscle coactivation during progressive fatigue in humans. *Journal of Physiology, 485*, 857-864

Sands, W.A., McNeal, J.R., Stone, M.H., Russell, E.M., & Jemni, M. (2006). Flexibility Enhancement with Vibration: Acute and Long-Term. *Medicine and Science in Sports and Exercise, 38*, 720-5

Sands, W.A., McNeal, J.R., Stone, M.H., Haff, G.G., & Kinser, A.M. (2008). Effect of vibration on forward split flexibility and pain perception in young male gymnasts. *International Journal of Sports and Physiology Performance, 3,* 469-81

Shin, S., Lee, K., & Song, C. (2015). Acute effects of unilateral whole body vibration training non single leg vertical jump height and symmetry in healthy men. *Journal of Physical Therapy and Science, 27*, 3923-3928.

Stone, M.H., Ramsey, M.W., Kinser, A.M., O'Bryant, H.S., Ayres, C., & Sands, W.A. (2006). Stretching: acute and chronic? The potential consequences. Strength and Condition Journal, *28,* 66-74.

Swearingen, J., Lawrence, E., Stevens, J., Jackson, C., Waggy, C., & Davis, D.S. (2011). Correlation of single leg vertical jump, single leg hop for distance, and single leg hop for time. *Physical Therapy in Sport, 12,* 194-198.

Torvinen, S., Kannus, P., Sievanen, H., et al. (2002a). Effect of four-month vertical whole body vibration on performance and balance. *Medicine and Science in Sport and Exercise, 34*(9), 1523-1528

Tsopani, D., Dallas, G., Tsiganos, G., Papouliakos, S., Di Cagno, A., Korres, G., Riga, M., & Korres, St. (2014). Short-term effect of whole-body vibration training on balance, flexibility and lower limb explosive strength in elite rhythmic gymnasts. *Human Movement Science, 33*, 149-158.

Wyon, M., Guinan, D., & Hawkey, A. (2010). Whole-body vibration training increases vertical jump height in a dance population. *Journal of Strength and Conditioning Research, 24*, 866-870.

Corresponding author:

George Dallas
National and Kapodistrian University of Athens - Physical Education
and Sport Scienc
41, Ethnikis Antistaseos Dafne,
Athens 17237, Greece
T: +0030 210 66 43 704
F: ++0030 210 727 6028
E-mail: gdallas@phed.uoa.gr

MECHANICAL LOWER LIMB MUSCLE FUNCTION AND ITS ASSOCIATION WITH PERFORMANCE IN ELITE TEAM GYMNASTS

Ole H. Hansen [1], Lars G. Hvid [2], Per Aagaard[1] and Kurt Jensen [1]

[1]Department of Sports Science and Clinical Biomechanics, University of Southern Denmark, Odense, Denmark
[2]Section of Sport Science, Department of Public Health, Aarhus University, Aarhus, Denmark

Original article

Abstract

TeamGym (TG) differs from individual gymnastics as it is performed in teams including 6-12 participants competing in acrobatic performance in three disciplines: trampette jumping, tumbling track jumping, and floor exercises. The physical demands required by TG athletes largely remain unknown, and likely are dictated by the specific disciplines and equipment used. This study aimed at describing physiological capacity by investigating mechanical lower limb muscle function and its association with TG performance in 24 senior elite (12 males, 12 females) team gymnasts. Methods: Anthropometrical data as well as 25m sprint ability, repetitive jumps (RJ), countermovement jumping (CMJ), drop jumping from a height of 48cm (DJ_{48}), maximal isometric leg press muscle strength (MVC) and rate of force development (RFD) were measured. Results: Significant sex differences ($p<0.05$) were observed for all variables, except MVC. Total sprint times were 3.36±0.1s in males vs. 3.70±0.1s in females, CMJ height 0.51±0.05 vs. 0.41±0.03m, DJ_{48} rebound height 0.43±0.06 vs. 0.34±0.06m, with no difference in concentric peak power production between CMJ and DJ_{48}. MVC was 38.3±9.9N/kg in males vs. 36.4±9.2N/kg in females. In female gymnasts, correlations ($r^2=0.41-0.46$, $p<0.05$) were found between trampette and tumbling performance and sprint ability. In male gymnasts, correlations ($r^2=0.44$, $p<0.05$) emerged between trampette performance and relative RFD (%MVC/s). Conclusions: Moderate associations were found between mechanical lower limb muscle function and functional tumbling performance in male and female TeamGym, indicating that performance in elite TeamGym also relies on factors other than isolated mechanical muscle function.

Keywords: *TeamGym, sprint, jumping, maximal strength, RFD, acrobatic performance.*

INTRODUCTION

The sport of gymnastics comprises different disciplines like sports acrobatics, rhythmic sports gymnastics and artistic gymnastics. As a sub-discipline, TeamGym (TG) is becoming increasingly popular with European Championships conducted biannually since 1993 (Elbaek & Froberg 1993). In TG the gymnasts compete in teams of 6-12 gymnasts in 3 disciplines: 1) advanced acrobatics on the trampette, with and without vaulting table, 2) tumbling with both forward, and backwards acrobatic routines, and 3) floor routine with dance elements, acrobatics, and choreography. The performances of the gymnasts are evaluated on basis of the difficulty and the quality of the acrobatic drills and the floor routine (Sjöstrand et al. 2015). The combined scores assigned to the 3 disciplines determine the final ranking of the teams.

Few scientific studies have investigated TG, most of them with a focus on common types and frequency of musculoskeletal injuries (Harringe et al. 2004; Harringe et al. 2007). In general, the acrobatic performance of gymnastics involves highly complex full-body movements and TG has been shown to induce substantial stress on the lower extremities (Harringe et al. 2004; Harringe et al. 2007; Lund & Myklebust 2011).

In an early study conducted in 1992, the year prior to the first European Championship, Elbaek & Froberg (1993) investigated the capacity of Danish club-level TG gymnasts. They concluded that TG athletes were characterized by superior anaerobic power and strength levels compared to a control group of physical education students. Since this early report, exercise equipment such as the tumbling track and the trampette has evolved considerably worldwide resulting in increased levels of difficulty of the acrobatic skills. Accordingly, an increased demand for high technical and physical capacity has been introduced in modern TG competitions.

Power generation, explosive-type movements and high anaerobic capacity are among performance-decisive factors across various gymnastic disciplines. (Elbaek & Froberg 1993; Bale & Goodway 1990; Jensen et al. 2013; Jemni et al. 2000; Suchomel et al. 2016; Aleksić-Veljković et al. 2016). However, these aspects have not previously been systematically examined in elite TG athletes. Therefore, the purpose of the present study was to describe the physiological capacity of international level TG athletes by examining mechanical lower limb muscle function (Power, MVC strength, RFD) and its associations to TG performance in Danish elite male and female team gymnasts. It was hypothesised that several of the test outcome would be related to TG performance among these athletes.

METHODS

The participants recruited for the study were senior gymnasts from the 2016 National Danish Teams (male, female and mix). Testing was performed prior to the Danish National Championship. Exclusion criterion was current musculoskeletal injuries to the back or the lower extremities. Participants were experienced in performing regular testing in their clubs or at National Team training camps. They gave their informed consent to participate in the test protocols and were well informed of the potential risks. A total of 12 male and 12 female team gymnasts completed the tests. Age, body height, body weight, body fat, training hours and TG performance are reported in Table 1.

Participants reported their current performance level in different acrobatically skills. The reported skills were divided into (i) trampette jumping and (ii) tumbling jumping. The international Code of Points (Sjöstrand et al. 2015) were used to rate the difficulty of performance (D-score) and the total score of the three most difficult skills in both trampette and tumbling were selected for analysis. Notably, the D-score has no upper limits. To the best knowledge of the authors, the highest scores for an individual skill in trampette or series of skills in tumbling recorded at any international championships (males) have been 2.35 and 2.9 points, respectively.

All participants were instructed to refrain from strenuous exercise 24 hours prior to testing. Participants received instructional videos and photos of the tests prior to testing, alongside written information about the test procedures. The tests were executed in the presented order.

All participants performed the tests barefooted wearing regular training clothes.

Body height was measured using a standard wall measuring scale and the nearest 0.5cm was registered (SECA, Hamburg, Germany). Body and fat mass were measured using bioelectrical impedance (Tanita MC-780MA Body Composition Analyzer, Tokyo, Japan).

Time to sprint 25m from a standing start with intermediate times recorded at 5, 10, 20m and 25m was assessed using an automatic photo cell-based timing system (Swift Performance SpeedLight Dual-beam, Wacol, Australia). The start of the sprint was initiated from a sensor placed on the ground at the 0m marking. Participnts warmed up for 5 minutes by graded running and were instructed to complete two sprints of ~80-90% of their maximal voluntary effort. Participants performed the test barefooted on a wooden floor. Participants performed one sub-maximal trial (~80-90% of maximal effort) running between the light gates to get familiarized with the equipment. Subsequently, participants performed three maximal trials, where they were instructed to pass the 25m markers as fast as possible. In case of continous improvement over the three trials, an extra trial was given. The test leader (OHH) provided strong verbal encouragement during all trials.

RJ was performed on a contact-mat (0.6 by 0.6m) (Swift Performance SpeedMat, Wacon, Australia) as previously described (Hérbert-Losier & Eriksson 2014). The test consisted of a series of jumps where the aim was to perform 10 continuous vertical jumps as high as possible using the shortest possible contact time. The test was performed with the hands placed on the hips and participants performed as many sub-maximal trials as desired before performing two maximal trials. First and final jump were excluded, leaving 8 jumps for analysis. Reactive strength index (RSI = jump height / contact time) was calculated (Young 1995). The trial with the highest RSI was selected for further analysis.

CMJ was performed on a force plate embedded into the floor of the Lab (0.6 by 0.4m) (Kistler 9281 B, Amherst, US) as described in detail previously (Thorlund et al. 2008). The vertical ground reaction force signal (Fz) was digitally sampled at 1000Hz. Participants stood still on the force plate with their hands placed at their hips and then performed a smooth movement into a self-chosen depth, followed by a fast-upward movement resulting in take-off and a vertical flight phase (cf. Fig.2 in Thorlund et al. 2008). The participants performed a self-chosen number of familiarization trials maybe at ~80% of maximal effort before completing three CMJ trials at maximal effort. The trial with the highest jump was selected for analyses. Maximal vertical jump height of the Body Centre of Mass (BCM) and peak leg extensor power during the concentric take-off phase were calculated by second order integration of the Fz signal as described in detail elsewhere (Thorlund et al. 2008).

DJ_{48} was performed from a 0.48m elevated drop force plate (0.51 by 0.46m) (AMTI R6-1000, Watertown, MA) while landing on the Kistler force plate used for CMJ. The Fz signals from both the AMTI and Kistler force plates were synchronously digitally sampled at 1000Hz. The analytical approach regarding the dual force plate method has previously been described in details by Baca (1999). The Kistler force plate acted as the rebound surface, whereupon the participants performed a drop landing followed by a rapid rebound movement (CMJ) followed by a rebound flight phase and subsequently landing on the ground level force plate (Kistler). Maximal vertical BCM flight height and peak leg extensor power during the concentric rebound phase were calculated as described above for the CMJ. Participants performed a self-chosen number of familiarization trials at ~80% of maximal effort and subsequently performed a minimum of three trials at maximal effort.

Maximal strength and rate of force development (RFD) of the participants' dominant leg were assessed using static leg press testing in a custom-built leg press device with a fixed footplate instrumented with piezoelectric force transducers (Kistler 9367/8 B, Amherst, US) (Caserotti et al. 2008). The force signal was digitally sampled at 1000Hz, and subsequently lowpass filtered by a digital fourth-order, zero-lag Butterworth filter using a cut-off frequency of 10Hz. The latter was carried out off-line using a custom-built MatLab macro (MatLab 15a. MathWorks, MA, US).

Participants were seated with their thigh in a horizontal position and the knee joint fixed at a 120° position (0° = full extension). Arms were crossed over the chest and the back kept straight during all trials. Following three submaximal warm-up trials, three trials were performed at maximal voluntary effort. Participants were instructed to produce as much force as possible and to reach maximal force output as fast as possible. Participants received real-time visual feedback of the force output and were verbally encouraged during all trials. If there were a variation of more than 5% between the two best trials, an additional trial was performed. The trial with the highest force output (maximal voluntary contraction, MVC) was selected for further analysis. Onset of contraction was defined as the instant when force production exceeded the baseline level force by 2% of the maximal force value. All trials with a visible initial countermovement were discarded from the analysis. Contractile rate of force development (RFD) was derived as the average tangential slope of the force–time curve (Δforce/Δtime) calculated in the time interval 0-30ms and 0-100ms relative to the onset of contraction (RFD_{30ms} and RFD_{100ms}). Additionally, relative RFD was calculated as RFD_{30ms} and RFD_{100ms} normalized to MVC to examine qualitative muscle properties during the initial phase of rising muscle force (Aagaard et al. 2002).

Statistical analysis was performed using SPSS 24.0. Sex difference was tested with an unpaired t-test along with a 95% confidence interval of the difference of means. Assumption of normality was tested using the Shapiro-Wilk test for each variable and Pearson's product moment correlation was used to examine potential relationships between selected tests variables and TG performance. Results are presented as mean ± standard deviation (SD) unless otherwise stated.

RESULTS

Differences between male and female TG athletes were noted for all variables. Males were 11% older, 8% taller, had a 19% greater body mass and 8% lower fat mass than the females. Further, male athletes demonstrated ~50% greater acrobatic difficulty scores than female athletes, despite no significant difference in overall training volume (Table 1).

During 25m sprint testing male TG athletes demonstrated 6-11% faster split-intervals along with 9.2% faster total sprint time compared to female athletes (Table 2). During RJ testing, males had 48% higher RSI than female participants. During stretch-shortening cycle (SSC) testing male TG athletes jumped 24% higher in CMJ accompanied by a 24% greater peak power per kg body weight and jumped 25% higher in the DJ_{48} accompanied by a 18% greater peak power per kg body weight compared to female athletes (Table 2). No sex differences emerged for MVC expressed relative to body mass or for absolute and relative RFD obtained during leg press testing (Table 2). One male participant was excluded in the MVC analysis due to corrupted data signals.

Table 1

Anthropometry and TG performance including P values and 95% confidence intervals of the difference between males and females.

	Male	Female	P	Difference of mean 95% CI
Age (years)	22.2 ± 2.3	20.0 ± 2.3	= 0.02	(0.3, 4.1)
Height (cm)	175.8 ± 5.5	163.0 ± 5.7	<0.001	(8.4, 17.3)
Body mass (kg)	73.3 ± 8.3	61.4 ± 5.8	<0.001	(6.1, 17.6)
Fat mass (%)	13.1 ± 3.0	21.0 ± 3.6	<0.001	(-10.5, 5.2)
Training volume (hours)	9.9 ± 2.6	9.7 ± 1.6	>0.05	(-1.5, 1.5)
Tumbling performance (p)	5.8 ± 0.6	3.9 ± 0.5	<0.001	(1.4, 2.4)
Trampette performance (p)	5.5 ± 0.4	3.7 ± 0.3	<0.001	(1.5, 2.1)

Table 2

Sprint performance and lower limb mechanical muscle function in male and female elite team gymnasts including 95% confidence intervals of the difference between males and females.

	Male	Female	P	Difference of means 95% CI
25 meters sprint test				
Sprint 5m (s)	0.84 ± 0.03	0.92 ± 0.04	<0.001	(-0.1, -0.04)
Sprint 10m (s)	1.57 ± 0.06	1.72 ± 0.05	<0.001	(-0.2, -0.1)
Sprint 20m (s)	2.79 ± 0.09	3.06 ± 0.07	<0.001	(-0.3, -0.2)
Sprint 25m (s)	3.36 ± 0.09	3.70 ± 0.09	<0.001	(-0.4, -0.3)
RJ				
RSI (height/contact-time)	195 ± 32	132 ± 36	<0.001	(36.1, 90.5)
CMJ				
Jump height (cm)	50.7 ± 4.5	41.0 ± 3.0	<0.001	(6.5, 12.9)
Peak power (W/kg)	58.9 ± 7.9	47.6 ± 6.1	<0.001	(5.7, 16.9)
DJ_{48}				
Jump height (cm)	42.7 ± 5.8	34.2 ± 6.1	<0.001	(3.5, 13.5)
Peak power (W/kg)	57.1 ± 4.0	48.3 ± 6.4	<0.001	(4.5, 13.0)
Isometric leg press test				
Peak MVC (N/kg)	38.3 ± 9.9	36 ± 9	>0.05	(-5.9, 9.8)
RFD_{30ms} (N/kg/s)	96.3 ± 27.3	86 ± 43	>0.05	(-18.7, 40.0)
RFD_{100ms} (N/kg/s)	117.3 ± 38,9	110 ± 56	>0.05	(-31.5, 46.6)
Relative RFD_{30ms} (%MVC/s)	253 ± 51	230 ± 79	>0.05	(-31.0, 76.9)
Relative RFD_{100ms} (%MVC/s)	309.0 ± 88.5	298 ± 112	>0.05	(-70.7, 93.69

Table 3
Correlation analysis of male and female team gymnasts' test variables and acrobatic performance.

	Male				Female			
	Total tumbling performance		Total trampette performance		Total tumbling performance		Total trampette performance	
Variables	*Pearson Correlation*	*P-value*	*Pearson Correlation*	*P-value*	*Pearson Correlation*	*P-value*	*Pearson Correlation*	*P-value*
Sprint 5m (s)	-0.065	0.842	-0.031	0.924	**-0.622**	**0.031**	**-0.638**	**0.026**
Sprint 10m (s)	-0.001	0.997	0.023	0.942	-0.515	0.087	**-0.672**	**0.017**
Sprint 20m (s)	0.143	0.657	-0.010	0.975	-0.431	0.162	**-0.680**	**0.015**
Sprint 25m (s)	0.221	0.489	-0.040	0.902	-0.377	0.227	**-0.672**	**0.017**
RJ (RSI)	0.113	0.726	-0.055	0.866	0.367	0.240	0.164	0.612
CMJ (cm)	-0.212	0.509	-0.105	0.745	0.099	0.759	0.416	0.178
CMJ (W/kg)	-0.314	0.320	-0.162	0.615	0.245	0.442	0.430	0.163
DJ_{48} (cm)	-0.417	0.177	0.162	0.615	0.054	0.867	0.451	0.141
DJ_{48} (W/kg)	-0.260	0.414	-0.031	0.923	0.204	0.525	0.515	0.087
Peak MVC (N)	-0.210	0.536	-0.348	0.295	0.416	0.179	-0.042	0.898
Peak force (N/kg)	-0.140	0.682	-0.342	0.303	0.408	0.188	-0.144	0.655
RFD_{30ms} (N/kg/s)	-0.198	0.560	0.088	0.798	0.476	0.118	0.125	0.698
RFD_{100ms} (N//kg/s)	-0.189	0.579	0.102	0.765	0.444	0.148	0.128	0.693
Relative RFD_{30ms}	-0.097	0.778	**0.663**	**0.026**	0.245	0.444	0.189	0.555
Relative RFD_{100ms}	-0.026	0.939	0.440	0.175	0.174	0.588	0.146	0.651

Group means ± SD. Abbreviation: RJ: Reactive Jumps; RSI: Reactive Strength Index, measured by a series of 8 jumps as the [mean jump height / mean contact time between each jump]; CMJ: Countermovement Jump; DJ_{48}: Drop Jump (drop height of 48cm); MVC: Maximal Volunteer Contraction; RFD: Rate of Force Development, defined as the rise in force over time in the early phase (0-100ms) of muscle contraction (ΔForce / ΔTime). Numbers in bold express a significant correlation ($P < 0,05$) between test variables and total tumbling performance and total trampette performance.

Associations between TG performance and mechanical muscle function

Female TG expressed moderate-to-strong relationships between trampette performance and sprint capacity evaluated at 5m ($r^2 = 0.41$, p = 0.02), 10m ($r^2 = 0.45$, p = 0.01), 20m ($r^2 = 0.46$, p = 0.01) and 25m ($r^2 = 0.45$, p = 0.01). Also, 5m-sprint split-time was correlated to females' tumbling performance ($r^2 = 0.39$, p = 0.03). In addition, a moderate-to-strong relationship was found between trampette performance and relative RFD_{30ms} in male TG athletes ($r^2 = 0.44$, p = 0.03).

DISCUSION

The aim of this study was to examining mechanical lower limb muscle function and its associations to TG performance in Danish elite male and female team gymnasts and we hypothesised that several of the test outcome would be related to TG performance. Moderate-to-strong associations were observed between sprint capacity or mechanical lower limb muscle function versus acrobatic performance in the present group of male and female elite TG athletes.

Anthropometrical characteristics

When comparing height and body mass to that of highly trained individual gymnasts, the present male and female TG appears to be taller, heavier and with a higher body fat percentage compared to gender matched individual gymnasts (Jemni et al. 2000; Aleksić-Veljković et al. 2016; Rodrígues et al 2010; George et al. 2013). Rodrígues and colleagues (2013) have previously reported senior male trampoline gymnasts to have a higher fat percentage and greater body mass compared to artistic gymnasts. It has been argued that a small body size in individual gymnastics is beneficial for competitive performance (Bale & Goodway 1990; George et al. 2013). The notion that TG athletes were considerable taller and heavier than reported for individual gymnasts may be explained by differences in equipment and specific performance disciplines between TG and individual gymnastics. Thus, the rebounding equipment in TG may allow the gymnast to use a relatively longer contact time than possible in individual gymnastics, which might be beneficial for vertical impulse generation when the body mass is greater than typically seen in artistic gymnasts.

Sprint capacity

TG gymnasts have a run-up distance of maximum 25m in order to accelerate to the horizontal approach speed needed for performing their acrobatic drills. The present group of TG gymnasts showed faster sprint split-times compared to athletes in intermittent sports like i.e. football, hockey, netball who also rely on high sprinting velocity (Tanner & Gore 2013), indicating that high anaerobic muscle power is important in TG. In TG, the surface of the trampette is normally set to an angle of 20-30° relative to horizontal, which makes it possible for the TG gymnast to effectively convert a high horizontal run-up speed into a high vertical speed in the take-off phase, in turn resulting in a long flight time and high vertical jump height. In theory, an increased run-up speed will lead to a greater vertical jump height, due to a gain in vertical take-off velocity. However, in real-life settings even highly experienced TG gymnast may not benefit entirely from maximal running velocity during the run-up. The gymnast must overcome the reactive force during the time of contact with the trampette prior to take-off. If the achieved approach velocity is too high, the gymnast may find it difficult to reach the preferred hip and knee joint angle position at the instant of eccentric-to-concentric SSC transition as well as at the instant of take-off, thereby not reaching optimal vertical height of the jump. Thus, it is unlikely for TG athletes to use their maximal sprint capacity. In contrast, in competitive team sports such as football and team handball the ability to repeat maximal sprints during a match generally is considered a highly important factor (Bangsbo et al. 2006).

Sprint capacity at 5, 10, 20 and 25m were moderate-to-strongly associated with trampette performance in female TG athletes, explaining 41-46% of the observed variance in TG scores. Further, a correlation between 5m sprint capacity and tumbling performance was observed in female TG athletes indicating that high acceleration capacity is important for executing drills with high difficulty in acrobatic performance, at least among females. Thus, gymnasts with a strong acceleration capacity may be able to obtain more optimal control of the magnitude and direction of the impact force vector exerted on the trampette throughout the take-off phase.

Vertical Jumping Capacity

Trampette jumping and tumbling drills are fundamental aspects in TG-training. To evaluate different aspects of jumping performance, a range of vertical jump tests were used in the present study such as CMJ, drop jumping (DJ) and reactive jumping (RJ). During CMJ testing duration of the take-off is often longer than observed when performing rapid DJ from a given drop height (Bobbert et al.1986) and longer than in RJ where the athletes intend to achieve a short take-off time (<250ms) combined with a high vertical jump height. These different jump types may be used to indicate the ability of the gymnast to produce SSC muscle power. CMJ testing represents the simplest way to assess anaerobic SSC leg muscle power, while DJ testing also reflects eccentric power generation that transits into a rebound-jump movement while also monitoring the concurrent concentric power production for the lower limb extensors. RJ reflects the ability to repeat vertical jumping of maximal flight height using a short take-off time, which may be relevant for tumbling performance. During the present application of CMJ, male TG athletes demonstrated relative high jumping capacity (0.51m BCM flight height) accompanied by substantial amounts of maximal muscle power generation in the concentric take-off phase (59W/kg). Our female TG athletes showed corresponding values of 0.41m and 48W/kg, which seem substantially higher than previously reported by Donti and colleagues in female artistic gymnasts (0.30m and 40W/kg, respectively) (Donti et al. 2014). Also, in comparison to Danish male trampoline gymnasts, the present male TG athletes demonstrated greater vertical jump height during CMJ (Jensen et al. 2013). Further, when compared to a group of mixed athletes (ski jumpers, alpine and freestyle skiers, snowboarders, and gymnasts) (Hilfiker et al. 2007), the present male and female TG athletes were within the same range of maximal vertical jump height (~0.32-0.47m) and leg extensor peak power (~45-65W/kg). This comparison indicates that TG athletes have relatively strong SSC jumping (CMJ) capabilities, which might be due to large amounts of TG training with focus on ballistic-type SSC movements.

The DJ_{48} test was chosen to simulate the impact and take-off phase in the trampette and the tumbling drills. Male and female TG athletes demonstrated reduced DJ rebound height (but not peak power production) compared with CMJ, which may not be surprising due to the high eccentric impact loads imposed on the leg extensor muscles during the deceleration and acceleration phases of the DJ (Young 1995; Tanner & Gore 2013). In the present study males and females jumped from the same drop height (0.48 m). Ideally, DJ height should have been individually adjusted in order to assess and compare the capacity for absorbing kinetic energy and impulse during the rebound phase to increase rebound-jumping height across different participants (Young 1995; Tanner & Gore 2013; Taube et al. 2012). Suchomel and colleagues (2016) previously investigated the DJ abilities of male elite junior artistic gymnasts (~15 years). Compared to these junior gymnasts (rebound-jump height ~0.30m), our male TG athletes showed a markedly higher rebound-jump height (~0.43m). When compared to elite male volleyball, basketball, soccer players and recreational athletes (drop jump rebound height ~0.32m) (Cappa & Behm 2013), male TG athletes also appeared to jump higher.

The RJ test was implemented to study the ability of rapidly transforming a landing to a take-off in a series of repetitive jumps, simulating performance in the tumbling discipline. It was hypothesised that team gymnasts would be comparable to track and field jumpers, as jumping exercise of various forms comprise a large part in the training performed in TG. The reactive strength index (RSI) was calculated as the ratio between average jump height and take-off time (Young 1995). Surprisingly, compared to athletics, the present gymnasts demonstrated a 58% lower RSI compared to track and field jumpers, indicating that TG athletes are not equally explosive or powerful in the transmission between landing and take-off compared to state-of-the-art athletes in this field. It is possible that the relatively soft equipment used in tumbling causing the gymnasts to get used to employing a longer contact time (>250ms) between successive landings performed in an acrobatic combination, compared to the contact times observed in track and field sprinting and high jumping (<250ms).

Maximal lower limb muscle strength and RFD

High maximal muscle force capacity would seem a desirable feature for elite TG gymnasts, due to the high take-off forces generated during the impact with the trampette and tumbling track prior to take-off, and the impact forces during the subsequent landing phase (McNitt 1993). The present male TG athletes demonstrated MVC values that were comparable to that observed in newly drafted males prior to initiation of military training (age 20 years, height 175cm, force 2884N) (Asmussen & Heebøl-Nielsen 1961). The present group of female TG athletes had MVC values that were slightly higher than previously reported in female students (age 20 years, height 165cm, force 2099N) (Asmussen & Heebøl-Nielsen 1961).

MVC-normalized RFD (%MVC/s) represents a measure of the athlete's ability to express the maximal force-generating capacity in an explosive movement (Maffiuelti et al. 2016). This ability appears to be enhanced in track and field power athletes (determined at 0-50ms from onset of muscle contraction) compared to non-athlete (Tillin et al. 2010). This difference could be an indication of qualitative adaptations in power athletes, who may be characterized by higher maximal motor unit discharge rates and elevated proportions of type II muscles fibres (Maffiuelti et al. 2016). These possible adaptations and inherent neuromuscular properties have been suggested to have important influence on athletic performance (Tillin et al. 2010). In the present study, male TG gymnasts with superior performance in the trampette were also able to produce a relatively higher proportion of their maximal force capacity when evaluated in the most initial phase of muscle contraction (0-30ms). This early-phase RFD-component is likely important in the initial phase of trampette contact, due to the rapid extension of the knees and hips at the instant of contact. This rapid extension is performed to produce as much force as possible to produce a maximal reactive breaking impulse, to enable a maximal amount of elastic energy storage in the trampette for use (recoil) in the subsequent take-off phase.

In summary, female elite TeamGym athletes demonstrated moderate-to-strong associations between TG performance and sprint capacity while also positively related to relative rate of force development in male athletes. In addition, TG athletes showed high sprint capacity while also characterized by high muscle power production and performance outcome during selected jumping tasks indicating that high running velocity and superior power production may be important in elite TeamGym. However, as only moderate-to-strong associations were found, performance in elite TeamGym must also rely on factors other than isolated mechanical muscle function.

Limitations

The chosen test battery might not fully complete to detect which physiological factors might best describe the sport in team gymnasts. Sport specificity could be improved by using a more specific foot position during the unilateral strength test as most gymnastic skills are performed with both feet close together at take-off, and therefore the unilateral leg press test might not be the ideal test for performance in TG. Also, although the gymnasts were high skilled, the results might be improved by including familiarization trials. Another limitation would be, that only tests involving lower body were included. Kaldas and colleagues (2017) showed a significant correlation between performance level in artistic gymnastics and a push-up test ($r^2 = 0.91$) as well as a pull-up test ($r^2 = 0.80$). In future studies of TeamGym, upper body strength is recommended to be included in the battery. As in studies with elite athletes, the number of participants is limited to the very best. However, the strength is, that these athletes are supposed to be representative for top best sport performance.

CONCLUSIONS

This study shows that team gymnasts should focus to reach a high vertical jumping capacity, accompanied by strong sprint and acceleration skills in order to improve the physiological and biomechanical basis for their TG performance. Accordingly, it is recommended that TG athletes become exposed to plyometric jump training as well as heavy resistance training to form a strong base of muscle strength and power capacity as a prerequisite for developing the specific acrobatic expertise involved in TeamGym performance.

ACKNOWLEDGEMENT

Authors would like to thank the volunteers who participated in the study.

REFERENCES

Aagaard, P., Simonsen, E.B., Andersen, J.L., Magnusson, P., Dyhre-Poulsen, P. (2002). Increased rate of force development and neural drive of human skeletal muscle following resistance training. *J Appl* Physiol *93*(4),1318-1326.

Aleksić-Veljković, A., Veličković, S., Sands, W.A., Đurović, D., Trajković, N. (2016). Explosive power in gymnasts: Is there any scientific basis for gender differences? *Facta Universitatis: Series Physical Education & Sport 14*(1),121-126.

Asmussen, E., Heebøl-Nielsen, K. (1961). Isometric muscle strength of adult men and women. *Communications,* 43-43.

Baca, A. (1993). A comparison of methods for analyzing drop jump performance. / Comparaison de differentes methodes d'analyse de la performance lors de sauts en profondeur. *Med Sci Sports Exerc 31*(3),437-442.

Bale, P., Goodway, J. (1990). Performance variables associated with the competitive gymnast. / Variables de performance du gymnaste de competition. *Sports Medicine 10*(3),139-145.

Bangsbo, J., Mohr, M., Krustrup, P. (2006). Physical and metabolic demands of training and match-play in the elite football player. *J Sports Sci 24*(7),665-674.

Bobbert, M.F., Mackay, M., Schinkelshoek, D., Huijing, P.A., van Ingen Schenau, G.J. (1986). Biomechanical analysis of drop and countermovement jumps. *Eur J Appl Physiol Occup Physiol* 54(6):566-573

Cappa, D.F., Behm, D.G. (2013). Neuromuscular Characteristics of Drop and Hurdle Jumps with Different Types of Landings. *J Strength Cond Res* 27(11), 3011-3020.

Caserotti, P., Aagaard, P., Buttrup Larsen, J., Puggaard, L. (2008). Explosive heavy-resistance training in old and very old adults: changes in rapid muscle force, strength and power. *Scand J Med Sci Sports 18*(6),773-782.

Donti, O., Tsolakis, C., Bogdanis, G.C. (2014). Effects of Baseline Levels of Flexibility and Vertical Jump Ability on Performance Following Different Volumes of Static Stretching and Potentiating Exercises in Elite Gymnasts. *J Sports Sci Med 13*(1), 105-113.

Elbaek, L., Froberg, K. (1993). *Specific physical training paramaters in relation to danish team gymnastics* (Les parametres d'entrainement physique specifique rapportes a l'equipe danoise de gymnastique). In. Allemagne: Koln: Sport und Buch Strauss.

George, D., Elias, Z., George, P. (2013). Physiological profile of elite Greek gymnasts. *Journal of Physical Education & Sport 13*(1), 27-32.

Harringe, M., Lindblad, S., Werner, S. (2004). Do team gymnasts compete in spite of symptoms from an injury? *Br J Sports Med 38*(4), 398-401.

Harringe, M., Renström, P., Werner, S. (2007). Injury incidence, mechanism and diagnosis in top-level teamgym: a prospective study conducted over one season. *Scand J Med Sci Sports 17*(2),115-119.

Hébert-Losier, K., Eriksson, A. (2014). Leg stiffness measures depend on computational method. *J Biomech 47*(1),115-121.

Hilfiker, R., Hübner, K., Lorenz, T., Marti, B. (2007). Effect of drop jumps added to the warm-up of elite sport athletes with high capacity for explosive force development. *J Strength Cond Res 21*(2), 550-555.

Jemni, M., Friemel, F., Lechevalier, J.M., Origas, M. (2000). Heart rate and blood lactate concentration analysis during a high-level men's gymnastics competition. / Analyse de la frequence cardiaque et du lactate sanguin lors d ' une competition de haut niveau en gymnastique masculine. *J Strength Cond Res 14*(4), 389-394.

Jensen, P., Scott, S., Krustrup, P., Mohr, M. (2013). Physiological responses and performance in a simulated trampoline gymnastics competition in elite male gymnasts. *J Sports Sci 31*(16), 1761-1769.

Kaldas, J., Bisson, C., Hogue, A-C., Apinis, C., Berbiche, D., Gaudrealt, N. (2017). Construct validity and inter-rater reliability of the Gymnastic Functional Measurement Tool in the classification of female competitive gymnasts in Canada. *Physical Therapy in Sport 28,* 9-14.

Lund, S.S., Myklebust, G. (2011). High injury incidence in TeamGym competition: a prospective cohort study. *Scand J Med Sci Sports 21*(6), 439-444.

Maffiuletti, N., Aagaard, P., Blazevich, A., Folland, J., Tillin, N., Duchateau, J. (2016). Rate of force development: physiological and methodological considerations. *Eur J Appl Physiol 116*(6), 1091-1116

McNitt, G-J. (1993). Kinetics of the lower extremities during drop landings from three heights (Cinetique des membres inférieurs lors de la reception de sauts en profondeur a partir de trois hauteurs.). *J Biomechs 26*(9), 1037-1046.

Rodríguez, L.A.G-L., Santana, M.V., Bedoya, J.L. (2010). Somatotipo y composición corporal en gimnastas de Trampolín masculino español de alto nivel. / Somatotype and body composition in elite male Spanish Trampoline. *RICYDE Revista Internacional de Ciencias del Deporte 6*(19), 141-153.

Sjöstrand, P., Lemmetty, H., Hughes, K., Gryga, P., Dvoracek, R., Jónsdóttir, S. (2015). European Championship in TeamGym - Seniors and Juniors Code of Points.

Suchomel, T.J., Sands, W.A., McNeal, J.R. (2016). Comparison of static, countermovement, and drop jumps of the upper and lower extremities in U.S. junior national team male gymnasts. *Science of Gymnastics Journal 8*(1), 15-30.

Tanner, R.K., Gore, C.J. (2013). *Physiological Tests for Elite Athletes.* 2.ed. Australia: Human Kinetics.

Taube, W., Leukel, C., Lauber, B., Gollhofer, A. (2012). The drop height determines neuromuscular adaptations and changes in jump performance in stretch-shortening cycle training. *Scand J Med Sci Sports 22*(5), 671-683.

Thorlund, J.B., Michalsik, L.B., Madsen, K., Aagaard, P. (2008). Acute fatigue-induced changes in muscle mechanical properties and neuromuscular activity in elite handball players following a handball match. *Scand J Med Sci Sports 18*(4), 462-472.

Tillin, N.A., Jimenez-Reyes, P., Pain, M.T.G., Folland, J.P. (2010). Neuromuscular Performance of Explosive

Power Athletes versus Untrained Individuals. *Med Sci Sports Exerc 42*(4), 781-790.

Young, W. (1995). Laboratory strength assessment of athletes. / Evaluation en laboratoire de la force des athletes. *New Studies in Athletics 10*(1), 89-96.

Corresponding author:

Kurt Jensen
Department of Sports Science and Clinical Biomechanics
University of Southern Denmark,
Campusvej 55, 5220,
Odense M,
Denmark
Phone +45 65506089
E-mail: kjensen@health.sdu.dk

IMPACT OF GYMNASTICS TRAINING ON THE HEALTH-RELATED PHYSICAL FITNESS OF YOUNG FEMALE AND MALE ARTISTIC GYMNASTS

Iliya Kiuchukov[1], Iliya Yanev[1], Lubomir Petrov[1], Stefan Kolimechkov[1,2], Albena Alexandrova[1], Dilyana Zaykova[1], Emil Stoimenov[1]

[1] National Sports Academy, Sofia, Bulgaria
[2] Elite Gymnastics Academy CIC - Coaching Department, London, Great Britain

Original article

Abstract

Artistic gymnastics can be practised from an early age and develops the main components of physical fitness. The aim of this study was to assess the physical fitness of young competitive artistic gymnasts from Bulgaria. A total of 161 gymnasts (81 females and 80 males), who were divided into three groups (from 5-8, 9-11, and 12-15 years of age), with sports experience from 12 to 180 months, took part in this study. All of the participants completed the extended version of the Alpha-Fit physical fitness test battery, with European norms being applied to calculate percentile scores for each fitness test. The height-for-age percentile scores in the groups between the ages of 9-11 and 12-15 were significantly lower from the 50th percentile of the international norms, both for male and female gymnasts. Gymnasts showed substantially lower body fat, and only one gymnast was assessed as overweight, with two being classified as obese. The percentile scores of the standing long jump and the 4x10 m SRT in the groups were significantly greater than the 50th percentile of the available European norms. The percentile scores of the VO_2max in all female groups were also higher than the 50th percentile of the European norms, while those for males did not differ from the 50th percentile, except in the 5-8 age range. Artistic gymnastics improves the physical fitness components and positively influences children's physical development. Both female and male artistic gymnasts had better physical fitness in most parameters, in comparison with their peers.

Keywords: *physical fitness, artistic gymnasts, gymnastics, alpha-fit.*

INTRODUCTION

Artistic gymnastics is one of the few sports which can be practised from a very young age, and which develops different components of physical fitness. Pupils learn basic elements which are of great significance, especially for children's orientation in space, such as jumps and leaps, hanging, rotating, crawling, rolling, etc. (Pajek, Cuk, Kovac, & Jakse, 2010).

Health-related physical fitness is a major factor in children's health, and it has a multidimensional structure consisting of the following components: body composition, musculoskeletal fitness, motor fitness (speed, agility and coordination), and cardiorespiratory fitness (ALPHA, 2009; Artero et al., 2011; Ruiz et al., 2009; Ruiz et al., 2010). There are different fitness test batteries, such as Alpha-fit, Eurofit, FitnessGram, etc., which are applied around the world in order to assess physical fitness in children and adolescents (Kolimechkov, 2017). Based on many longitudinal and cross-sectional studies, a wide range of authors define the Alpha-fit test battery as an ideal tool, encompassing a valid, reliable and safe set of tests for the assessment of physical fitness in children and adolescents (Cvejic, Pejovic, & Ostojic, 2013; Romero et al., 2010; Ruiz et al., 2010; Santos & Mota, 2011).

Optimal health and level of physical fitness are essential for all gymnasts in order to be able to effectively and accurately perform varied elements and routines. The physical fitness assessment can provide information which allows us to track the impact of the sport on each gymnast's health (British Gymnastics, 2015).

There are currently around 700 artistic gymnasts who are registered with the Bulgarian Gymnastics Federation, and more than 600 of them are under the age of 17. Therefore, the aim of this study was to assess the physical fitness levels of a representative sample of young competitive artistic gymnasts from different regions in Bulgaria, and show the impact of the training on the gymnasts' health by using the Alpha-Fit test battery.

METHODS

This study included a representative sample of 25% of all registered young artistic gymnasts. Thus, this study involved the participation of 161 artistic gymnasts (81 females and 80 males) who regularly took part in, or were preparing for, competitions. The gymnasts were between the ages of five and fifteen, from four different cities in Bulgaria (Sofia, Blagoevgrad, Veliko Tarnovo and Ruse) representing nine different gymnastics clubs which are registered with the Bulgarian Gymnastics Federation. The average sports experience of all participants in artistic gymnastics was 3.6 years (from 1 to 15 years).

The gymnasts were divided into three age groups (from 5 to 8, 9 to 11, and 12 to 15 years of age) and according to gender.

Institutional ethics approval for this research was granted by the National Sports Academy in Sofia, and informed consent was obtained from the parent/guardian of each gymnast.

All artistic gymnasts completed the extended version of the Alpha-Fit physical fitness test battery (ALPHA, 2009), which included the following anthropometric measurements and tests: height, weight, waist circumference, triceps and subscapular skinfolds to assess body composition; handgrip strength and standing long jump to assess musculoskeletal fitness; the 4x10 m shuttle run test (4x10 m SRT) to assess motor fitness; and the 20 m shuttle run test (20 m SRT) to assess cardiorespiratory fitness.

Stature was measured to the nearest 0.1 cm with a stadiometer, body mass was recorded to within an accuracy of 0.1 kg by using the Omron BF511 electronic scale, and waist and arm circumferences were measured to the nearest 0.1 cm with the Lufkin W606PM tape measure. All of the measurements were recorded by following the anthropometric procedures thoroughly (NHNES, 2007; Piwoz & Viteri, 1985). Body mass index (BMI) was calculated as: body mass in kilograms/stature in metres squared. In addition, the percentile scores for each gymnast's height, weight and BMI were computed and assessed by using the WHO AnthroPlus specialised software, provided by the World Health Organisation (WHO, 2011). The following classification of the BMI percentile scores (PRs) for children and adolescents between the ages of 5 and 19, provided by the WHO, was applied:

BMI > 85th PRs is classified as 'overweight'; BMI > 97th PRs is 'obese'; BMI < 15th PRs is 'thinness'; and BMI < 3rd PRs is 'severe thinness' (WHO, 2007a).

Waist-to-height ratio (WHtR) was calculated by dividing waist circumference (cm) by height (cm), and the simple cut-off of WHtR = 0.500 was used to assess increased health risk in children relating to an excessive accumulation of body fat on the upper body (Ashwell & Hsieh, 2005; McCarthy & Ashwell, 2006).

The triceps and subscapular skinfolds were measured with the Lange Skinfold Caliper, Beta Technology Inc, Cambridge to an accuracy of 1 mm. Body fat percentage (%Fat) was determined by the sum of the two skinfolds, using Slaughter's equations (Heyward & Stolarczyk, 1996; Slaughter et al., 1988), which are highly recommended for children and adolescents because of the accuracy and simplicity of this method (ALPHA, 2009; Boye et al., 2002; Laurson, Eisenmann, & Welk, 2011). Body fat percentile scores were computed by using the recent international norms for Caucasian children and adolescents (McCarthy, T.J. Cole, T. Fry, S.A. Jebb, & Prentice, 2006). In order to classify %Fat the following cut-offs were applied: %Fat > 85th PRs is classified as 'overweight'; %Fat > 95th PRs is 'obese'; and %Fat < 2nd PRs is 'underfat' (McCarthy et al., 2006).

The upper arm muscle area (UAMA) was calculated from the arm circumference and the triceps skinfold by using the following formula (Addo, Himes, & Zemel, 2017):

$$\text{UAMA} = [\text{Arm circumference} - (\pi \times \text{triceps skinfold})]^2 \div 4 \times \pi$$

Percentile scores for the UAMA were computed for each gymnast by using the recent norms for children and adolescents (Addo et al., 2017). In addition, the relative UAMA (cm^2/kg) was also calculated by dividing the UAMA (cm^2) by body mass (kg).

Handgrip strength was measured for both hands by using the SH5001 Hydraulic Hand Dynamometer to assess upper body isometric strength. The elbow of the tested hand was fully extended and the testing procedure was strictly followed (ALPHA, 2009; NHANES, 2013). The relative handgrip strength for each participant was also calculated by dividing the average handgrip strength (kg) by the body mass (kg).

The standing long jump test was performed to assess lower body explosive strength on a non-slippery hard surface, and the test was recorded to within an accuracy of 1 cm. The distance was measured from the take-off line to the point where the back of the heel, nearest to the take-off line, lands on the ground (ALPHA, 2009).

Percentile scores for the average handgrip strength and the standing long jump were computed by using the available European norms for children (Miguel-Etayo et al., 2014) and adolescents (Ortega et al., 2011). Linear interpolations and extrapolations between the existing European norms were applied in order to compute percentile scores for those ages which were not published, these being 5, 10, 11 and 12-year-old children (Kolimechkov, Petrov, & Alexandrova, 2018).

The 4x10m SRT at maximum speed was performed to measure speed of movement, agility and coordination, in accordance with the standard procedure described in the Alpha-fit test battery (ALPHA, 2009). The test was recorded in seconds by using a stopwatch to an accuracy of 0.1 sec. The percentile scores of the results were calculated by using the available European norms for children (Roriz De Oliveira, Seabra, Freitas, Eisenmann, & Maia, 2014) and adolescents (Ortega et al., 2011). Percentile scores for the missing years (5, 11 and 12-year-old children), in which there was a gap in the norms, were computed by using linear interpolations and extrapolations of the existing

European percentiles (S. Kolimechkov et al., 2018).

The estimated maximal oxygen uptake (VO_2max) was calculated by using a modified version of the 20 m SRT in order to assess the cardiorespiratory fitness of the artistic gymnasts. The modified test required running between two lines which were 10 m apart, in time with an audio signal, instead of the original 20 m. This modification made the administration of the test more convenient when conducted inside the gymnastics centres (on the gymnastics floor 12x12 m). An extended specialised version of the BeepShuttle Junior software (Kolimechkov, Petrov, Alexandrova, & Cholakov, 2018) was applied in order to administer the 10 m SRT. The software applies the original 1-minute protocol, which starts at a speed of 8.5 km/h and increases in speed by 0.5 km/h after each minute, as described by Leger et al. (Leger, Lambert, Goulet, Rowan, & Dinelle, 1984). Moreover, the software calculated the predicted VO_2max by using Leger's equation (Leger, Mercier, Gadoury, & Lambert, 1988) in addition to the percentile score for each participant based on age- and gender-specific international norms (Miguel-Etayo et al., 2014; Tomkinson et al., 2016).

All anthropometric measurements were taken twice, and the mean was used in the analyses, as recommended in the test manual of the Alpha-fit battery. The handgrip strength test, standing long jump test and 4x10 m SRT were performed twice, and the better score was used in the analyses, whilst the cardiorespiratory test was performed once (ALPHA, 2009).

The statistical analyses were conducted with SPSS Statistics 19 software, using descriptive statistics and One-way ANOVA with the Bonferroni *post hoc* test. Statistically significant differences between the average values were evaluated at $p < 0.05$, and all data in the text are presented as mean ± SD. In addition, the percentile scores of the parameters were compared to the 50th percentile by using one sample t-test. Cohen's effect size was calculated for those parameters which differed significantly from the 50th percentile, and the following classification was applied: d (0.01) = very small, d (0.20) = small, d (0.50) = medium, d (0.80) = large, d (1.20) = very large, and d (2.00) = huge (Sawilowsky, 2009).

RESULTS

The anthropometric parameters, their percentile scores and their effect size vs the 50th percentiles (PRs) of the female artistic gymnasts, divided into three age groups, are presented in Table 1. The group which included gymnasts between the ages of 12 and 15 has the greatest average sports experience (7 years and 6 months). Therefore, the outcomes on physical development and physical fitness from practising artistic gymnastics should be clearly evident in this group. The average frequency of the gymnastics training ranged from 4 to 5 sessions per week. The height-for-age percentile scores in the groups between the ages of 9-11 and 12-15 were significantly lower than the 50th percentile of the international norms for children and adolescents at this age provided by the World Health Organization (WHO, 2006). The average weight of the gymnasts increased gradually with age and did not differ from the average international standards. However, it should be taken into account that the World Health Organization (WHO) does not provide weight-for-age reference data for children over 10 years of age, because this indicator cannot distinguish between height and body mass at an age when many children are experiencing the pubertal growth spurt (WHO, 2007b). The body mass index (BMI) did not show significant differences from the international percentile scores, except with the first age group (5-8 years), where the Cohen's effect size was small (d=0.41). The average waist-to-height ratio in all three age groups was below the boundary of 0.500, which distinguishes children at risk as far as their health is concerned (Ashwell & Hsieh, 2005; McCarthy & Ashwell, 2006). The %Fat percentile scores in all groups were greatly lower than the 50th percentile of the international norms for children and adolescents (McCarthy et al., 2006), and the Cohen's effect size was large (d=1.05) for 5-8-year-old gymnasts, very large (d=1.37) for 9-11-year-old gymnasts, and huge (d=3.17) for 12-15-year-old gymnasts, in accordance with the benchmarks provided by Cohen and Sawilowsky (Lakens, 2013; Sawilowsky, 2009). The upper arm muscle area (UAMA) percentile scores for all three groups are lower than the 50th percentile, but this difference was significant only in the group with gymnasts between the ages of 9 and 11 with a medium effect size (d=0.50).

Table 1
Anthropometric parameters, their percentile scores and effect size vs the 50th percentile (PRs) of the female artistic gymnasts divided into three age groups (mean ± SD).

	5-8 years (n=28)	9-11 years (n=39)	12-15 years (n=14)
Age (years)	7.45 ± 0.92	10.25 ± 0.95	13.52 ± 1.28
Sports experience (months)	23.71 ± 12.91 C	36.76 ± 23.07 C	79.57 ± 38.77
Sessions per week	4.05 ± 0.88 B^{c}	4.86 ± 0.80	4.94 ± 0.85
Height (cm)	123.96 ± 8.26 BC	138.38 ± 8.98 C	153.13 ± 6.57
Height – percentile score	51.53 ± 31.56	39.98 ± 29.35	32.96 ± 25.07
Effect size vs 50th PRs	NS	0.01 a	0.68 a
Weight (kg)	25.73 ± 5.87 BC	33.22 ± 6.25 C	44.50 ± 7.55
Weight – percentile score	58.18 ± 29.20 B	50.54 ± 23.33**	-*
Effect size vs 50th PRs	NS	NS	
BMI (kg/cm^2)	16.54 ± 1.99 ^{c}	17.23 ± 1.86 c	18.84 ± 1.90
BMI – percentile score	61.09 ± 27.29	53.93 ± 25.70	44.81 ± 22.96
Effect size vs 50th PRs	0.41 a	NS	NS
Arm circumference (cm)	18.31 ± 2.05 BC	20.02 ± 1.70 C	22.16 ± 1.59
Waist circumference (cm)	53.66 ± 5.87 ^{b}C	57.99 ± 3.79 c	61.84 ± 4.45
Waist-to-height ratio	0.43 ± 0.04 c	0.42 ± 0.03	0.40 ± 0.02
Subscapular skinfold (mm)	6.95 ± 3.00	7.13 ± 2.61	7.88 ± 1.67
Triceps skinfold	10.52 ± 3.72	11.38 ± 4.21	9.61 ± 3.29
% Fat	16.27 ± 4.60	17.14 ± 4.73	16.54 ± 3.88
% Fat - percentile score	21.04 ± 27.53	17.32 ± 23.77	10.39 ± 12.51
Effect size vs 50th PRs	1.05 A	1.37 A	3.17 A
UAMA (cm^2)	18.07 ± 3.42 BC	21.67 ± 3.77 C	29.34 ± 4.64
UAMA – percentile score	43.20 ± 26.64	38.29 ± 23.25	39.61 ± 23.94
Effect size vs 50th PRs	NS	0.50 ^{a}	NS
Relative UAMA (cm^2/kg)	0.71 ± 0.10	0.66 ± 0.11	0.67 ± 0.12

* WHO does not provide weight-for-age reference data for children older than 10 years of age (WHO, 2007b).
** n=19 because 20 out of 39 female gymnasts were older than 10 (see *).
a – p < 0.05 vs 50th PRs; a – p < 0.01 vs 50th PRs; A – p < 0.001 vs 50th PRs;
b – p < 0.01 vs 9-11 years; B – p < 0.001 vs 9-11 years;
c – p < 0.05 vs 12-15 years; c – p < 0.01 vs 12-15 years; C – p < 0.001 vs 12-15 years;
NS – not significant

Table 2

Results of the handgrip strength test, standing long jump, 4x10 m SRT, 20m SRT, their percentile scores and effect size (vs 50th percentile) of all female artistic gymnasts (mean ± SD).

	5-8 years (n=28)	9-11 years (n=39)	12-15 years (n=14)
	Musculoskeletal Fitness: Upper body strength		
Handgrip strength test* (kg)	8.87 ± 2.91 BC	13.72 ± 4.24 C	20.05 ± 4.18
Handgrip strength test (percentile score)	32.32 ± 30.27	31.65 ± 28.57	26.88 ± 21.09
Effect size vs 50th PRs	0.58 ^{a}	0.64 A	1.10 ^{a}
Relative handgrip strength (kg/ kg body weight)	0.34 ± 0.08 b^{c}	0.41 ± 0.11	0.45 ± 0.06
	Musculoskeletal Fitness: Lower body strength		
Standing long jump (cm)	129.46 ± 17.95 BC	160.83 ± 20.92 C	195.71 ± 15.29
Standing long jump (percentile score)	83.45 ± 20.27	88.65 ± 16.06	96.26 ± 4.65
Effect size vs 50th PRs	1.65 A	2.41 A	9.95 A
	Motor Fitness		
4x10 m shuttle run test (sec)	13.81 ± 0.94 BC	12.76 ± 1.12 C	11.57 ± 0.64
4x10 m shuttle run test (percentile score)	74.38 ± 17.44	69.26 ± 25.45	83.30 ± 14.05
Effect size vs 50th PRs	1.40 A	0.76 A	2.37 A
	Cardiorespiratory Fitness		
VO_2max (ml/kg/min)	49.06 ± 1.99 ^{b}C	46.48 ± 2.92 C	43.25 ± 3.49
VO_2max (percentile score)	79.23 ± 14.90 B	61.19 ± 22.35	72.42 ± 16.48
Effect size vs 50th PRs	1.96 A	0.50 ^{a}	1.36 A

* - values expressed as average of right and left hands
a – $p < 0.01$ vs 50th PRs; A – $p < 0.001$ vs 50th PRs;
b – $p < 0.05$ vs 9-11 years; b – $p < 0.01$ vs 9-11 years; B – $p < 0.001$ vs 9-11 years;
c – $p < 0.01$ vs 12-15 years; C – $p < 0.001$ vs 12-15 years;
NS – not significant

Table 3

Anthropometric parameters, their percentile scores and effect size vs the 50th percentile (PRs) of the male artistic gymnasts divided into three age groups (mean ± SD).

	5-8 years (n=35)	9-11 years (n=28)	12-15 years (n=17)
Age (years)	7.45 ± 1.09	10.29 ± 0.93	13.48 ± 1.10
Sports experience (months)	27.66 ± 14.60 BC	49.57 ± 16.70 C	84.94 ± 31.23
Sessions per week	4.51 ± 0.68 ^{b}c	5.06 ± 0.62	4.98 ± 0.61
Height (cm)	122.64 ± 8.28 BC	135.11 ± 7.60 C	148.06 ± 9.67
Height – percentile score	41.71 ± 27.49 C	31.36 ± 23.04 c	11.99 ± 9.54
Effect size vs 50th PRs	NS	0.81 A	3.10 A
Weight (kg)	23.98 ± 3.65 BC	30.73 ± 4.95 C	38.66 ± 8.71
Weight – percentile score	47.43 ± 25.90 B	39.22 ± 27.61**	-*
Effect size vs 50th PRs	NS	NS	
BMI (kg/cm^2)	15.88 ± 1.31 ^{c}	16.74 ± 1.65	17.38 ± 1.76
BMI – percentile score	53.42 ± 25.35 ^{c}	48.76 ± 26.52 c	28.64 ± 22.16
Effect size vs 50th PRs	NS	NS	0.96 ^{a}
Arm circumference (cm)	17.87 ± 1.58 BC	20.23 ± 1.80 c	21.88 ± 2.13
Waist circumference (cm)	54.79 ± 3.32 bC	57.87 ± 4.83 ^{c}	62.14 ± 4.43
Waist-to-height ratio	0.45 ± 0.03 ^{b}C	0.43 ± 0.03	0.42 ± 0.02
Subscapular skinfold (mm)	5.49 ± 1.54	5.99 ± 1.70	5.97 ± 1.06
Triceps skinfold	8.15 ± 2.25	8.45 ± 2.99 c	6.43 ± 2.20
% Fat	13.22 ± 3.20 c	13.13 ± 3.76 c	10.31 ± 3.00
% Fat - percentile score	15.56 ± 23.78	15.34 ± 23.46	5.93 ± 9.12
Effect size vs 50th PRs	1.45 A	1.48 A	4.83 A
UAMA (cm^2)	18.81 ± 3.48 BC	24.87 ± 5.29 C	31.80 ± 7.65
UAMA – percentile score	36.52 ± 27.82	51.67 ± 30.42	31.86 ± 22.81
Effect size vs 50th PRs	0.48 ^{a}	NS	0.80 ^{a}
Relative UAMA (cm^2/kg)	0.79 ± 0.12	0.82 ± 0.18	0.83 ± 0.13

* WHO does not provide weight-for-age reference data for children older than 10 years of age (WHO, 2007b).
** n=14 because 14 out of 28 male gymnasts were older than age of 10 (see *).
a – $p < 0.01$ vs 50th PRs; A – $p < 0.001$ vs 50th PRs;

b – p < 0.05 vs 9-11 years; b – p < 0.01 vs 9-11 years; B – p < 0.001 vs 9-11 years;
c – p < 0.05 vs 12-15 years; c – p < 0.01 vs 12-15 years; C – p < 0.001 vs 12-15 years;
NS – not significant

Table 4
Results of the handgrip strength test, standing long jump, 4x10 m SRT, 20m SRT, their percentile scores and effect size (vs 50th percentile) of all male artistic gymnasts (mean ± SD).

	5-8 years (n=35)	9-11 years (n=28)	12-15 years(n=17)
	Musculoskeletal Fitness: Upper body strength		
Handgrip strength test* (kg)	9.69 ± 2.66 BC	15.71 ± 4.18 C	25.18 ± 5.89
Handgrip strength test (percentile score)	31.90 ± 24.47	37.29 ± 27.00	36.72 ± 27.77
Effect size vs 50th PRs	0.74 A	0.47 a	NS
Relative handgrip strength (kg/ kg body weight)	0.40 ± 0.09 ^{b}C	0.51 ± 0.12 C	0.66 ± 0.15
	Musculoskeletal Fitness: Lower body strength		
Standing long jump (cm)	140.92 ± 21.18 BC	174.75 ± 21.12 C	208.03 ± 19.08
Standing long jump (percentile score)	87.01 ± 13.03	89.87 ± 14.25	91.82 ± 5.29
Effect size vs 50th PRs	2.84 A	2.80 A	7.91 A
	Motor Fitness		
4x10 m shuttle run test (sec)	13.99 ± 1.44 BC	12.22 ± 1.08	11.32 ± 0.72
4x10 m shuttle run test (percentile score)	54.09 ± 22.89	65.66 ± 26.76	71.35 ± 22.45
Effect size vs 50th PRs	NS	0.59 ^{a}	0.95 ^{a}
	Cardiorespiratory Fitness		
VO_2max (ml/kg/min)	49.13 ± 3.12 c	48.38 ± 4.20	46.14 ± 3.82
VO_2max (percentile score)	65.69 ± 21.20	59.23 ± 26.86	56.93 ± 20.30
Effect size vs 50th PRs	0.74 A	NS	NS

* - values expressed as average of right and left hands
a – p < 0.05 vs 50th PRs; ^{a} – p < 0.01 vs 50th PRs; A – p < 0.001 vs 50th PRs;
^{b} – p < 0.01 vs 9-11 years; B – p < 0.001 vs 9-11 years;
c – p < 0.05 vs 12-15 years; C – p < 0.001 vs 12-15 years;
NS – not significant

The results of the handgrip strength test, standing long jump, 4x10 m SRT, 20m SRT, their percentile scores and their effect size (vs the 50th percentile) of all female artistic gymnasts are presented in Table 2. The handgrip strength percentile scores in all groups were lower than the 50th percentile of the international norms for children and adolescents, and the Cohen's effect size was medium for 5-8-year-old gymnasts (d=0.58) and 9-11-year-old gymnasts (d=0.64), and large (d=1.10) for 12-15-year-old gymnasts. The standing long jump percentile scores in all three groups were significantly higher than the 50th percentile of the available European norms for children and adolescents at this age (Miguel-Etayo et al., 2014; Ortega et al., 2011), and the effect size was very large (d=1.65) for those female gymnasts who were from 5 to 8 years of age, and huge for the older ones (d=2.41 for the 9-11-year-old gymnasts and d=9.95 for the 12-15-year-old gymnasts). The 4x10 m SRT percentile scores were also significantly higher than the 50th percentile in all groups, and the effects sizes were: very large (d=1.40 for the 5-8-year-old gymnasts), medium (d=0.76 for the 9-11-year-old gymnasts), and huge (d=2.37 for the 12-15-year-old gymnasts). The percentile scores of the VO_2max obtained by the modified 20 m SRT in all three groups were also higher than the 50th percentile of the European norms, and the effect size was very large (d=1.96 for the 5-8-year-old gymnasts, and d=1.36 for the 12-15-year-old gymnasts), and medium (d=0.50 for the 9-11-year-old gymnasts).

The anthropometric parameters, their percentile scores and their effect size vs the 50th percentiles (PRs) of the male artistic gymnasts, divided into three age groups, are presented in Table 3. As expected, the group which included the oldest male gymnasts had the greatest average sports experience (7 years), which was also registered with the female gymnasts. The average frequency of the gymnastics training ranged between 4 and 6 sessions per week. The height-for-age percentile scores in the groups between the ages of 9-11 and 12-15 were significantly lower than the 50th percentile of the international norms, with a large (d=0.81) and huge effect size (d=3.10), respectively. The average weight of the male gymnasts did not differ significantly from the international standards. The body mass index (BMI) did not show significant differences from the international percentile scores, except in the third group (12-15 years), where the effect size was large (d=0.96). The average waist-to-height ratio in all three age groups was within healthy norms, as was registered with the female gymnasts. The %Fat percentile scores in all male groups were substantially lower than the 50th percentile of the international norms for children and adolescents, and the effect size was very large both for the 5-8-year-old gymnasts (d=1.45) and the 9-11-year-old gymnasts (d=1.48), and huge for 12-15-year-old gymnasts (d=4.83). UAMA percentile scores for two of the groups (5-8-year-old and 12-15-year-old male gymnasts) were significantly lower than the 50th percentile, with a small (d=0.48) and large effect size (d=0.80), respectively.

The results of the handgrip strength test, standing long jump, 4x10 m SRT, 20m SRT, their percentile scores and their effect size (vs the 50th percentile) of all male artistic gymnasts are presented in Table 4. The handgrip strength percentile scores in all groups were lower than the 50th percentile of the international norms for children and adolescents, but differ significantly only in the groups with the younger gymnasts: 5-8 years of age and 9-11 years of age. The effect size was medium (d=0.74) and small (d=0.47), respectively. The standing long jump percentile scores in all three groups were significantly greater than the 50th percentile of the available European norms, and the effect size was huge for all three groups (d=2.84 for 5-8-year-old gymnasts, d=2.80 for the 9-11-year-old gymnasts and d=7.91 for the 12-15-year-old gymnasts). The 4x10 m SRT percentile scores were significantly higher than the 50th percentile in two of the groups: 9-11-year-old male gymnasts with a medium effect size (d=0.59), and 12-15-year-old male gymnasts with a large effect size (d=0.95). The percentile scores of the VO_2max did not differ from the 50th percentile of the European norms, except in the 5-8-year-old male gymnasts, where the PRs scores were significantly higher, and the effect size was medium (d=0.74).

DISCUSION

The progressive decrease of the percentile scores in the height of the gymnasts (Table 1 & Table 3) is probably because of the fact that those of shorter stature are more likely to have an advantage when performing many of the gymnastics exercises. For instance, top level male artistic gymnasts (n=10) from the Swiss National team had an average stature of 168.6 ± 4.5 cm (Hubner & Scharer, 2015), which is below the average height (178.2 cm), in accordance with national norms for Swiss male adults (Grasgruber, Sebera, Hrazdira, Cacek, & Kalina, 2016). Cuk et al. concluded that there was no difference in the height of top level male artistic gymnasts in 1933 and those in 2000, with their average height being 168 cm (Cuk et al., 2007). Similarly, there was no significant difference in the average height of top level male artistic gymnasts in 2000 from those in 2015 (Sibanc, Kalichova, Hedbavny, Cuk, & Pajek, 2017). This lower than average stature is also seen in other studies (Benardot, 2014), where the average values of the height of young gymnasts are similar to those in our study. For instance, the height-for-age in female junior elite gymnasts progressively dropped from the 48th to the 20th percentile as age increased (Benardot & Czerwinski, 1991). However, that does not mean that gymnastics training slows down growth. In a recent review about the role of intensive training on the growth of artistic gymnasts, Malina et al. (2013) concluded that adult height or near adult height of artistic gymnasts of both genders is not compromised by intensive gymnastics training at a young age or during the pubertal growth spurt. Artistic gymnasts are shorter and lighter than average, but gymnastics training does not attenuate growth of upper or lower body segments (Malina et al., 2013). In fact, gymnastics is a unique sport that provides competitive opportunities for the smallest and lightest athletes in a world where many sports are clearly biased in favour of athletes who are tall and/or big (Sands, 1999).

Although the BMI is the most popular method and is widely used for the assessment of body composition (Flegal, Tabak, & Ogden, 2006; Keys, Fidanza, Karvonen, Kimura, & Taylor, 2014; Pekar, 2011), it did not provide correct individual assessment of some of the gymnasts involved in our study, because the BMI does not distinguish between fat and muscle mass. That is why some authors highlight that the BMI is not appropriate for some groups of people, such as professional athletes, body building enthusiasts, people engaged in jobs with strenuous physical activity (Bogin & Varela-Silva, 2012) and adolescent athletes (Lutoslawska et al., 2014). Moreover, the BMI was also shown to be an inadequate indicator of weight and body composition in child athletes with greater muscle mass (Kolimechkov et al., 2013).

The percentage body fat was very low, both in female and male artistic gymnasts, which is normal for children and adolescents involved in gymnastics (Jemni, 2011). The results of %Fat from our study are similar to those reviewed by Benardot, 2014, where the average %Fat for children and adolescents engaged in gymnastics ranged between 8.6% and 21.5%.

The percentile scores for the handgrip strength in both female and male gymnasts were lower than the 50^{th} percentile for their age. On the whole, artistic gymnasts have smaller body sizes (especially in older children), in comparison to those for their age and gender, than the international norms, and, therefore, the evaluation of the strength parameters will be better assessed by relative parameters. In addition, the workload in artistic gymnastics comes mainly from the gymnasts' body weight. Consequently, percentile scores of relative handgrip strength (per kg body weight), as well as percentile scores of relative UAMA (per kg body weight), will be a better way to appropriately assess both the gymnasts' muscle mass and strength. However, to the best of our knowledge, such norms for children are still not available in the literature, and we are of the opinion that these norms should be obtained in future research.

The standing long jump represents the relative lower body strength and, not unexpectedly, this test witnessed better results in artistic gymnasts, because jumps in height and length are included in artistic gymnastics training. The 4x10 m SRT represents the lower body strength, speed and agility, and shows a high correlation with the standing long jump test ($r = -0.73$, $p < 0.001$ and -0.83, $p < 0.001$ for girls and boys, respectively). The results of the 4x10 m SRT were also expected to be better in artistic gymnasts, because of the short distance sprints which precede gymnastic vaults and acrobatic series. Similarly, rhythmic gymnasts between the ages of 7 and 17, who completed the Alpha-fit test battery, also achieved their best results in those two tests (Montosa, Vernetta, & López-Bedoya, 2018). As can be expected, the results from the standing long jump and the 4x10 m SRT in our study showed the largest effect size in the group with the most experience in gymnastics (12-15 years of age), Table 2 and Table 4.

Unfortunately, the Alpha-fit test battery is not fully completed in terms of available percentile scores for the evaluation of the tests results. There are still certain age groups without European percentile scores for the standing long jump test, handgrip strength test, 4x10 m SRT and 20 m SRT. Miguel-Etayo et al. also talk about this reference gap between the ages of 10 and 12 at the European level, which has to be filled in (Miguel-Etayo et al., 2014). Meanwhile, interpolated and extrapolated percentile scores of the existing data can be used in order to evaluate the results of children and adolescents at any age (S. Kolimechkov et al., 2018).

The maximal oxygen uptake (VO_2max) of the female artistic gymnasts decreased significantly with age, but remained significantly higher than the 50^{th} percentile of the international age- and gender-specific norms. The effect size was very large (d=1.36) in the group with the most experience in gymnastics. The VO_2max of the male artistic gymnasts also gradually decreased with age, and the values are similar to those published for artistic gymnasts in the literature, with an average VO_2max of 50 ml/kg/min (Jemni, 2011). Although higher average values were reported for the American elite female gymnasts, around 60 ml/kg/min, (Noble, 1975), Jemni (2011) points out that the VO_2max of international level gymnasts reported over the last 50 years remains the same, around 50 ml/kg/min (Jemni, 2011). Barantsev (1985) found out that VO_2max decreases between adolescence and adulthood, with average values dropping from 53.2 ± 6.3 at age 12 to 47.2 ± 6.7 ml/kg/min at age 25 (Barantsev, 1985). Furthermore, Jemni (2011) highlights that this regression is not evident before puberty, and is associated with the higher volume and intensity of training for the strength and power required for difficult technical exercises, specifically in men's gymnastics (Jemni, 2011). The higher percentile scores for the female gymnasts are probably due to the greater average duration of the gymnastics routines (Jemni, Friemel, Le Chevalier, & Origas, 2000). In addition, on three out of the four female gymnastics apparatuses, the lower body is constantly involved, while the exercises on most of the male apparatuses are predominantly concentrated on the upper body.

CONCLUSIONS

Artistic gymnastics improves all health-related components of physical fitness and positively influences children's physical development. Both female and male artistic gymnasts had better physical fitness in most parameters, in comparison to the international norms for their peers.

The results suggest that body fat percentage should be used instead of BMI for gymnasts in order to accurately assess their body composition. Percentile scores of relative handgrip strength and relative upper arm muscle area (UAMA) should be obtained in future research and applied in order to appropriately assess artistic gymnasts.

ACKNOWLEDGEMENT

This research was financially supported by Grant '08/15.02.2018' from the National Sports Academy, Sofia, Bulgaria.

REFERENCES

Addo, O. Y., Himes, J. H., & Zemel, B. S. (2017). Reference ranges for midupper arm circumference, upper arm muscle area, and upper arm fat area in US children and adolescents aged 1-20 y. *Am J Clin Nutr, 105*(1), 111-120. doi: 10.3945/ajcn.116.142190

ALPHA. (2009). The ALPHA Health-related Fitness Test battery for Children and Adolescents, Test Manual.

Artero, E. G., Espana-Romero, V., Castro-Pinero, J., Ortega, F. B., Suni, J., Castillo-Garzon, M. J., & Ruiz, J. R. (2011). Reliability of field-based fitness tests in youth. *Int J Sports Med, 32*(3), 159-169. doi: 10.1055/s-0030-1268488

Ashwell, M., & Hsieh, S. D. (2005). Six reasons why the waist-to-height ratio is a rapid and effective global indicator for health risks of obesity and how its use could simplify the international public health message on obesity. *Int J Food Sci Nutr, 56*(5), 303-307. doi: 10.1080/09637480500195066

Barantsev, A. (1985). Do gymnasts need to develop aerobic capacity? *Soviet Sports Review, 25*(1), 20-22.

Benardot, D. (2014). Gymnastics. In R. Maughan (Ed.), *Sports Nutrition: The Encyclopedia of Sports Medicine* (Vol. VII, pp. 588-608). London: IOC Medical Commission Publication.

Benardot, D., & Czerwinski, C. (1991). Selected body composition and growth measures of junior elite gymnasts. *Journal of the American Dietetic Association, 91*(1), 29-33.

Bogin, B., & Varela-Silva, I. (2012). The Body Mass Index: the good, the bad and the horrid. *Bulletin de la Societe Suisse d'Anthropologie, 18*(2), 5-11.

Boye, K. R., T. Dimitriou, F. Manz, E. Schoenau, C. Neu, S. Wudy, & Remer, T. (2002). Anthropometric assessment of muscularity during growth: estimating fat-free mass with 2 skinfold-thickness measurements is superior to measuring midupper arm muscle area in healthy prepubertal children. *The American Journal of Clinical Nutrition, 76*(3), 628-632.

British__Gymnastics. (2015). *Level 3 Coaching Theory - Resource Pack.* UK.

Cuk, I., Korencic, T., Tomazo-Ravnik, T., Pecek, M., Bucar, M., & Hraski, Z. (2007). Differencies in morphologic characteristics between top level gymnasts of year 1933 and 2000. *Coll Antropol, 31*(2), 613-619.

Cvejic, D., Pejovic, T., & Ostojic, S. (2013). Assessment of physical fitness in children and adolescents. *Physical Education and Sport, 11*(2), 135-145.

Flegal, K. M., Tabak, C. J., & Ogden, C. L. (2006). Overweight in children: definitions and interpretation. *Health Educ Res, 21*(6), 755-760. doi: 10.1093/her/cyl128

Grasgruber, P., Sebera, M., Hrazdira, E., Cacek, J., & Kalina, T. (2016). Major correlates of male height: A study of 105 countries. *Econ Hum Biol, 21*, 172-195. doi: 10.1016/j.ehb.2016.01.005

Heyward, V. H., & Stolarczyk, L. M. (1996). *Applied Body Composition Assessment*. USA: Human Kinetics.

Hubner, K., & Scharer, C. (2015). Relationship between swallow, support scale and iron cross on rings and their specific preconditioning strengthening exercises. *Science of Gymnastics Journal, 7*(3), 59-68.

Jemni, M. (2011). *The Science of Gymnastics*. London, UK: Routledge.

Jemni, M., Friemel, F., Le Chevalier, G. M., & Origas, M. (2000). Heart rate and blood lactate concentration analysis during a high level men's gymnastics competition. *The Journal of Strength and Conditioning Research, 14*(4), 389-394.

Keys, A., Fidanza, F., Karvonen, M. J., Kimura, N., & Taylor, H. L. (2014). Indices of relative weight and obesity. *Int J Epidemiol, 43*(3), 655-665. doi: 10.1093/ije/dyu058

Kolimechkov, S. (2017). Physical Fitness Assessment in Children and Adolescents: A Systematic Review. *European Journal of Physical Education and Sport Science, 3*(4), 65-78.

Kolimechkov, S., Petrov, L., & Alexandrova, A. (2018). *Combined sets of European physical fitness percentile scores, with appropriate interpolations, for children and adolescents for the Alpha-fit test battery*. Paper presented at the 13th FIEP European Congress and 29th FIEP World Congress, Istanbul, Turkey.

Kolimechkov, S., Petrov, L., Alexandrova, A., & Cholakov, K. (2018). BeepShuttle Junior: Software for the

Administration of the 20m Shuttle Run Test in Children and Adolescents. *Journal of Advanced Sport Technology, 1*(3), 35-40.

Kolimechkov, S., Petrov, L., Ilinova, B., Alexandrova, A., Andreeva, L., & Atanasov, P. (2013). Assessment of the physical development of pre-school and primary school children practising artistic gymnastics. *Journal of Sport Science, 4*, 106-115.

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Front Psychol, 4*, 863. doi: 10.3389/fpsyg.2013.00863

Laurson, K. R., Eisenmann, J. C., & Welk, G. J. (2011). Body fat percentile curves for U.S. children and adolescents. *American Journal of Preventive Medicine, 41*(4 Suppl 2), S87-92. doi: 10.1016/j.amepre.2011.06.044

Leger, L., Lambert, J., Goulet, A., Rowan, C., & Dinelle, Y. (1984). [Aerobic capacity of 6 to 17-year-old Quebecois--20 meter shuttle run test with 1 minute stages]. *Can J Appl Sport Sci, 9*(2), 64-69.

Leger, L. A., Mercier, D., Gadoury, C., & Lambert, J. (1988). The multistage 20 metre shuttle run test for aerobic fitness. *J Sports Sci, 6*(2), 93-101. doi: 10.1080/02640418808729800

Lutoslawska, G., M. Malara, P. Tomaszewski, K. Mazurek, A. Czajkowska, A. Keska, & Tkaczyk, J. (2014). Relationship between the percentage of body fat and surrogate indices of fatness in male and female Polish active and sedentary students. *Journal of Physiological Anthropology, 33*(10). doi: 10.1186/1880-6805-33-10

Malina, R. M., Baxter-Jones, A. D., Armstrong, N., Beunen, G. P., Caine, D., Daly, R. M., . . . Russell, K. (2013). Role of intensive training in the growth and maturation of artistic gymnasts. *Sports Med, 43*(9), 783-802. doi: 10.1007/s40279-013-0058-5

McCarthy, H. D., & Ashwell, M. (2006). A study of central fatness using waist-to-height ratios in UK children and adolescents over two decades supports the simple message--'keep your waist circumference to less than half your height'. *Int J Obes (Lond), 30*(6), 988-992. doi: 10.1038/sj.ijo.0803226

McCarthy, H. D., T.J. Cole, T. Fry, S.A. Jebb, & Prentice, A. M. (2006). Body fat reference curves for children. *International journal of Obesity, 30*, 598-602.

Miguel-Etayo, P., L. Gracia-Marco, F. Ortega, T. Intemann, R. Foraita, L. Lissner, . . . Moreno., L. (2014). Physical fitness reference standards in European children: the IDEFICS study. *International journal of Obesity, 38*, 57-66.

Montosa, I., Vernetta, M., & López-Bedoya, J. (2018). Assessment of health-related fitness by the ALPHA-fitness test battery in girls and adolescents who practise rhythmic gymnastics. *Journal of Human Sport and Exercise, 13*(1), 1-17.

NHANES. (2013). Muscle Strength Procedures Manual: National Health and Nutrition Examination Survey (NHANES).

NHNES. (2007). *National Health and Nutrition Examination survey (NHNES). Anthropometry procedures manual*. USA: CDC.

Noble, L. (1975). Heart rate and predicted Vo2 during women's competitive gymnastic routines. *The Journal of sports medicine and physical fitness, 15*(2), 151-157.

Ortega, F., E. Artero, J. Ruiz, V. España-Romero, D. Jiménez-Pavón, G. Vicente-Rodriguez, . . . Castillo, M. (2011). Physical fitness levels among European adolescents: the HELENA study. *British Journal of Sports Medicine, 45*, 20-29.

Pajek, M., Cuk, I., Kovac, M., & Jakse, B. (2010). Implementation of the gymnastics curriculum in the third cycle of basic school in Slovenia. *Science of Gymnastics Journal, 2*(3), 15-27.

Pekar, T. (2011). Body Mass Index. *IMS Magazine, Summer 2011*, 21-22.

Piwoz, G., & Viteri, F. (1985). Food and Nutrition Bulletin. *UNU, 07*(4), 86.

Romero, V., E. Artero, D. Jimenez-Pavon, M. Cuenca-Garcia, F. Ortega, J. Castro-Pinero, . . . Ruiz, J. (2010). Assessing Health-Related Fitness Tests in the School Setting: Reliability, Feasibility and Safety; The ALPHA Study *Int J Sports Med*.

Roriz De Oliveira, M. S., Seabra, A., Freitas, D., Eisenmann, J. C., & Maia, J. (2014). Physical fitness percentile charts for children aged 6-10 from Portugal. *The Journal of sports medicine and physical fitness, 54*(6), 780-792.

Ruiz, J., J. Castro-Pinero, E. Artero, F. Ortega, M. Sjostrom, J. Suni, & Castillo, M. (2009). Predictive validity of health-related fitness in youth: a systematic review. *Br J Sports Med, 43*(12), 909-923.

Ruiz, J., J. Castro-Pinero, V. Espana-Romero, E. Artero, F. Ortega, M. Cuenca, . . . Castillo, M. (2010). Field-based fitness assessment in young people: the ALPHA health-related fitness test battery for children and adolescents. *Br J Sports Med*.

Sands, W. (1999). Why Gymnastics? *USA Gymnastics Online: Technique, 19*(3).

Santos, R., & Mota, J. (2011). The ALPHA health-related physical fitness test battery for children and adolescents. *Nutr. Hosp., 26*(6), 1199-1200.

Sawilowsky, S. (2009). New Effect Size Rules of Thumb. *Journal of Modern Applied Statistical Methods, 8*(2), 597-599.

Sibanc, K., Kalichova, M., Hedbavny, P., Cuk, I., & Pajek, M. (2017). Comparison of morphological characteristics of top level male gymnasts between the years of 2000 and 2015. *Science of Gymnastics Journal, 9*(2), 201-211.

Slaughter, M., T. Lohman, R. Boileau, C. Horswill, R. Stillman, M. Van Loan, & Bemben, D. (1988). Skinfold equations for estimation of body fatness in children and youth. *Human biology, 60*(5), 709-723.

Tomkinson, G. R., Lang, J. J., Tremblay, M. S., Dale, M., LeBlanc, A. G., Belanger, K., & Leger, L. (2016). International normative 20 m shuttle run values from 1 142 026 children and youth representing 50 countries. *Br J Sports Med*. doi: 10.1136/bjsports-2016-095987

WHO (2006). WHO Child Growth Standards based on length/height, weight and age. *Acta Paediatr Suppl, 450*, 76-85.

WHO. (2007a). BMI-for-age (5-19 years). *Body Mass Index for age (5-19 years), WHO AnthroPlus software.* Retrieved accessed on 20 September, 2017, from http://www.who.int/growthref/who2007_bmi_for_age/en/

WHO (2007b). Weight-for-age (5-19 years). *Weight for age (5-19 years), WHO AnthroPlus software.* Retrieved accessed on 20 October, 2017, from http://www.who.int/growthref/who2007_weight_for_age/en/

WHO (2011). WHO Anthro for personal computers, version 3.2.2, 2011: Software for assessing growth and development of the world's children. Geneva: WHO, 2010.

Corresponding author:

Stefan Kolimechkov
Elite Gymnastics Academy CIC -
Coaching Department
2 The Broadway
London N9 0TR
United Kingdom of Great Britain and
Northern Ireland
E-mail: dr.stefan.kolimechkov@gmail.com

HEAD-TOE DISTANCE AS A SIMPLE MEASURE TO EVALUATE AMPLITUDE OF CIRCLES ON POMMEL HORSE

Toshiyuki Fujihara[1], Pierre Gervais[2], Gareth Irwin[3]

[1]Osaka University of Health and Sport Sciences, Osaka, Japan
[2]University of Alberta - Faculty of Kinesiology, Sport, and Recreation, Edmonton, Canada
[3]Cardiff Metropolitan University - Cardiff School of Sports, Cardiff, Great Britain

Original article

Abstract

To develop scientifically-valid tools to monitor performance in practice, a critical question is what to measure. On pommel horse, the importance of fundamental skills called circles is uncontroversial, and one of the key performance qualities of circles is the amplitude of the movement. Previous studies have used joint angles or the magnitude of a body part's trajectory to evaluate the amplitude, but we hypothesized that the distance between two points, namely a head and toes might be substituted despite its relative simplicity. This study examined the use of Head-Toe Distance (HTD) normalized by the gymnast's body height as a simple variable to potentially evaluate the amplitude of circles. The kinematic data of circles performed by 18 elite gymnasts were collected with a Qualisys motion capture system operating at 100 Hz. HTD and its horizontal component, HTDh, were computed along with their relationships to the outcome scores given by the official judges, as well as the other amplitude variables: the horizontal diameters of shoulder and ankle trajectories; the body flexion angle; and in the rear support position, the shoulder extension angle and the head position. The results supported HTDh, rather than HTD, for its potential usage as a single variable to evaluate the amplitude of circles. The benefits of HTDh compared to the other variables lies in its potential validity despite its relative simplicity in assessment. Because computing HTDh requires only the positional data of the head and toes, it may have greater practical applications as an evaluative tool in gymnastics.

Keywords: *gymnastics, rotation, quality, evaluation, feedback, coaching, judging.*

INTRODUCTION

"Circles" are the most basic skill on pommel horse, and they are fundamental skills due to the fact they are precursors to the development of more complex skills. Coaches focus much attention on the technical quality of the fundamental skill because of its importance in the effective development of successful performance. As George explained in his book (George, 2010), maximising the movement amplitude is one of the keys to optimising technique and successful performance in gymnastics, and this is well applied for circles. The important aspect for the quality of circles is the amplitude of horizontal rotation. Horizontal rotation refers to phase dependent rotation of: rotation of the mass centre about the supporting hands and rotation of the body itself about the mass centre (Fujihara, Fuchimoto and Gervais, 2009). This partially describes the mechanics of horizontal rotation, yet more studies will be helpful to facilitate our understanding of the motion. Among practitioners, however, it would be a clearer agreement that a gymnast should keep his body as straight as possible throughout an exercise (Karácsony & Čuk, 1998; Yoshida & Shiroma, 2001). Figure 1 provides a typical example of higher-quality and lower-quality circles, which have a relatively straight body and bent body, respectively. Kaneko (1974) asserted that ideal circles should show great amplitude characterized by a straight body and maximal possible circular trajectory of his feet. This technical claim are in line with the rules, as the *Code of Points* (International Gymnastics Federation, 2017) states that "ideally circles and flairs must be performed with complete extension. Lack of amplitude in body position is deducted as an individual deduction on for each element. (p. 54)" It should be noted that the *Code of Points* (International Gymnastics Federation, 2017) also states that "circles with a slightly hollow position are permitted. (p.54)" The question here is how slight the position would be considered permissible, and this is likely to rely on judges' subjective perception at least in the current paradigm.

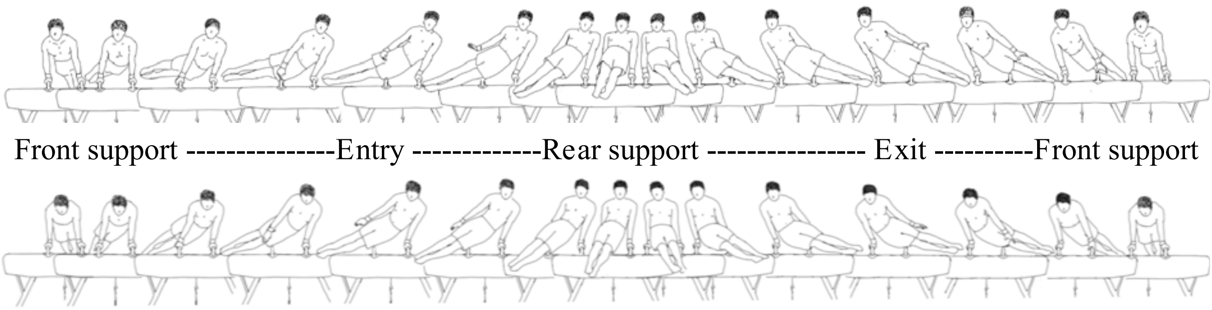


Figure 1. Description of typical higher-quality (top) and lower-quality (bottom) circles and phase definitions. Phases are often divided into four phases based on the relative position of the legs with respect to the pommel horse and the hand release and re-grasp. Front and rear support phases are the double-hand support phases, and entry and exit phases are the single-hand support phases.

In biomechanics, some studies have objectively examined the amplitude of circles. Most common mechanical variables that can discriminate the level of expertise include hip or body angle, and the horizontal diameter of the ankles' excursion (Baudry et al., 2009; Fujihara & Gervais, 2012a). When the hip or body angles were considered, some studies computed the flexion and side flexion separately (e.g. Fujihara and Gervais, 2010). According to Baudry et al. (2009), the horizontal diameter of shoulders' excursion and the shoulder extension angle in the rear support phase (See Figure 1 for the phase definitions) also show significant differences between the skilled and the unskilled gymnasts. These mechanical variables could be helpful to objectively evaluate the quality of circles, but the complexity of computation and a time-consuming data collection procedure may limit a practical application in a daily training.

As a simpler variable, Fujihara and Gervais (2013) pointed out that the head position particularly in the rear support phase is strongly correlated with the scores given by the official gymnastics judges. In fact, this variable showed high correlations with other amplitude variables introduced above: a body flexion angle, the horizontal diameter of shoulders' excursion and the shoulder extension angle in the rear support. Intriguingly, the horizontal diameter of ankles' excursion was the only variable that did not show significant correlation with the head position in the rear support. Because all investigated variables were more or less correlated with the scores by the judges, the motions of head and feet may contain unique information for score prediction whereas other measures such as a body or shoulder angle could be regarded as redundant with the information about the head motion.

Based on these previous studies, we hypothesized that using these two body parts, namely head and feet, or toes in order to differentiate whether or not toes are pointed, might be a plausible method to evaluate the amplitude of circles in a simpler manner. By taking into account the trajectory of the feet in addition to the position of the head segment, which has redundant information on body and shoulder angles, the distance between the head and the centre of the toes (Head-Toe Distance: HTD) can represent much about the quality of circles despite its simplicity (Figure 2). It appeared to be valid from both a practical viewpoint and a theoretical viewpoint of 'straight body' as supported by the previous research. The purpose of this study was to investigate the possible use of HTD as a simple measure for evaluating the amplitude of circles on pommel horse. Such a simple objective measure could be beneficial for evaluation of the performance, assisting coaches and athletes during training and return to best play following injury. Also, this simple measure could potentially provide additional assessment information for judges in a practical setting.

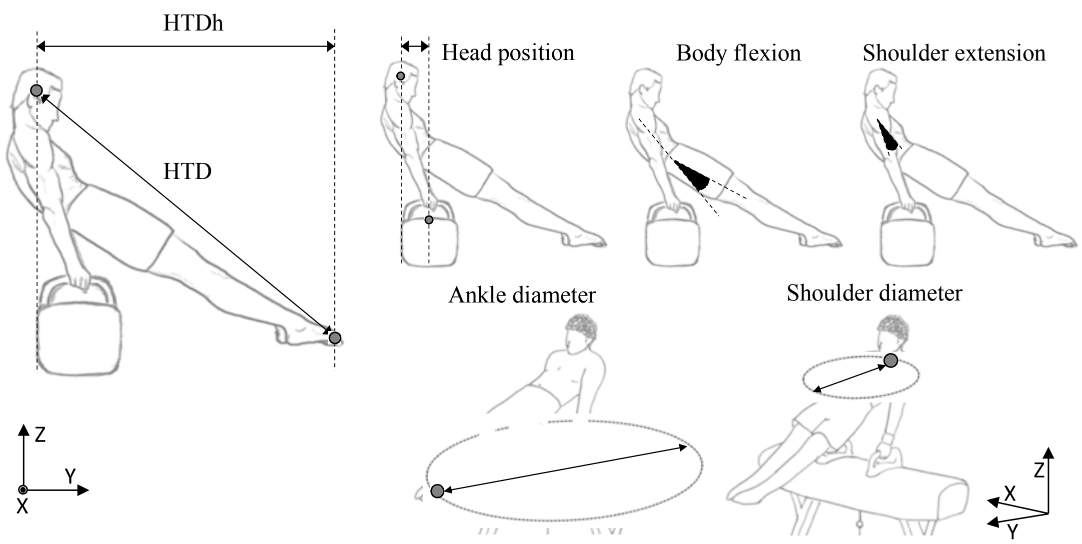


Figure 2. Illustrations of Head-Toe Distance (HTD), its horizontal version (HTDh), and the other amplitude variables computed.

METHODS

Data collected from successful previous studies were employed (Fujihara & Gervais, 2012b) and extended the analysis. Fourteen national-level and four international-level male gymnasts participated in the experiment. All 18 gymnasts were able to consistently perform 20 consecutive circles on two handles of a pommel horse. The mass, height, and ages of the gymnasts were 47.7 ± 10.8 kg, 1.55 ± 0.11 m, and 16.2 ± 3.6 years. They had 9.4 ± 2.9 years of experience in competitive gymnastics and trained 20.3 ± 3.5 hours per week at the time of data collection. Written informed consent was obtained of all the gymnasts and the guardians of under-18 gymnasts. Prior to the start of this project, ethical approval was obtained through the institutional research ethics review board.

A no-leg pommel horse was placed in the laboratory, and the kinematic data were collected using a Qualisys motion capture system with 13 cameras placed around the pommel horse (ProReflex MCU 240, f6 lens, Qualisys AB, Sweden). According to the results of the inter-marker-distance accuracy tests, which were performed before and after each data collection, the standard deviation and the range of the 750.2 mm-wand length were at most 1.3 mm and 8.3 mm, respectively. The centre of the top surface of the pommel horse was defined as the origin of the laboratory coordinate system, and the X-, Y-, and Z-axes were the horizontal lines along the long and short axes of the horse and the vertical line through the origin. The positive directions of the X-, Y-, and Z-axes were rightward, forward, and upward with respect to the direction of the performance (Figure 2).

After general and event-specific warm-ups, the participants were fitted with retro-reflective markers on the anatomical landmarks suggested by de Leva (1996) and performed three sets of 10 circles on the pommel horse. For the full description of the marker placement and the procedure of the anatomical calibrations, please refer to Fujihara and Gervais (2012b). Three-dimensional (3-D) kinematic data were recorded at 100 Hz. For each set of 10 circles, 7 circles (3rd – 9th) were used so that the individual mean data were computed from the data of 21 circles. The 3-D coordinate data were smoothed using a fourth-order Butterworth digital filter at the optimal cut-off frequencies (3.0 Hz – 12.2 Hz) determined by an automatic algorithm (Yokoi & McNitt-Gray, 1990). The head segment was defined as a line from a vertex (top of head) to the centre of right and left gonions, and its mass centre was estimated as a point at 59.76% from the vertex (de Leva, 1996). Hip joint centres were estimated using Halvorsen's algorithm (2003), and all other joint centres were estimated as the centres of two markers attached on the surface of each joint.

HTD was computed as the 3-D distance between the head mass centre and the centre of two markers attached on the right and left acropodions (Figure 2). The head mass centre should reflect the position of the segment better than a vertex. HTD was also computed on a horizontal plane (HTDh), and both HTD and HTDh were normalized by the body height of each gymnast (unit: %BH). As representative kinematic variables for amplitude evaluation of circles, the following variables were also considered: horizontal diameters of shoulder and ankle trajectories (shoulder diameter, ankle diameter), a body flexion angle, a shoulder extension angle in the rear support, and the head position in the rear support position (Fujihara & Gervais, 2012a; b; 2013). The diameters and angles were computed by following Grassi et al. (2005) and Fujihara and Gervais (2010), respectively. The illustrations of these variables are shown in Figure 2, but more detailed computational descriptions can be found in Fujihara and Gervais (2012b).

Four internationally accredited judges

scored the video-recorded circles. A perfect score was set at 10.0 and deductions were applied in step of 0.1 according to technical faults or execution errors. Then, the average of four scores was determined as the final score. The intra-class correlation coefficient, computed as an estimate of the inter-judge reliability, was 0.944. Pearson's product-moment coefficient of correlation was considered among the scores and all computed variables. The normality of the data was checked using the Kolmogorov-Smirnov test. The experiment-wise error rate was set at $p < 0.05$, and the Holm's correction (Holm, 1979) was applied for multiple univariate statistics (Knudson, 2009). The purpose of this study was to explore the possible use of HTD as a simple measure in relation to the quality of circles, instead of to find the best way to predict a score given by the judges participated in this particular study. Therefore, stepwise multiple regression analysis was conducted by a two-block method: first block took HTD and HTDh, and then the second block took the all other variables computed as potential predictors. IBM SPSS statistics v.23 was used for the statistical computations.

RESULTS

Table 1 shows the scores given by the judges and the all computed variables for each individual gymnast. According to the results of the Kolmogorov-Smirnov tests, the distributions of all variables analyzed were not significantly different from a normal distribution. Also, there was no outlier that largely deviated from each variable's mean (< 3 standard deviation). The overall averages of HTD and HTDh for all gymnasts were 88 ± 3 %BH and 75 ± 2 %BH, respectively. The gymnast who had the best score out of 18 gymnasts exhibited the greatest HTD (94 %BH) and HTDh (80 %BH) as the average of 21 circles analysed (Table 1). See Figure 3 for the time-series change in HTD and HTDh during circles for each gymnast. Both HTD and HTDh tended to decrease around the rear support phase where the difference in the head position was found in the previous study (Fujihara & Gervais, 2013). However, the higher-scored gymnasts, who had scores greater than 9.0 out of 10.0, showed less decrease in both HTD and HTDh, maintaining a relatively high value throughout a circle (Figure 3).

The average standard deviation of HTD and HTDh for each gymnast (21 circles) was 0.43 ± 0.16 %BH and 0.56 ± 0.18 %BH, so the intra-gymnast variability was smaller than the inter-gymnast variability. Figure 4 plots the standard deviations of HTD and HTDh for each gymnast against the scores. The higher-scored gymnasts tended to show smaller variability, implying more consistent performance.

Table 2 displays the correlations among the scores and all the amplitude variables computed. The average HTD and HTDh were both significantly correlated with the scores given by the official gymnastics judges, but HTDh showed a stronger correlation than HTD (HTD: r = 0.556, p = 0.017, HTDh: r = 0.735, p = 0.001). As a result of the stepwise multiple regression analysis, two models showed statistical significance (Table 3). The first model included HTDh alone as a predictor (adjusted R^2 = 0.511). The second model included HTDh and HTD, increasing the adjusted R^2 to 0.662. After these two variables were entered at the first step, no other amplitude variables were entered at a statistically significant level.

Table 1
Scores and the performance variables for each individual gymnast.

Gym -nast	Score	HTD (%BH)	HTDh (%BH)	Head position (m)	Body flexion (°)	Shoulder extension (°)	Shoulder diameter (%BH)	Ankle diameter (%BH)
1	9.675 ± 0.340	94	80	-0.15	2	34	30	101
2	9.575 ± 0.544	91	77	-0.15	-1	26	31	100
3	9.375 ± 0.556	90	77	-0.11	9	20	30	99
4	9.350 ± 0.387	89	77	-0.11	9	28	31	98
5	9.300 ± 0.594	89	76	-0.17	16	26	29	100
6	9.300 ± 0.622	90	77	-0.17	11	15	29	100
7	9.100 ± 0.898	92	78	-0.20	-2	33	32	95
8	9.100 ± 0.707	88	75	-0.09	13	22	29	100
9	8.975 ± 0.822	87	73	-0.05	24	16	27	98
10	8.975 ± 0.608	88	76	-0.07	16	17	28	103
11	8.750 ± 0.686	91	77	-0.18	15	27	31	96
12	8.575 ± 0.939	89	76	-0.15	3	24	29	98
13	8.425 ± 0.911	86	75	-0.06	15	18	28	98
14	8.425 ± 0.709	84	71	-0.05	22	7	26	95
15	8.300 ± 1.030	84	71	-0.01	35	10	26	96
16	7.950 ± 0.526	88	74	-0.05	25	9	28	94
17	7.300 ± 0.963	87	73	-0.08	24	21	29	95
18	6.650 ± 1.109	87	72	-0.04	35	14	27	94
Aver -age	8.728	88	75	-0.10	15	20	29	98
SD	0.798	3	2	0.06	11	8	2	3

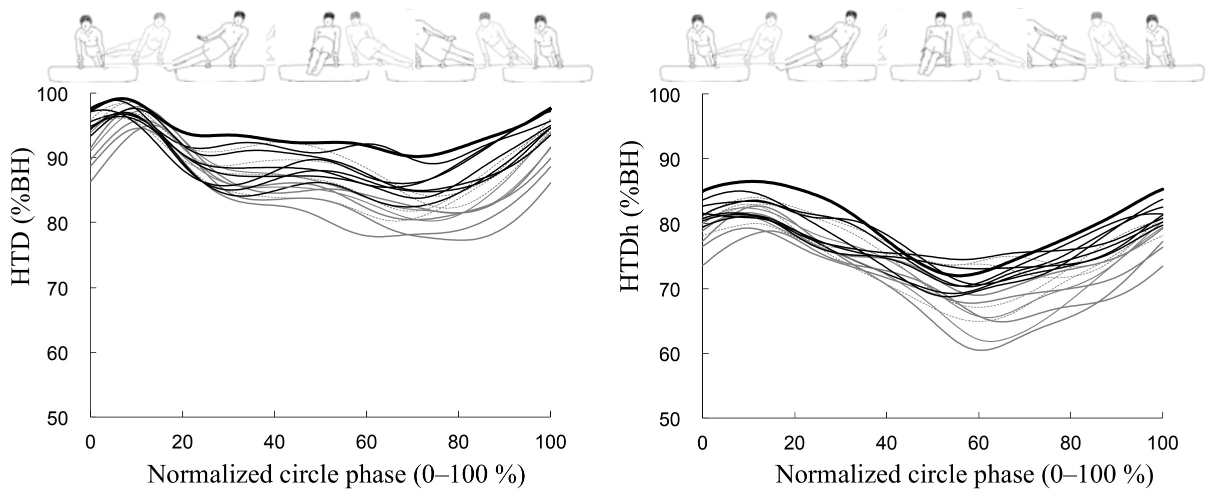


Figure 3. Change in HTD and HTDh during a single circle. Each line represents the average of 21 circles by each gymnast. Higher-scored (>9.0) - and lower-scored (< 8.5) gymnasts are shown in black and grey lines, respectively. The grey broken lines are the gymnasts whose scores were between 9.0 and 8.5. The thickest black line shows the highest-scored gymnast (9.675). The gymnasts with higher scores demonstrate relatively higher HTD and HTDh throughout a whole circle, particularly from the rear support.

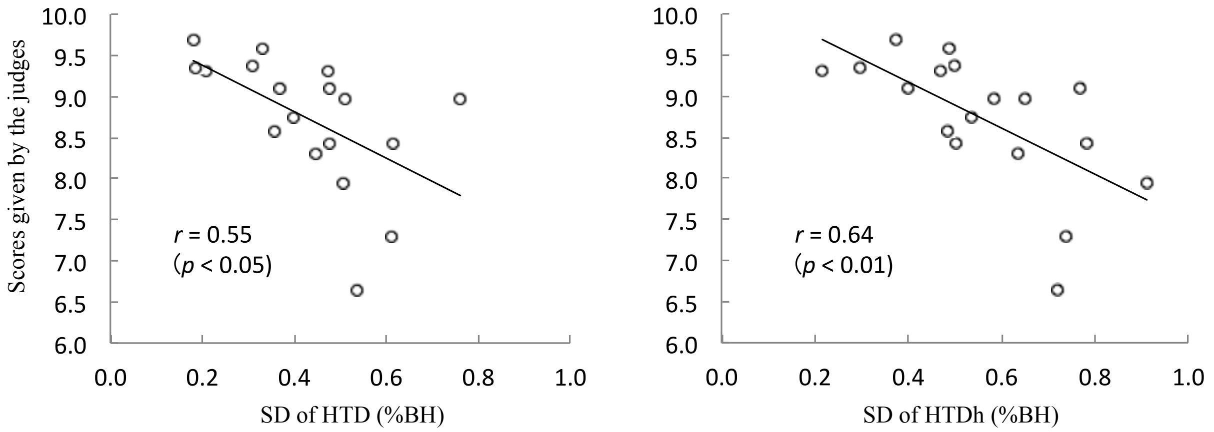


Figure 4. The relationships between the scores given by human judges and the standard deviation of HTD (left) and HTDh (right) among 21 circles (7 circles x 3 sets).

Table 2
Correlations among the scores and the amplitude variables.

Variables	*r*	*p*	Critical *p*	Sig.
Body flexion	0.737	0.000	0.007	*
HTDh	0.735	0.001	0.008	*
Ankle diameter	0.725	0.001	0.010	*
Head position	-0.576	0.012	0.013	*
HTD	0.556	0.017	0.017	*
Shoulder extension	0.517	0.028	0.025	
Shoulder diameter	0.498	0.035	0.050	

Table 3
The results of stepwise multiple regression analysis.

Model	Predictors	Adjusted R^2	F	Sig.	Partial Correlation (Excluded variables)					
					HTD	Head Position	Body flexion	Shoulder extension	Shoulder diameter	Ankle diameter
1	HTDh	0.511	18.78	0.001	-0.593	0.059	0.295	-0.172	-0.297	0.550
2	HTDh, HTD	0.662	17.65	0.000	-	-0.24	0.329	0.036	-0.006	0.304

DISCUSION

Providing simple, scientifically rigorous and ecologically valid methods to assess the quality of skill is a desirable tool for coaches, sports judges, and scientists. This study investigated the use of HTD, a simple measure using head and toes to evaluate the quality of circles, finding that its horizontal component, HTDh, is a potential variable. The results shown in Figure 3 supported the possible use of HTDh both on individual and group levels. The higher-scored gymnasts showed less decrease in HTDh during and after the rear support phase, resulting in the greater

HTDh on average (Table 1). HTD also showed a strong relationship with the scores and the other variables but not as strong as that of the HTDh. When both HTDh and HTD were used to predict the scores, more variance was significantly explained (Table 3). Whilst there are more thorough ways to evaluate the quality of circles e.g. using multiple biophysical variables to reflect different aspects, but HTDh seems to be a good option as a single variable to evaluate the amplitude of horizontal rotation.

Recall that in this study the judges followed two rules: that a perfect score was 10.0, and that a deduction was applied in step of 0.1 according to technical faults or execution errors. The highest score seen among the participants was 9.675 (Table 1), so all of them seemed to have room to improve their performance to some extent. In fact, some judges provided their comments on the performances in addition to the score. Based on their comments, a judge appears to look at body extension, amplitude, rhythm, leg form errors, consistency, and the timing of hip turns. The scores given by the judges in this study should be considered to be more comprehensive and therefore more complicated than just focusing on the amplitude. In Figure 4, a few of the lowest-scored gymnasts showed relatively greater deviation from the regression line, implying that the judges more than likely found multiple technical errors, including the amplitude, in those performances. As shown in Figure 4, the lower-scored gymnasts demonstrated less consistent performances. Looking to future studies, an examination of the relationship between the amplitude variables with respect to human-judged evaluation that is concentrated only on the amplitude would be interesting.

Using HTDh as an objective measure for the amplitude may become more attractive when its computational simplicity is taken into account. For instance, the body flexion angle was slightly better than HTDh for predicting a score (Table 2), but this variable used in this study as well as the previous studies (Fujihara & Gervais, 2010; 2012) required the 3-D angular computations in a couple of moving coordinate systems. The results of 3-D angular computations were often influenced by the definition of angles as well as the way to determine the joint centre. HTDh, on the other hand, required only the 3-D positional data of the two points and a simple computation of the distance between them. It is much simpler and easier to quantify the amplitude as a measure of the performance quality. Computing the head mass centre using Grassi et al's method, which computes the horizontal diameter of ankle or shoulders trajectory, also needs only positional data to quantify performance quality (Grassi et al., 2005). In their method, the average position throughout a whole circle is regarded as the centre of rotation, and the radius or diameter is calculated based on this rotational centre at each time point. It is, therefore, impossible to evaluate the amplitude at any single time frame independently. In contrast, HTDh does not need any reference point for its computation. It is only the distance between the two points at any time. Furthermore, there is no need for the identification of the phases. Because the shoulder extension angle and the head position as the amplitude variables were expected to show significant differences during the rear support phase, identifying a phase is a necessary requirement to compute these variables.

While some may argue that sports like gymnastics need objective scores to prevent issues associated with human qualitative assessment, others may argue that the quality of a performance in such sports should not or cannot be evaluated in any quantitative manner. This is mainly a matter of validity. The question is not whether it is qualitative or quantitative but whether it is valid or invalid. Human perception tends to be influenced by various factors. For example, Plessner and Schallies (2005) reported the significant influence of viewpoint when the gymnastics judges were asked to evaluate the Cross on rings. Judges in artistic gymnastics are seated in assigned locations around the apparatus when judging performances at competition (Article 5.6, p18, International Gymnastics Federation, 2017), implying people tacitly accept a possible influence of a view angle. Considering the plane of motion during circles on pommel horse, the amplitude of horizontal rotation would be best evaluated from above. Figure 5 may help us to accept the possible influence of the view angle on our impression of the performance. Although recent TV broadcasts often include video from above, in the current rules, no judge on pommel horse may evaluate from above. An aerial view is also unlikely to be available in regular training facilities. As discussed in Fujihara, Yamamoto, and Fuchimoto (2017), objective information could become more useful to supplement subjective feedback or evaluation if such objective information with good validity and reliability is provided with an easy and immediate manner at a low cost. The immediate feedback of the HTDh could be of very practical benefit to gymnasts and coaches.

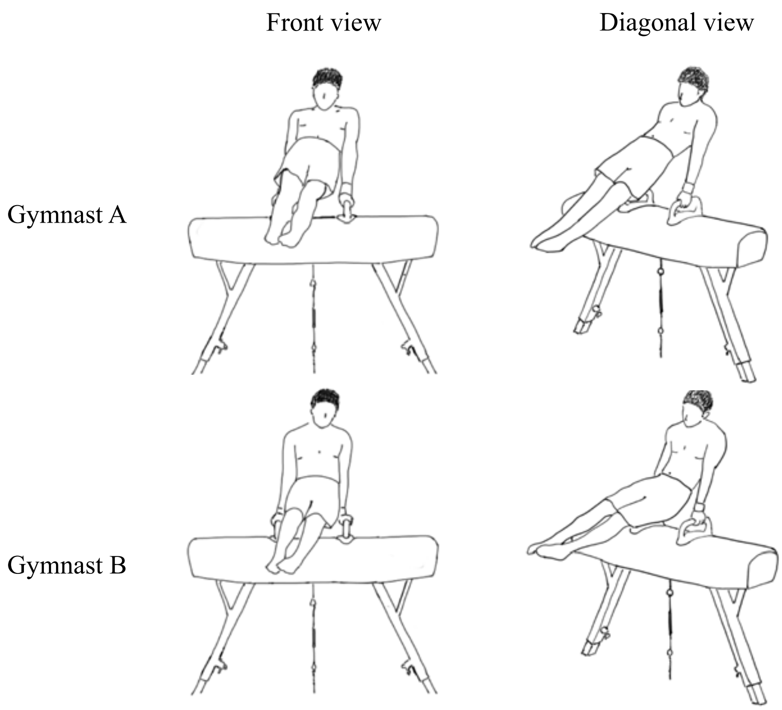


Figure 5. Descriptions of the possible different impression caused by a different view position. For each gymnast A or B, two figures shows the rear support position at the same time from a different viewpoint. The difference in body alignment, especially a piked body in gymnast B, is less clear in the front view. It should be noted that the original videos for tracing these figures were not those that were recorded for the current study. Therefore the models for these figures are do not match with any individual shown in Table 1.

This simplicity may contribute to a more practical application of biomechanical knowledge in a regular training or possibly in a competition. To date in the gymnastics community, the complexity of typical biomechanical procedures have limited the practical use of such an objective information for coaching in a regular training session or judging in a competition. Nevertheless, more recent technology may change the situation in the near future. Mr. Morinari Watanabe, the current president of the International Gymnastics Federation, presented his plan to develop a judging support system in collaboration with a Japanese company, Fujitsu (Liubov, 2017). Fujihara (2017) introduced the potential usage of a Kinect device to identify the top of the head and the tip of toes during circles on pommel horse, as a non-invasive approach to provide immediate feedback in a regular training session. Although the Kinect system captured the positions of the top of the head, not the head mass centre, to compute HTDh, the possible difference should be within an acceptable range in a practical setting. When we computed HTDh with a vertex instead of the head mass centre, the Pearson's correlation coefficient was still high (r = 0.69). On a horizontal plane, the top of the head would be closer to the head mass centre than a vertex.

To use HTDh as an amplitude measurement, there are several things to be considered. First, what would be the best use of HTDh was not considered in the current study. Only the average of HTDh during a whole circle was computed, but there might be a more valid way to evaluate a performance. Because especially in the front support position, it is less persuasive to argue that the greater HTDh always means the better performance. Therefore, setting a certain benchmark value for amplitude could be a possible option. Let us say that 80% of body height is the standard, and then a point is deducted if HTDh is lower than this value thus indicating lack of amplitude. Such an evaluation method was tested, but the correlation with the scores was very similar to the case with mean HTDh (r = 0.73) with the current data set. Second, using multiple variables in addition to HTDh could improve the score prediction because the ankle diameter still seemed to contain unique information, which was not reflected in HTDh. One possible explanation for this is the presence of centrifugal force. Fujihara (2016) presented that skilled gymnasts are better at maintaining a higher centrifugal force during a transitional phase than their unskilled counterparts. A greater centrifugal force contributes to a horizontal rotation of the mass centre that is dynamically balanced on a higher plane, resulting in a greater diameter of the distal points (feet and toes). This detail may not be fully reflected in HTDh, therefore accompanying measures could improve the validity of the evaluation. We have to acknowledge that the results of this study were based on relatively homogenous samples of the gymnasts and the scores of only four judges. Finding the best way of score prediction was beyond the purpose of this research. Additionally, a different aspect of performance quality, such as consistency, will be a task for future study.

CONCLUSIONS

Previous findings led us to hypothesize that the distance between the head and toes, HTD and HTDh for its horizontal version, could be a more practical and simpler tool to evaluate the amplitude of circles. In this study, we investigated HTD and HTDh by examining the relationships between these novel variables and the human-judged score as well as the other amplitude variables used in the literature. The results supported the use of HTDh rather than HTD or any other amplitude variable as a single variable to objectively evaluate the amplitude of circles on pommel horse. In addition to the potential validity as an objective measure, its simplicity in concept and an actual process to obtain the data may provide us more opportunities to apply it in a practical setting. As such this grounded scientific approach with high ecological validity presents practical applications and warrants the further exploration of the use of HTDh. Integrating an advanced technology and a novel idea may enhance the quality of information to the sport.

REFERENCES

Baudry, L., Sforza, C., Leroy, D., Lovecchio, N., Gautier, G., & Thouvarecq, R. (2009). Amplitude variables of circle on the pedagogic pommel horse in gymnastics. *Journal of Strength and Conditioning Research / National Strength and Conditioning Association, 23*(3), 705-711.

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223-1230.

Fujihara, T. (2017) *Using a kinect device to evaluate amplitude of horizontal rotation on the pommel horse. Proceedings of the 35th Conference of the International Society of Biomechanics in Sports*, Cologne. Germany.

Fujihara, T. , Fuchimoto, T., & Gervais, P (2009) Biomechanical analysis of circles on pommel horse. *Sports Biomechanics, 8*(1), 22-38.

Fujihara, T., Yamamoto, E., & Fuchimoto, T. (2017). Run-up velocity in the gymnastics vault and its measurement. *Japan Journal of Physical Education, Health, and Sport Sciences, 62*, 435-453.

Fujihara, T., & Gervais, P. (2010). Kinematics of side and cross circles on pommel horse. *European Journal of Sports Sciences, 10*(1), 21-30.

Fujihara, T., & Gervais, P. (2012a). Circles on pommel horse with a suspended aid: Influence of expertise. *Journal of Sports Sciences, (30)6*, 583-589.

Fujihara, T., & Gervais, P. (2012b). Circles on pommel horse with a suspended aid: Spatio-temporal characteristics. *Journal of Sports Sciences,* (30)6, 571-581.

Fujihara, T., & Gervais, P. (2013) *Head positions are related to the performance quality of circles on pommel horse. Proceedings of the 31st Conference of the International Society of Biomechanics in Sports*, Taipei. Taiwan.

Fujihara, T., Yamamoto, E., & Gervais, P. (2015). *Toward an ideal performance of circles on pommel horse—centrifugal force and mass-centre velocity—. Proceedings of the 33rd International Conference on Biomechanics in Sports*, Poitiers, France.

George, G.S. (2010). Championship gymnastics: Biomechanical techniques for shaping winners. Carlsbad, CA: Designs for Wellness Press.

Grassi, G., Turci, M., Shirai, Y. F., Lovecchio, N., Sforza, C., & Ferrario, V. F. (2005). Body movements on the men's competition mushroom: a three dimensional analysis of circular swings. *British Journal of Sports Medicine, 39*(8), 489-492.

Halvorsen, K. (2003). Bias compensated least squares estimate of the center of rotation. *Journal of Biomechanics, 36*(7), 999-1008.

Holm, S. (1979). A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics, 6*, 65–70.

International Gymnastics Federation. FIG Men's Technical Committee (Ed.) (2013). *Code of Points*. Retrieved from http://www.fedintgym.com/rules/docs/06-code/01-mag/codemag0701-efs.zip

International Gymnastics Federation. FIG Men's Technical Committee (Ed.) (2017). *Code of Points*. Retrieved from http://www.fig-gymnastics.com/publicdir/rules/files/en_MAG CoP 2017-2020.pdf

Kaneko, A. (1974). *Coaching of artistic gymnastics* Tokyo: Taishukan.

Karácsony, I., & Čuk, I. (1998). *Pommel horse exercises: methods, ideas, curiosities, history* Ljubljana: University of Ljubljana and Hungarian Gymnastics Federation.

Knudson, D. (2009). Significant and meaningful effects in sports biomechanics research. *Sports Biomechanics*, *8(1)*, 96-104.

Liubov, B. (2017). Robot judging is coming to gymnastics. Retrieved Date Accessed, 18th September, 2017 from http://eng.gymnovosti.com/robot-judging-is-coming-to-gymnastics/.

Plessner, H., & Schallies, E. (2005). Judging the cross on rings: a matter of achieving shape constancy. *Applied Cognitive Psychology, 19*(9), 1145-1156.

Yokoi, T., & McNitt-Gray, J. L. (1990). A threshold to determine optimum cutoff frequency in automatic data smoothing using digital filter. In American Society of Biomechanics (Ed.), *Proceedings for the 14th annual meeting of the American Society of Biomechanics* (pp. 209-210). FL: University of Miami.

Yoshida, K., & Shiroma, A. (2001). Pommel horse. In Men's Artistic Gymnastics Department of Japan Gymnastics Association (Ed.), Training manual for male junior gymnasts (pp. 50–126). Wakayama: Minakuchi Corp.

Corresponding author:

Osaka University of Health and Sport Sciences - School of Health andSport Sciences
1-1, Asashirodai
Kumatori-cho Sennan-gun
Osaka 590-0496
Japan
T: +81 72 479 3115
E-mail: fujihara@ouhs.ac.jp

DIFFERENCES IN VAULT RUN-UP VELOCITY IN ELITE GYMNASTS

Lucija Milčić, Kamenka Živčić, Tomislav Krističević

University of Zagreb, Faculty of Kinesiology, Croatia

Original article

Abstract

The aim of this study was to compare differences in run-up velocity between Handsprings, Tsukahara and Yurchenko entry on vault. A sample consisted of 48 jumps performed on vault, 19 Handsprings, 17 Tsukahara and 12 Yurchenko entry on vault. Data were collected on a World Cup competition held in Osijek, 2017. Run-up velocity was measured by speed radar gun (Stalker ATS, S PRO II). Descriptive statistic was calculated for all variables and differences in run-up velocity were determined by one-way ANOVA and Bonferroni post-hoc test at the level of statistical significance at p<.05. Average run-up velocity at Handspring entry was 8,06 m/s, Tsukahara, 8,06 m/s and Yurchenko entry on vault table was 7,66 m/s. ANOVA showed that exist statistical significant differences in run-up velocity between handspring and Yurchenko and between Tsukahara and Yurchenko entry. The results of this study indicated that different entry on vault table has different run-up velocity, which will help coaches and scientists to improve the vault technique.

Keywords: *artistic gymnastics, vault, velocity, run-up.*

INTRODUCTION

The vault is an apparatus in artistic gymnastics characterized by complex and very short (not much more than 7 seconds in average) dynamic movements (Čuk & Karacsony, 2004). Different from other apparatus on which gymnasts performing exercise lasting for ninety seconds, jumps on vault lasting up to five to six seconds. Gymnastic elements at the vault are classified on the structural characteristics of the jumps, which, together with the development of artistic gymnastics, have been further refined and supplemented (Živčić Marković & Krističević, 2016). Velocity is defined as a function of time where measures the distance of the object travelled through time, and measurement unit is in meters per second (m/s).

As the run-up velocity did not investigate on competitions since 2012., we wanted to see if there are some changes considering that the elements on all apparatus are more difficult to perform. Entry on the apparatus can be in the forward, backward and sideward direction to the vault. The most common entry on vault are Handsprings, Tsukahara/Kasamatsu and Yurchenko. Handsprings jumps are executed after run-up and take-off from the springboard in the forward direction with face to the vault, after that hands are placed in shoulder-width on the vault table. From that position hands do take-off from the vault table and performing the salto with different rotations. Yurchenko vaults are consisted of run-up and performing round-off which ends with a take-off on the springboard. After that gymnasts performing backward handspring with different salto from tucked to stretched salto with turns. Tsukahara jumps are consisted of run-up and take off from the springboard and performing handsprings with turn for 90° or 180° and take off from the apparatus in backward salto. Vault consist of seven phases: 1. run-up; 2. jumping on the springboard; 3. springboard support; 4. first flight phase; 5. table support; 6. second flight phase and 7. landing (Prassas & Gianikellis, 2002; Prassas, Kwon, & Sands, 2006; Čuk & Karácsony, 2004; Takei, Dunn, & Blucker, 2007; Ferkolj, 2010; Atiković & Smajlović, 2011). Each phase depends on previous, so it is important that execution of all seven phases is without mistakes. The most investigated group of jumps on the vault are Handsprings (45%), Yurchenko (10%) and Tsukahara (5%) (Fernandes, Carrara, Serrão, Amadio & Mochizuki, 2016). There is a little investigation that is conducted on the new vault table on the competition considering that the technique of the elements constantly progresses and today´s gymnasts performing much more elements with high values and complexity. In artistic gymnastic tendency of gymnasts and coaches are to perform the hardest elements which means that those elements have highest difficulty value, and also, they are much more complex for execution than elements with lower difficulty value. Run-up velocity have been studied on competition (Van der Eb, et al., 2012; Naundorf, Brehmer, Knoll, Bronst, & Wagner, 2008; Takei, et al., 2000; Sands, 2000; Krug, Knoll, Kothe, & Zocher, 1998) and on the training (Bradshaw, Hume, Carlton, & Aisbett, 2010; Brehmer, 2011).

Generally, is accepted that the speed of the run-up and take off from the springboard, linear and angular momentum are more important than contact with the vault table (Prassas, et al., 2006). After the introduction of the new vault table, the run-up velocity has significantly increased since 1997. year in both genders, excepting Yurchenko jumps where men were faster than women, so new vault table does not have the influence of the run-up velocity (Naundorf, et al., 2008). Velocity of run-up has been stabilized between 1997 and 2010, because of physical limitation or it is optimally run-up velocity for the type of the vault (Van der Eb, et al., 2012). Positive correlations between take-off velocity and final score indicate that increase in run-up velocity will influence on take-off velocity (Van der Eb, et al., 2012). This is the explanation of all phases at the vault, which have to be connected. If run-up is slow, the next phase of the vault or difficulty value of the jump will be lower. Each gymnast will develop optimal velocity by running which depends on the type and complexity of jump. The gymnast should try to attain the highest velocity that can control (Sands, 2000). The run-up velocity is related to the complexity of the jump, for example, run-up velocity is lower at Yurchenko jumps than at Handsprings jumps, but the velocity decreases in the jumps where the rotation is reversed in the second stage of the flight (Prassas & Gianikellis, 2002). Veličković, Petković, & Petković, (2011) investigated run-up velocity with 3D kinematics analyses and Optojump system, and results have shown that there are differences in run-up velocity between elite gymnasts (in the middle of the run-up was recorded a decrease of velocity), but in the average gymnast run-up velocity constantly grows. Čuk, Bricelj, Bučar, Turšič, & Atiković (2007) investigated the connection between the start value of the vault and run-up velocity in top level male artistic gymnasts, and results have shown that there is a correlation between run-up velocity and the start value of that jump.

In sports biomehanics various devices have been used for velocity measurement. Laser and radars mostly are used for measuring running velocity. Harrison, Jensen, & Donoghue, 2005 investigated validity and reliability of laser measuring system compared with the reliability of video based system during running, and have concluded that laser system are validated and reliable instrument for velocity measurements. In artistic gymnastics to determine run-up velocity are used lasers (Krug, et al., 1998; Naundorf, et al., 2008). The radar system is also used because of very simple usage (Sands, 2000). Recently are used OPTO-TRACK system which has optical sensors placed along the whole track (Veličković, et al., 2011).

Motor skills that are important for performing vault jumps are strength, especially explosive power for take-off from legs and hands, and velocity. Jumps on vault require an explosive power of upper and lower extremities. The run-up velocity is transferred to a springboard, allowing the gymnast to perform a successful jump. The aim of this paper was to determine the differences in the run-up velocity during the performance of the different groups of vaults jumps on the competition.

METHODS

The sample consisted of 48 jumps performed on the vault of which 19 were Handsprings, 17 Tsukahara and 12 Yurchenko entry to the vault. Data were collected in competition, at the World Cup in Osijek, 2017 (MAG and WAG Artistic Gymnastics). Run-up velocity was measured by Stalker ATS, S PRO II (Applied Concepts, Inc., Texas, USA), from the beginning of the run-up to the moment of take-off, i.e. the last step before the springboard. The device was placed behind the mat for landing. Stalker radar has a speed range of 0.2 m/s to 18.0 m/s – from below 1 mph (miles per hour) to over 40 mph – with an accuracy of ±0.1 m/s. High speed is 150 mph (241 km/h, 130 knots, 67 m/s). When it was compared with photocells which are the gold standard for speed measurement, validity was $r^2 = 0.99$, p\0.01 (Chelly & Denis, 2001; di Prampero, Fusi, Sepulcri, Morin, Belli & Antonutto, 2005; Haugen & Buchheit, 2016; Morin, Jeannin, Chevallier, & Belli, 2006).

Run-up velocity was measured in km/h, and converted into m/s, with the mathematic formula: km/h x 1000/3600. Variable Hnd was used for a Handspring, Tsuk for Tsukahara and Yurc for Yurchenko vault. This study was approved by Ethical Committee of Faculty of Kinesiology.

Statistica 12 was used for data analysis. Normality of distribution was determined by Kolmogorov-Smirnov test. Variables were normally distributed. Basic descriptive parameters were calculated for all variables, and the differences of run-up velocity between groups of vault jumps were determined by the one-way ANOVA and the Bonferroni post-hoc test. Level of statistical significance was set at $p<0.05$.

RESULTS

Basic descriptive parameters of measured variables are shown in Table 1.

Results of One-way ANOVA for Velocity of measured variables are shown in Table 2. Results indicated that there were statistical significant differences between run-up velocities of vault entry $p<.01$.

In Table 3 are shown results of Bonferroni Post Hoc test for variables group of vaults. There is a statistical significant difference $p<0.01$ difference in run-up velocity between the Handsprings and Yurchenko entry, and between Tsukahara and Yurchenko entry on vault.

Table 1
Descriptive parameters of run-up velocity on different vault elements.

Variables	Valid N	Mean	Min	Max	Std.Dev.
Hnd	19	8.06	7.40	8.90	0.36
Tsuk	17	8.06	7.08	8.68	0.41
Yurc	12	7.66	7.25	7.93	0.26

Note. Hnd: run-up velocity of Handspring entry on vault; Tsuk: run-up velocity of Tsukahara entry on vault; Yurc: run-up velocity of Yurchenko entry on vault; Valid N: number of samples; Mean: average values; Min: minimum values; Max: maximum values; Std.Dev.: Standard Deviation.

Table 2
One -way ANOVA analysis of velocity.

Dependent Variable	Multiple R	Multiple R2	Adjusted R2	SS Model	df Model	MS Model	SS Residual	df Residual	MS Residual	F	p
Velocity m/s	0.45	0.20	0.17	1.47	2	0.74	5.83	45	0.13	5.68	0.01*

Note. * level of significance p<0.05.

Table 3
Bonferroni Post Hoc test.

Group of vaults	{1} 8,06	{2} 8,06	{3} 7,66
1		1.00	0.01*
2	1.00		
3	0.01*	0.01*	0.01*

Note. {1}: Handsprings entry on vault; {2}: Tsukahara entry on vault; {3}: Yurchenko entry on vault; * level of significance p<0.05.

DISCUSSION

The results showed that the run-up velocity for Handsprings entry to the vault was 8.06 m/s, Tsukahara 8.06 seconds and Yurchenko entry to the vault was 7.66 m/s. Yurchenko entry had a slightly lower run-up velocity than the Tsukahara entry. Investigations of run-up velocity have shown differences between vault type or entry on vault table, depending on weather are performing Yurchenko, handspring or Tsukahara vault (Sands, 2000; Veličković, et al., 2011; Naundorf, et al., 2008; Dolenec, Čuk, Karacsony, Bricelj, & Čoh, 2006). In the last decade, vault run velocity has changed. Those changes are influenced by new vault table and each Olympic cycle new Code of Points. Naundorf, et al (2008) have investigated run-up velocity and concluded that the run-up velocity has been significantly increased since 1997. The reason for that is in the precision of placing the hands in the first flight phase and elements which will be performed in the second flight phase. Investigation by Sands (2000; 2002), have shown that Yurchenko vaults have slower run-up velocity than Handsprings and Tsukahara vaults, because of coming with back to the apparatus and the precision of the round-off performance before the vaulting table. These results are similar to our results.
ANOVA has shown that there are significant differences in the run-up velocity between the Handsprings and Yurchenko entry, and between Tsukahara and Yurchenko entry on vault.

Handsprings and Tsukahara entry have a faster run-up velocity than Yurchenko entry to the vault for better visual control of devices and springboard which allows the gymnast greater precision of entrance at the springboard and vault table and therefore a faster run-up.

The Handsprings group requires a larger amplitude in the second flight time and is considered more difficult to perform (Farana, Uchytil, Zahradník, Jandacka, & Vaverka, 2014). The reason is that from front handsprings they are usually performed rotated around the transverse axis of the body and this is the same with the Tsukahara vault, where the rotations are performed around the transverse axis, but the rotation is performed in backward rotation. Also, an important role in achieving the optimal run-up velocity is the number of steps for each jump. In one study (Čuk & Karacsony, 2004), investigated the speed of the jump according to the difficulty of execution of the jumps and concluded that the run-up velocity should be from 7.5 to 8.5 m/s, and for the difficult jumps of 8.5 to 9.5 m/s for jumps with double salto, run-up velocity should be over 10m/s. Some gymnasts need more steps to achieve the optimal run-up velocity. In each group of vault jumps, higher run-up velocity requires jumps of higher difficulty value and the number of rotations (Bradshaw, 2004). It is important where gymnast will place the springboard for different jumps and also where will start with run-up. For some vaults gymnasts use shorter or larger run-up, it depends on own style of performance. Previous research has shown that errors occurring during the run-up and take-off are difficult to compensate in later stages of the jump (Prassas, et al., 2006). For example, if the gymnasts have a low run-up velocity and weak take-off, then they will reduce height of the jump and the inability to perform the predicted number of rotations during the second flight phase. Since we only collected this information for the optimal run-up velocity, the run-up velocity has its acceleration. The speed of the last ten steps is progressive, and the highest is in the last step at the top (elite) (9.95 m/s) and at High level gymnast is 8.57 m/s. (Veličković, et al., 2011). In the last step, gymnasts decrease run-up velocity because of some preparatory motions for take-off (Fujihara, 2016).

CONCLUSIONS

In the development of the optimal run-up velocity, it is necessary to pay attention in the training process that the maximum speed is reached before the contact with the springboard, i.e. that it has not decreased in the last steps. Today´s popularity of performing double or triple rotations in the second flight phase is huge. Gymnasts trying to perform as high as possible difficulty values of jumps, so they can get better grades of referees and make competition attractively for watching. Considering the importance of investigations of run-up velocity and giving the feedback about key performance parts to coaches, further research should be more detailed to clarify the run-up velocity and put them in relations with other kinematical parameters especially on competitions.

REFERENCES

Atiković, A., & Smajlović, N. (2011). Relation between vault difficulty values and biomechanical parameters in men's artistic gymnastics. *Science of Gymnastics Journal*, *3*(3), 91-105.

Bradshaw, E. (2004). Target-directed running in gymnastics: a preliminary exploration of vaulting. *Sports Biomechanics*, *3*(1), 125-144.

Bradshaw, E., Hume, P.A., Carlton, M. & Aisbett, B. (2010). Reliability and variability of day-to-day vault training measures in artistic gymnastics. *Sports Biomechanics, 9,* 18.

Brehmer, S.N. (2011). Age-related development of run-up velocity on vault. *Science of Gymnastics Journal*, 3.

Chelly, S.M., & Denis, C. (2001). Leg power and hopping stiffness: relationship with sprint running performance. *Medicine and Science in Sports and Exercise*, *33*(2), 326-333.

Čuk, I., Bricelj, A., Bučar, M., Turšič, B., Atiković, A. (2007). Relations between start value of vault and runway velocity in top level male artistic gymnastics. In N.Smajlović (Ed.), *Proceedings Book of 2rd International Scientific Symposium, Sarajevo, 2007, "NTS New Technolgies in Sport"*, (p. 64-67). Sarajevo: Faculty of Sport and PE, University of Sarajevo.

Čuk, I., & Karacsony, I. (2004). *Vault: methods, ideas, curiosities, history*: ŠTD Sangvinčki.

di Prampero, P.E., Fusi, S., Sepulcri, L., Morin, J.B., Belli, A., & Antonutto, G. (2005). Sprint running: a new energetic approach. *Journal of experimental Biology*, *208*(14), 2809-2816.

Dolenec, A., Čuk, I., Karacsony, I., Bricelj, A., Čoh, M. (2006). Runway characteristics of vault in women gymnastics. *Kalokagathia*, *3*(4), 127-136.

Farana, R., Uchytil, J., Zahradník, D., Jandacka, D., & Vaverka, F. (2014). Differences in the key kinematic parameters of difficult Handpsring and Tsukahara vaults performed by elite male gymnasts. *Science of Gymnastics Journal, 6*(2), 53-61.

Ferkolj, M. (2010). A kinematic analysis of the handspring double salto forward tucked on a new style of vaulting table. *Science of Gymnastics Journal*, *2*(1), 35-48.

Fernandes, S.M.B., Carrara, P., Serrão, J.C., Amadio, A.C., & Mochizuki, L. (2016). Kinematic variables of table vault on artistic gymnastics. *Revista Brasileira de Educação Física e Esporte*, *30*(1), 97-107.

Fujihara, T. (2016). Revisiting run-up velocity in gymnastics vaulting. In M. Ae, Y. Enomoto & N. Fujii, H. Takagi (Eds.), *Proceedings of 34 International Conference on Biomechanics in Sports, Tsukuba, Japan* (p. 593-596). Michigan: Northern Michigan University.

Krug, J., K. Knoll, Kothe, T. & Zocher, H.D. (1998). Running approach velocity and energy transformation in difficult vaults in gymnastics. In: H.J. Riehle, M.M. Vieten, (Ed.), *ISBS '98 XVI International symposium on biomechanics in sports,* (p.160-163). Germany: UVK – Universitatsverlag.

Harrison, A.J., Jensen, R.L., & Donoghue, O. (2005). A comparison of laser and video techniques for determining displacement and velocity during running. *Measurement in physical education and exercise science*, *9*(4), 219-231.

Haugen, T., & Buchheit, M. (2016). Sprint running performance monitoring: methodological and practical considerations. *Sports Medicine*, *46*(5), 641-656.

Morin, J.B., Jeannin, T., Chevallier, B., & Belli, A. (2006). Spring-mass model characteristics during sprint running: correlation with performance and fatigue-induced changes. *International journal of sports medicine*, *27*(02), 158-165.

Naundorf, F., Brehmer, S., Knoll, K., Bronst, A., & Wagner, R. (2008). Development of the velocity for vault runs in artistic gymnastics for the last decade. In Y.H. Kwon, J. Shim, J.K. Shim & I.S. Shin (Eds.), *Proceedings of 26 International Conference on Biomechanics in Sports, Seoul, Korea* (p.481-484). Germany: University of Konstanz.

Prassas, S., & Gianikellis, K. (2002). Vaulting mechanics. In K. E. Gianikellis (Ed.), *Proceedings of 20 International Symposium of Biomechanics in Sports, Cáceres, Spain* (p. 1-4). Germany: University of Konstanz.

Prassas, S., Kwon, Y.H., & Sands, W.A. (2006). Biomechanical research in artistic gymnastics: a review. *Sports Biomechanics*, *5*(2), 261-291.

Sands, W.A. (2000). Vault run speeds. *Technique*, *20*(4), 1-5.

Sands, W.A., & McNeal, J.R. (2002). Some guidelines on the transition from the old horse to the new table. *Technique, 22*, 22-23.

Takei, Y., Dunn, J.H., Blucker, E.P., Nohara, H. & Yamashita, N. (2000). Techniques used in high- and lowscoring Hecht vaults performed at the 1995 World Gymnastics Championships. *Journal of Applied Biomechanics, 16,* 180-195.

Takei, Y., Dunn, J.H., & Blucker, E.P. (2007). Somersaulting techniques used in high-scoring and low-scoring Roche vaults performed by male Olympic gymnasts. *Journal of sports sciences*, *25*(6), 673-685.

Van der Eb, J.V.D.E., Filius, M., Rougoor, G., Van Niel, C., de Water, J., Coolen, B., & de Koning, H. (2012). Optimal velocity profiles for vault. In *ISBS-Conference Proceedings Archive* (Vol. 1, No. 1).

Veličković, S., Petković, D., & Petković, E. (2011). A case study about differences in characteristics of the run-up approach on the vault between top-class and middle-class gymnasts. *Science of Gymnastics Journal*, *3*(1), 25-34.

Živčić Marković, K., & Krističević T., (2016). *Osnove sportske gimnastike*. [Basics of gymnastics]. Zagreb: Faculty of Kinesiology, University of Zagreb.

Corresponding author:

Lucija Milčić
Faculty of Kinesiology
Horvaćanski zavoj 15
10 000 Zagreb
Croatia
Tel and Fax num: +385 981679752
E-mail: lucija.milcic@kif.hr

EFFICACY OF WRIST STRATEGY COACHING ON HANDSTAND PERFORMANCES IN NOVICES: INVERTING EXPLICIT AND IMPLICIT LEARNING OF SKILL-RELATED MOTOR TASKS

Jonas Rohleder, Tobias Vogt

German Sport University Cologne, Institute for Professional Sport Education and Sport Qualifications, Cologne, Germany

Original article

Abstract

In gymnastics, mainstream handstand coaching emphasizes developing an aligned rigid body configuration, frequently leaving wrist-controlled balance work to implicit learning. However, skill-related motor behavioral research suggests the wrists to primarily contribute postural control in handstands. Considering recent research on handstands revealing experience-dependent motor behavior, the present study aimed to examine motor learning effects of explicit wrist usage coaching on handstand performances in skilled and less skilled novices. Therefore, twenty-five volunteering sport students served as participants completing a three-week training intervention which solely and explicitly addressed successful wrist usage during handstand. A video-tutorial introducing participants to the wrist strategy of hand balance preceded five practical training sessions that all neglected providing explicit postural advice. Participants performed three handstands on a plane gymnastics mat prior to (pre-test) and after (post-test) completing the training intervention. Standardized video recordings of each trial allowed retrospective group assignment (skilled and less skilled novices) based on pre-test mean balance times. With this, balance times, expert assessments (postural execution and balance control strategies) and goniometric analyses of shoulder and hip joint angles served to detect practical changes in handstand performances. Enhanced balance times as well as increased scores for postural execution and balance control strategies were revealed for less skilled novices ($p < .05$), but not for skilled novices ($p > .05$). Furthermore, in both groups changes in shoulder and hip joint angles failed significance. In conclusion, present findings suggest practitioners to make entirely unexperienced handstand learners explicitly aware of the wrist strategy's operating principle.

Keywords: *skill acquisition, balance, postural control, declarative knowledge, model observation.*

INTRODUCTION

"You make a hollow back" or "open your shoulder angle" are regular phrases gymnastics coaches use to comment on defective handstand performances. Augmented feedback and instructions have obtained widespread acceptance to benefit motor skill learning (Schmidt & Lee, 2011). However, are suchlike explicit advice sufficient? And what is considered as crucial for learning handstands at all? With the handstand on the floor being an essential postural motor task in gymnastics

(Hedbávný, Sklenaříková, Hupka, & Kalichová, 2013), contemporary educational concepts on motor learning in handstand acquisition are suggested to respond these questions from interdisciplinary perspectives.

In general, a biomechanical point of view promises valuable knowledge regarding essential qualities for successful handstand performances. Due to modern technology allowing mobile data collection during sport-specific movements (Vogt, Kato, Schneider, Türk, & Kanosue, 2017) and handstand performances in particular (Blenkinsop, Pain, & Hiley, 2016), decoding motor behavior in handstands has still received considerable attention in recent research (Blenkinsop, Pain, & Hiley, 2017; Kochanowicz et al., 2017; Kochanowicz et al., 2018). Based upon previous studies addressing upright and inverted stance dynamics (Kerwin & Trewartha, 2001; Yeadon & Trewartha, 2003), it is meanwhile well accepted that postural control mechanisms during handstand on a plane surface initially depend on contributing torques by the most inferior joint (i.e., wrist). Compared to other involved muscles, wrist flexor torques have recently been reported to show the highest mean EMG activity (i.e., 60% RMS normalized to an isometric MVC) in handstand balances (Kochanowicz et al., 2018). In case of increasing postural oscillations, synergistic shoulder and hip torques are additionally used to maintain balance control (Hedbávný et al., 2013). With this, Gautier, Marin, Leroy and Thouvarecq (2009) accentuated that angular hip joint adjustments are only used by low-level gymnasts, whereas handstand performances executed by high-level experts are characterized by corrective movements in the most inferior joints. However, regardless of the applied balance control strategy, movement patterns facilitating maintenance in handstand benefit from visual control (Asseman & Gahéry, 2005; Gautier, Thouvarecq, & Chollet, 2007) and remain the center of mass (CoM) vertically above the base of support (Kerwin & Trewartha, 2001). Thus, skill-related motor behavior in handstand can be modelled as a single-segment inverted pendulum (Blenkinsop et al., 2017) with the body balanced above the wrists as one steady object (Yeadon & Trewartha, 2003).

This in mind, high-level handstand performances and, thus, practice are suggested to approach two fundamental motor skills; (1) postural modulations leading to a linear rigid body configuration, (2) balance control abilities due to wrist flexor muscular activation. Considering that several biomechanical and motor behavioral studies only deal with handstand performances of experienced gymnasts (e.g., Gautier et al., 2009), current research on handstand skill acquisition in unexperienced learners indicates that the importance of these two respective aspects has rather been neglected in literature. Instead, several reports focused on the know-how of handstand coaching, referring to the expedient application of general knowledge about augmented feedback (e.g., Post, Aiken, Laughlin, & Fairbrother, 2016; Veit, Jeraj, & Lobinger, 2016) and observational learning (e.g., Andrieux & Proteau, 2016; Blandin, Lhuisset, & Proteau, 1999; Braun, 2016; Breslin, Hodges, & Williams, 2009; Buchanan & Dean, 2014; Hayes, Hodges, Scott, Horn, & Williams, 2006; Janelle, Champenoy, Coombes, & Mousseau, 2003; Laguna, 2008; Rohbanfard & Proteau, 2011). Regarding handstand acquisition, there are some studies investigating verbal (Masser, 1993), tactile (Croix, Lejeune, Anderson, & Thouvarecq, 2010) and several combined feedback (e.g., tactile-verbal and visual-comparative feedback; Rohleder & Vogt, 2018b) and observational learning strategies (Maleki, Nia, Zarghami, & Neisi, 2010). For example, Croix et al. (2010) suggest light finger contact on the thigh to increase gymnasts' balance abilities in handstands. Previously, Masser (1993) observed enhanced handstand performances in students evoked by the verbal instruction “shoulder over your knuckles”. With these studies providing substantial insights into enhanced handstand education, research dealing with the weighting of crucial training contents (i.e. wrist work, postural adaptations) with respect to explicit (EL) and implicit learning (IL; Sun, Merrill, & Peterson, 2001) is still lacking. Aiming for efficient coaching, it is well accepted that the complexity of potential effects regarding EL and IL has to be taken into account, particularly with respect to adversely affected performances due to reinvestment (Lam, Maxwell, & Masters, 2009; Malhotra, Poolton, Wilson, & Omuro, 2015; Masters & Maxwell, 2008; Verburgh, Scherder, van Lange, & Oosterlaan, 2016). While reports by Uzunov (2008) as well as Rohleder and Vogt (2018) suggest that wrist work and a proper body line seem to be mutually dependent for successful handstands, current training methodology privileges the explicit development of the postural alignment preceding wrist-related practice (Uzunov, 2008). Considering recent reports suggesting the wrist strategy to be the most dominant control strategy even in perturbed handstand balances (e.g., Blenkinsop et al., 2017), the relatively low status of explicit hand balance abilities in current handstand educational concepts may be challenged. Conscious of facilitated balance practicing due to preceding learning of postural stabilization, however, investigations on adapted EL-based handstand coaching providing declarative knowledge regarding wrist usage, accompanied by only implicit postural training, remain to be elucidated in consideration of different skill levels (Gautier et al., 2009; Kochanowicz et al., 2018; Vogt et al., 2017).

Approaching altered learning of skill-related motor tasks compared to predominant handstand training, this study aimed to examine motor learning effects of explicit wrist strategy coaching on handstand performances in skilled and less skilled novices. With respect to presumably existing non-declarative knowledge regarding the wrist strategy in skilled novices, it is hypothesized that (1) less skilled compared to skilled novices show training-induced increases in balance time that are related to enhanced postural control patterns. (2) Less skilled compared to skilled novices are further hypothesized to show training-induced enhancements in postural performances that reflect beneficial effects of IL regarding an aligned body configuration.

METHODS

Thirty-two volunteering sport students (17 females: M_{age} = 20.71, SD = 0.99 years; M_{height} = 167.85, SD = 7.38 cm; M_{weight} = 59.68, SD = 7.17 kg; 15 males: M_{age} = 22.07, SD = 1.67 years; M_{height} = 183.40, SD = 5.77 cm; M_{weight} = 77.93, SD = 7.27 kg) were recruited from university courses to participate in this study. Volunteers who gained gymnastics experience well beyond school classes (i.e., particular history in organized gymnastics training systems) were excluded a priori. However, passing the university’s physical aptitude test guaranteed participants’ fundamental skill-related experience regarding the lunge entry and swing up to handstand movement. The study received approval by the University’s Human Research Ethics committee in compliance with the Declaration of Helsinki. All participants provided written consent.

Unaware of the experimental hypotheses, participants completed two experimental protocols (pre- and post-test) each comprising three trials (Gautier et al., 2007) of swinging up to handstand on the floor. Withholding augmented advice addressing a resistant linear body configuration, each participant was instructed beforehand to aim for long maintenance in handstand with their feet kept close together. Following individual warm up and preparation (handstands were not permitted), one single handstand rehearsal served as familiarization preceding test trials (Rohleder & Vogt, 2018a). In absence of any rules describing a standardized termination of the handstand position, participants were allowed to roll over, to leave the handstand sideways or to place their feet back. Any changes of the hand position during handstand led to discontinuation of the trial. Approaching sport-specific conditions in consideration of a user-orientated environment (Rohleder & Vogt, 2018b), the experiment was conducted in the University's gym using a certified gymnastics mat to perform the handstand trials. A rectangular corridor (dimensions: 80 × 30 cm) was affixed on the mat using white tape to standardize the position of hand support during handstand (Figure 1C).

Pre-tests were performed as described within one week (i.e., week 1; Figure 1A). Subsequently, participants received a video-tutorial providing concise declarative knowledge concerning the operating principle of the wrist strategy for successful handstand balances (Blenkinsop et al., 2017; Kerwin & Trewartha, 2001; Yeadon & Trewartha, 2003). Taking the current stage of research concerning effective observational learning into account, the tutorial used a mixed-model approach (Rohbanfard & Proteau, 2011) presenting one failed and one successful wrist-controlled hand balance. Video sequences were accompanied by screenshots and verbal comments (Janelle et al., 2003) raising participants' awareness for wrist-related knowledge of performance (Laguna, 2008) and models' skill level (Andrieux & Proteau, 2016). Limiting attentional cueing to wrist-related features ensured explicit and consistent focusing on the wrists' skill-related relevance (Breslin et al., 2009; Buchanan & Dean, 2014). Hence, advice stressing critical cues to facilitate postural adjustments were not taught.

Combining observational learning with physical practice (Blandin et al., 1999), participants completed five training sessions within the following three weeks (Maleki et al., 2010; Masser, 1993) including two sets of six different exercises. Based on afore conveyed expertise, all exercises intended skill-related motor control in terms of wrist flexor activation during handstand on a plane surface. Partially inspired by Uzunov (2008), exercises (E1-E6) were designed as follows (Figure 1B):

- E1: Winding up a rope (due to wrist flexions) which is connected with a weight plate (1.25 kg).
- E2: Oblique standing with straight arms parallel next to the ears and repeated hand pushing against a wall leading to sole wall touch by the fingertips.
- E3: Knee rest and repeated palmar flexion of the wrists (forehand view) with a weight plate (1.25 kg) in each hand.
- E4: Free practicing of the lunge entry and swing up to handstand aiming for a vertically placed CoM above the fingers. Self-controlled video feedback (delay: 12 sec) was provided using a tablet PC (iPad Air) (Post et al., 2016).
- E5: Free standing with straight arms parallel next to the ears and performing repeated palmar flexions of the wrists with a weight plate (1.25 kg) in each hand.
- E6: Lunge entry and swing up to handstand leaning the thighs against a bar (fingertips approximately 10 cm away from the bar's perpendicular) and removal of the thighs from bar contact (Croix et al., 2010) due to sole wrist flexions. Pushing the bar actively by the legs was explicitly prohibited.

In accordance with the video-tutorial, exercises aimed for explicit wrist flexor activation triggered by locating the CoM vertically above the support surface (i.e., E4 and E6). In favor of visual control (Asseman & Gahéry, 2005), participants were encouraged to gaze their hands throughout all exercises. Referring to recommended training loads (Uzunov, 2008), each exercise was executed for approximately thirty seconds followed by a self-determined recovery period (≤ 30 s). Postural adaptations and a controlled dosing (i.e., self-paced velocity) of the swing up to handstand movement were only addressed implicitly without any explicit cueing provided by the experimenters. After completion of the third training week, the post-test was conducted during the following week in conformity with the pre-test's modalities (Figure 1A).

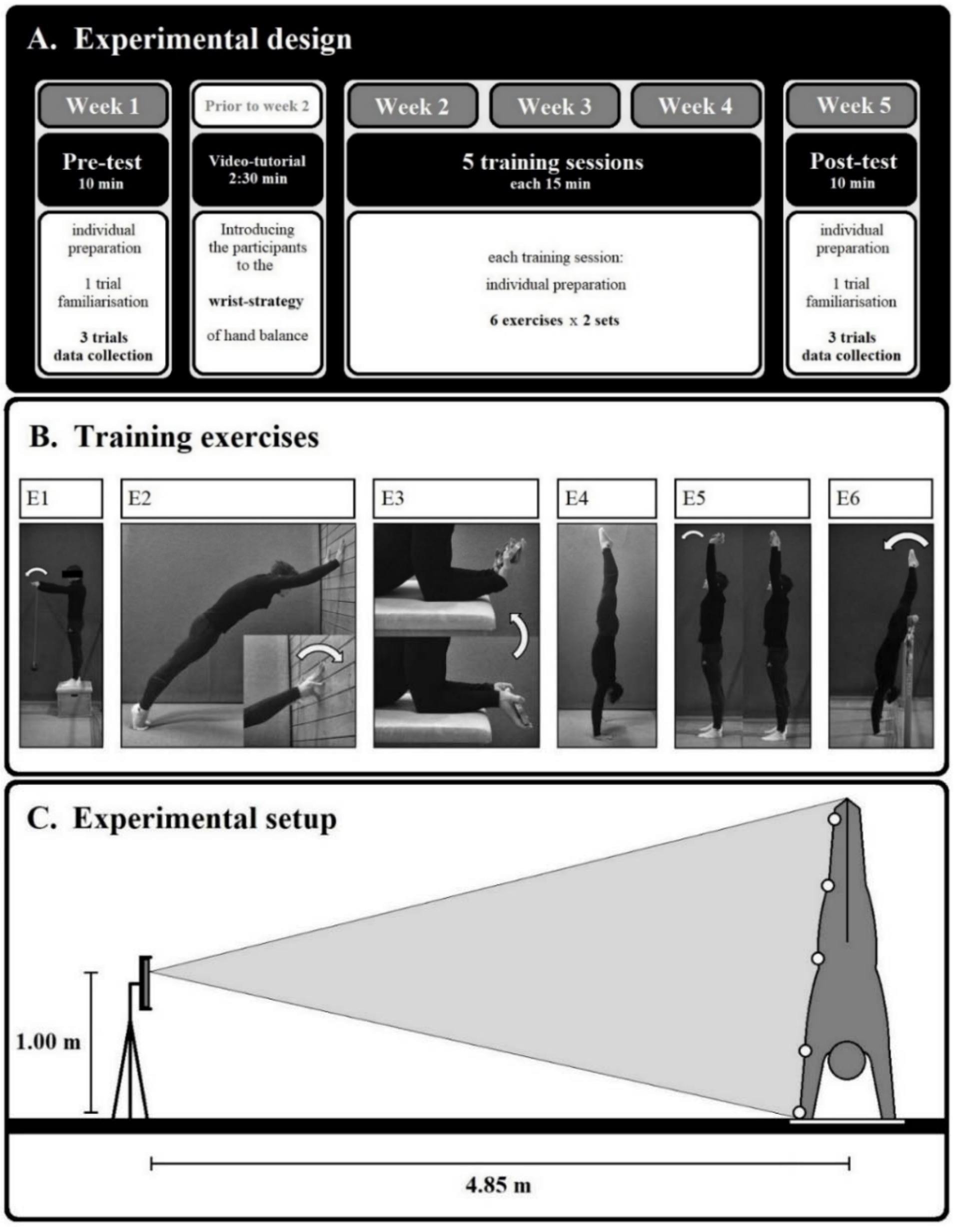


Figure 1. Schematic view displaying (A) the experimental design of the overall procedures, (B) the exercises performed within the training interventions (here: accurate execution quality by an experienced gymnast to emphasize the basic intention of the exercises best possible) and (C) the experimental setup for data collection.

Following a practical approach, a tablet PC (Apple iPad Air, frequency: 60 Hz; resolution: 1080p) was used to record all trials capturing the movement task in the sagittal plane. The tablet PC was fixed to a tripod at a height of one meter (distance to the middle of support surface: 4.85 m) ensuring a standardized point of view (Rohleder & Vogt, 2018a; Figure 1C). Tape markers were attached to the following anatomical landmarks to track the position of crucial body segments; 1: wrist (ulnar-styloid process), 2: shoulder (posterior deltoid), 3: hip (femur greater trochanter), 4: knee (lateral epicondyle of femur), 5: ankle (fibula apex of lateral malleolus). Based on recorded video sequences, kinematic data were further determined using the Kinovea 0.8.15 software.

In line with official criteria of the International Gymnastics Federation (FIG) concerning point deductions for handstand performances due to angular deviations (FIG, 2017), the balance time in handstand was measured using a corridor limited by a deviation of 15° to each side of vertical line above the wrists (Rohleder & Vogt, 2018a). With this, time measuring was started when both legs (ankles and knees) initially entered the corridor following the swing up to handstand. Moreover, time measuring was discontinued under the following conditions; 1: corridor exit of the feet or knees, 2: Initiation of the rolling over movement (i.e., incipient arm bending or rolling in of the head), 3: Initiation of the back placing of the feet (i.e., incipient increase of the maximum reduced feet gap).

The quality of postural execution was evaluated by four independent artistic gymnastics experts (i.e., two nationally licenced coaches and two judges; two male and female each) assigning scores between 0.0 and 10.0 points to each trial matching current FIG rules (FIG, 2017). For this, experts were briefed to completely neglect participants' balance time in handstand. Instead, experts were instructed to particularly evaluate unsteadiness, slightly bent arms and legs (in accordance with the criteria described in 2.4.1) as well as angular deviations from the perfect hold position (FIG, 2017). Trials of each participant (i.e., 3x pre-test; 3x post-test) were presented to the experts in randomized order.

Additionally, experts were asked to assign one of five balance control strategies to each trial with respect to the externally visible postural correction mechanisms in anterior-posterior direction. Balance control strategies were characterized as follows (Figure 2):

- Wrist strategy (4 points): robust body configuration from wrists to ankles with apparent wrist-controlled balance corrections
- Shoulder strategy (3 points): robust body configuration from shoulders to ankles with apparent shoulder-controlled balance corrections
- Shoulder-hip-coupling (2 points): apparent contrary shoulder- and hip-controlled balance corrections
- Hip strategy (1 point) robust body configuration from wrists to the hip with apparent hip-controlled balance corrections
- "No strategy" (0 points): no apparent motor skills to maintain the handstand position

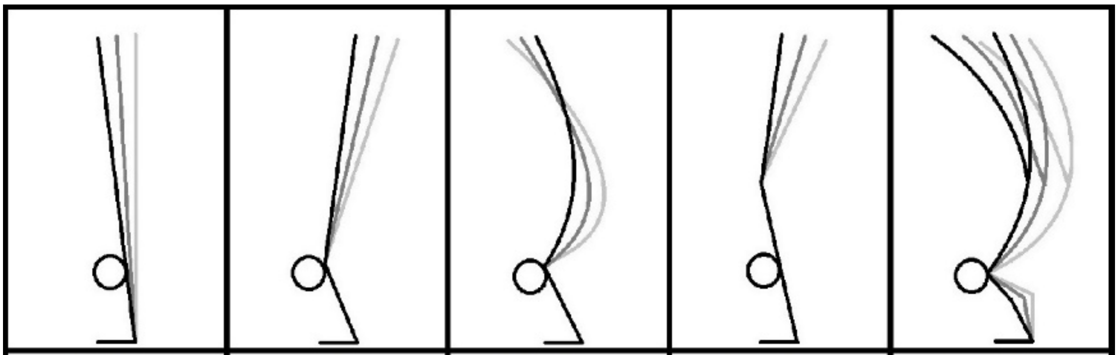


Figure 2. Categories of anterior-posterior balance control strategies in handstand assigned by the experts (inspired by Blenkinsop et al., 2017 and Gautier et al., 2009). Classification: The larger the distance of the primarily correcting joint to the support surface, the lower the points for the applied balance control strategy

Goniometric analyses focused on large body joints (i.e., shoulder and hip joint) which, except for the wrists, have been suggested to primarily contribute to postural control during handstand performances (Gautier et al., 2009). To determine joint-related angular changes during handstand, the individual optimum of each handstand trial was identified (Masser, 1993) based on predefined criteria derived from Rohleder & Vogt (2018b); (1) in case of rolling over trials, the moment where the participants' feet reached their highest point was set as optimum, (2) in case of trials characterized by side or back placement of the feet, the moment of incipient leg straddling or spreading served as optimum.

Due to conflicting schedules or unpredicted injuries caused by their sport studies, six participants did not complete the full experimental procedure and were excluded from statistical analyses. After checking interval scaled variables (balance time, shoulder angle, hip angle) for outliers using the 2σ-method, remaining participants (n = 25) were assigned to two groups based on rankings of attained pre-test mean balance times. Inspired by Vogt et al. (2017), the ranking list was divided into a long-balancing half ($M_{\text{balance time}}$ = 1.13 s, *SD* = .42, n = 13) and a short-balancing half ($M_{\text{balance time}}$ = .41 s, *SD* = .18, n = 12). According to this bisection of rankings (unpaired *t*-test revealed $t[23] = 5.40$, $p < .01$), participants were classified as skilled (long-balancing half) and less skilled novices (short-balancing half) for further analyses.

Repeated measures analyses of variance (ANOVAs) were computed for each dependent interval scaled variable (i.e., balance time, shoulder and hip angle) including group (skilled vs. less skilled) as between factor and test (pre- vs. post-test) as within factor. Further, pairwise comparisons (i.e., paired and unpaired *t*-tests) were calculated post hoc. For ordinal scaled variables (i.e., postural execution, balance control strategy), Wilcoxon signed-ranks tests and Mann-Whitney-U-tests were immediately performed as pairwise comparisons. All calculations for pairwise comparisons were adjusted for multiple testing by applying Bonferroni-Holm corrections. Kendall's coefficient of concordance (*W*) was calculated to ensure interrater reliability of the ordinal scaled variables concerning expert judgements (postural execution: $W(149) = .787$, $p < .01$; Balance control strategy: $W(149) = .487$, $p < .01$). Partial eta-squared (η^2_p) was used to identify ANOVAs' effects, whereas Cohen's *d* effect sizes were calculated to interpret pre-to-post changes. Statistical analyses were performed using the SPSS 25.0 software (International Business Machines Corp., Armonk, NY, USA). The level of significance was set at $p < .05$. Data in the text, tables and figures are presented as means (*M*) ± standard deviations (*SD*).

RESULTS

Balance time

Repeated measures ANOVA revealed significant interactions between factors group and test, $F(1, 23) = 6.40$, $p < .05$, $\eta^2_p = .22$; however, main effects revealed no differences for tests, $F(1, 23) = 1.88$, $p > .05$, $\eta^2_p = .08$. Post hoc tests showed significant enhanced balance times for less skilled, $t(11) = 3.93$, $p < .01$, $d = 1.30$, but not for skilled novices, $t(12) = .69$, $p > .05$, $d = .27$; further, post hoc tests showed significant group differences in the pre-test, $t(23) = 5.40$, $p < .01$, which were not obtained for the post-test, $t(23) = .92$, $p > .05$ (Figure 3; Table 1).

Postural execution

Wilcoxon signed-ranks test showed significantly increased scores for postural execution in less skilled novices, $Z = -2.67$, $p < .05$, $d = .79$, but not for skilled novices, $Z = -1.71$, $p > .05$, $d = .47$; further, Mann-Whitney-U-test showed significant group differences in the pre-test, $U = 22.50$, $p < .01$, which were not obtained for the post-test, $U = 77.50$, $p > .05$ (Figure 3; Table 1).

Balance control strategy

Wilcoxon signed-ranks test showed significantly increased scores for balance control strategy in less skilled novices, $Z = -2.43$, $p < .05$, $d = .91$, but not for skilled novices, $Z = -1.15$, $p > .05$, $d = .43$; further, Mann-Whitney-U-test showed no significant group differences in the pre-test, $U = 45.50$, $p > .05$, and in the post-test, $U = 63.00$, $p > .05$ (Figure 3; Table 1).

Goniometric analysis

Shoulder angle: repeated measures ANOVA revealed no interactions between factors group and test, $F(1, 23) = 1.43$, $p > .05$, η2p = .06; further, main effects revealed no differences for tests, $F(1, 23) = 1.86$, $p > .05$, η2p = .08 (Figure 3; Table 1).

Hip angle*: r*epeated measures ANOVA revealed no significant interactions between factors group and test, $F(1, 23) = 5.09$, $p > .05$, $\eta^2_p = .18$; further, main effects revealed no differences for tests, $F(1, 23) = .01$, $p > .05$, $\eta^2_p = .00$. (Figure 3; Table 1).

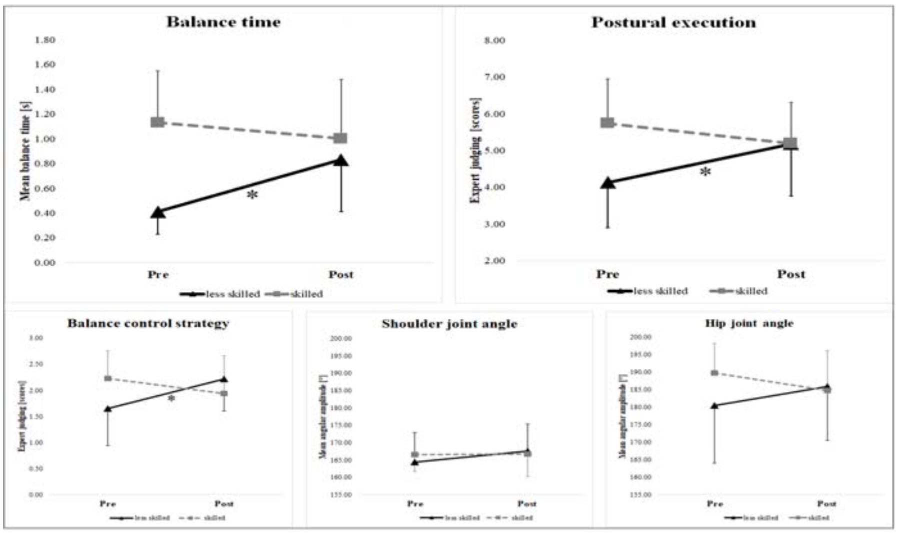


Figure 3. Interaction plots displaying means ± standard deviations for group-related changes (less skilled vs. skilled novices) of factors balance time, postural execution, postural control strategy as well as shoulder and hip joint angle. Level of significance in pairwise comparisons (adjusted to Bonferroni-Holm-corrections): *$p < .05$.

Table 1
Changes in handstand performances (means ± standard deviations) during pre- and post-test for less skilled and skilled novices.

	Less skilled		Skilled	
	Pre-test	Post-test	Pre-test	Post-test
Balance time [s]	0.41 ± 0.18	0.83 ± 0.42	1.13 ± 0.42	1.00 ± 0.48
Postural execution [points]	4.13 ± 1.23	5.18 ± 1.42	5.74 ± 1.21	5.19 ± 1.12
Balance control strategy [points]	1.65 ± 0.53	2.22 ± 0.72	2.23 ± 0.71	1.94 ± 0.61
Shoulder angle [°]	164.47 ± 8.40	167.58 ± 7.83	166.59 ± 4.95	166.79 ± 6.59
Hip angle [°]	180.45 ± 16.45	185.86 ± 15.39	189.69 ± 8.48	184.74 ± 11.44

DISCUSSION

The present study aimed to examine motor learning effects of explicit wrist strategy coaching on handstand performances in skilled and less skilled novices. With pre-test mean balance time rankings serving as criterion for skill level-based group assignment (i.e., skilled vs. less skilled novices), enhanced mean balance times, scores for postural execution and postural control strategies were observed in less skilled compared to unaffected parameters in skilled novices. Furthermore, in both groups changes in shoulder and hip joint angles failed significance.

According to our initial first hypothesis (1), increased mean balance times in less skilled novices reflect beneficial effects of EL evoking declarative knowledge (Sun et al., 2001) in entirely unexperienced learners regarding the wrist strategies' operating principle (Blenkinsop et al., 2017; Kerwin & Trewartha, 2001; Yeadon & Trewartha, 2003). With this, increased handstand balance times in less-skilled novices support combined physical practice with observational learning and augmented feedback to accelerate general (Magill, 2014; Schmidt & Lee, 2011), gymnastics-related (Braun, 2016; Veit et al., 2016) and even handstand-specific skill development (Maleki et al., 2010). However, while all participants (i.e., skilled and less skilled) received the same literature-based video-tutorial (e.g., Andrieux & Proteau, 2016; Janelle et al., 2003; Rohbanfard & Proteau, 2011) and training intervention (e.g., Asseman & Gahéry, 2005; Post et al., 2016; Uzunov, 2008), unaffected mean balance times in skilled compared to less skilled novices have to be discussed in light of large standard deviations and EL-induced performance-influencing factors (Lam et al., 2009; Malhotra et al., 2015). Taking recommended and, thus, implemented consistency in attentional directing and movement task usage into consideration (Breslin et al., 2009; Buchanan & Dean, 2014), there are reasons to assume that the present study's findings may be attributed to the reinvestment theory by Masters and Maxwell (2008) suggesting declarative task-relevant knowledge (i.e., wrist strategy usage) to interfere already automated motor processes which were presumably present in the skilled group prior to the intervention. Facing this, it seems reasonable that task-relevant knowledge may occasionally impair more skilled handstand balances (Masters & Maxwell, 2008), apparently independent of the approached coaching focus regarding skill-related motor tasks (e.g., wrist strategy usage vs. postural stabilization; Rohleder & Vogt, 2018a). Nevertheless, although showing negative tendencies, it has to be taken into account that impaired balance times and balance control strategies in skilled novices failed significance. Thus, interpretations of present effects with respect to reinvestment can only serve as assumptions and need further research. Furthermore, with Kochanowicz et al. (2018) and Gautier et al. (2009) reporting skill level dependencies of balance control, groups are considered to reflect emerging differences regarding altered motor behavior as a result of the training intervention. However, with respect to this, present findings disclose inconsistencies in view of comparable studies. For example, facilitated handstand balances due to light thigh touch during testing were revealed for experienced gymnasts (Croix et al., 2010). On the one hand, this contradicts advantageous balance performances in less skilled compared to skilled participants in the present study following training including a tactile advice on the thigh (E6). On the other hand, in the present study contact on the thigh was only applied during training, but not during testing which interferes comparability. Furthermore, Croix et al. (2010) then again applied a lateral touch compared to a dorsal touch in the present study and related enhanced balancing to the lateral, but not to the anterior-posterior direction which is essentially approached in the present study. With this, skill level-related comparisons must take the level of experience and setup-alterations into account in more detail. Using laboratory setups, Kochanowicz et al. (2018) compared two experienced groups (young and adult gymnasts) as well as Gautier et al. (2009) comparing high-level and low-level experts who were all able to maintain in the handstand for at least twenty seconds. Thus, although filling a stated research gap according to efficient coaching on wrist usage in handstand acquisition (Rohleder & Vogt, 2018a), broad evidence regarding motor behavior in experienced gymnasts (Blenkinsop et al., 2017; Gautier et al., 2007; Gautier et al., 2009; Kochanowicz et al., 2017; Kochanowicz et al., 2018) remains indistinct for unexperienced performers and, thus, complicates integrating our findings into an appropriate context of literature. This encourages to further elucidate novices motor behavior in response to altered educational concepts approaching EL and IL effects in handstand acquisition.

According to our second hypothesis (2), increased postural execution in less skilled novices suggests explicit wrist strategy coaching to even induce posture-related IL leading to more aligned body configurations. These findings confirm well-accepted knowledge regarding IL benefits (Lam et al., 2009; Verburgh et al., 2016) and are additionally in line with comparable studies reporting enhanced postural performances in handstands following feedback- and observation-based interventions (Maleki et al., 2010; Masser, 1993; Rohleder & Vogt, 2018b). However, while the present study revealed enhanced postural configurations following IL, Maleki et al. (2010) related observational learning benefits to additional (explicit) verbal teaching. In addition, the verbal cue „shoulder over your knuckles” used by Masser (1993) provides declarative knowledge in terms of postural adaptations which is in contrary to the present study's approach revealing implicit body alignment in less skilled novices. Moreover, Maleki et al. (2010) assumed the skill level to influence observational and physical practice benefits, which was partially reflected by unaffected postural execution in skilled novices. Additionally, from a goniometric perspective, shoulder joint angles remained unaffected in both groups which is in conflict to a previous study by Rohleder and Vogt (2018b) reporting feedback-induced shoulder angle changes in handstand positions in the absence of hip-related effects. Challenging these contradictory reports, it seems reasonable that the studies' divergent primary objectives which were explicitly taught to the participants a priori may have caused different postural adaptations. While Rohleder and Vogt (2018b) explicitly addressed high postural execution quality neglecting maintenance in handstands, the participants in the present study were exclusively instructed to aim for a long balance time, which may eventually induce different movement patterns regarding postural control. Additionally, although failing significance, slightly increased hip angles in less skilled novices provide reasons to assume that unexperienced learners implicitly tend to use opening the hip joint in order to locate the CoM vertically above the support surface. Although the comparability of skill-levels is partially limited, this assumption is in line with Gautier et al. (2009) reporting low-level experts to prefer increased hip joint involvement to coordinate postural control. Necessitating further research, this might indicate implicit postural adaptations in response to EL regarding wrist usage.

In summary, the present study's findings legitimize the underlying approach of handstand coaching concepts strictly geared to skill-related motor behavior in terms of an increased explicit focus on wrist usage. Confirming initial assumptions from previous reports (Rohleder & Vogt, 2018a), explicit wrist strategy coaching neglecting any kind of posture-related advice benefits comprehensive handstand acquisition in less skilled novices including enhanced balance and, remarkably, enhanced quality in handstands' postural execution. This is, at least in parts, in contrary to Uzunov (2008) suggesting rigid body line development preceding balance training. However, efficacy of wrist-related handstand coaching seems to be ineffective to relatively skilled performers. While these negative effects may again be discussed with respect to EL effects on reinvestment (Masters & Maxwell, 2008), there is a further need to clarify if the practical training or the taught "know how" in the video-tutorial (or, presumably, the combination of both) essentially caused observed changes in handstand performances. Although studies prefer combined observational learning and physical practice (Blandin et al., 1999; Hayes et al., 2006), there are few studies indicating positive EL effects even without practical training (Maleki et al., 2010; Rohleder & Vogt, 2018b). This, for example, suggests further research to exclusively address observational learning introducing novices to the wrist strategy of handstand balances.

LIMITATIONS

Considering that the small number of participants generally limits the power of the present study, the recruited sample size seemed to be appropriate in relation to comparable studies in this research field (e.g., Croix et al., 2010). Nevertheless, we are well aware that a missing group of participants receiving no kind of coaching and practice represents a methodological limitation. Although further investigations are suggested to take an additional control group into consideration, the premeditated group assignment was deemed appropriate with respect to our comparative approach on motor learning effects in dependence on novices' skill level. Furthermore, although the unsteadiness of durations in handstand position (leading to high standard deviations) limits the present approach, we see this limitation as a necessary expense for a study aiming to serve as a kick off for applied research on the coaching of unexperienced handstand learners. Additionally, choosing a practice-orientated setup may be discussed in relation to reliable data collection. However, in view of comparable laboratory-based studies with similar shortcomings (e.g., Gautier et al., 2007; comparable low-frequency video sampling), reserves in data reliability are disproportionate to validity-related benefits of the chosen setup providing familiar and safe conditions to allow natural movement execution which is uninfluenced by impeding laboratory framework. Finally, it has to be taken into account that the differentiation between judging postural execution and balance control strategies was a necessary, but difficult task for judges which probably further limits the present study.

CONCLUSIONS

To conclude, the present study investigated effects of explicit wrist strategy coaching on novices' handstand performances depending on the skill level. Present findings (i.e., increased balance time and execution quality) suggest practitioners to make entirely unexperienced learners explicitly aware of the wrist strategy's operating principle. This is with respect to a no less important coaching of postural stabilization. With this study extending practice-oriented knowledge of efficient motor learning in handstand acquisition, appropriate educational strategies need further investigations approaching insights into skill-related motor behaviour, especially in unexperienced handstand learners.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to all participants for their enthusiastic responses and reliable efforts in favor of the present study. This study was supported by an international grant of the German Academic Exchange Service (DAAD project no. 57320531) awarded to the supervising author.

REFERENCES

Andrieux, M., & Proteau, L. (2016). Observational Learning: Tell Beginners What They Are about to Watch and They Will Learn Better. *Frontiers in Psychology, 7*, 51. doi:10.3389/fpsyg.2016.00051

Asseman, F., & Gahéry, Y. (2005). Effect of head position and visual condition on balance control in inverted stance. *Neuroscience Letters, 375*(2), 134–137. doi:10.1016/j.neulet.2004.10.085

Blandin, Y., Lhuisset, L., & Proteau, L. (1999). Cognitive Processes Underlying Observational Learning of Motor Skills. *The Quarterly Journal of Experimental Psychology, 52*(4), 957–979. doi:10.1080/027249899390882

Blenkinsop, G. M., Pain, M. T. G., & Hiley, M. J. (2016). Evaluating feedback time delay during perturbed and unperturbed balance in handstand. *Human Movement Science, 48*, 112–120. doi:10.1016/j.humov.2016.04.011

Blenkinsop, G. M., Pain, M. T. G., & Hiley, M. J. (2017). Balance control strategies during perturbed and unperturbed balance in standing and handstand. *Royal Society Open Science, 4*(7), 161018. doi:10.1098/rsos.161018

Braun, C. (2016). Observational Learning in the Context of Skill Acquisition. In T. Heinen, I. Čuk, R. Goebel, & K. Velentzas (Eds.), Gymnastics Performance and Motor Learning: Principles and Applications (pp. 34–43). New York: Nova Science Publsihers, Inc.

Breslin, G., Hodges, N. J., & Williams, A. M. (2009). Effect of information load and time on observational learning. *Research Quarterly for Exercise and Sport, 80*(3), 480–490. doi:10.1080/02701367.2009.10599586

Buchanan, J. J., & Dean, N. (2014). Consistently modeling the same movement strategy is more important than model skill level in observational learning contexts. *Acta Psychologica, 146*, 19–27. doi:10.1016/j.actpsy.2013.11.008

Cicchetti, D. V. (1994). Guidelines, criteria, and rules of thumb for evaluating normed and standardized assessment instruments in psychology. *Psychological Assessment, 6*(4), 284–290. doi:10.1037/1040-3590.6.4.284

Croix, G., Lejeune, L., Anderson, D. I., & Thouvarecq, R. (2010). Light fingertip contact on thigh facilitates handstand balance in gymnasts.

Psychology of Sport and Exercise, 11(4), 330–333. doi:10.1016/j.psychsport.2010.02.003

FIG (2017). 2017 Code of Points: Men's Artistic Gymnastics. Lausanne: Fédération Internationale de Gymnastique.

Gautier, G., Thouvarecq, R., & Chollet, D. (2007). Visual and postural control of an arbitrary posture: The handstand. *Journal of Sports Sciences, 25*(11), 1271–1278. doi:10.1080/02640410601049144

Gautier, G., Marin, L., Leroy, D., & Thouvarecq, R. (2009). Dynamics of expertise level: Coordination in handstand. *Human Movement Science, 28*(1), 129–140. doi:10.1016/j.humov.2008.05.003

Hayes, S. J., Hodges, N. J., Scott, M. A., Horn, R. R., & Williams, A. M. (2006). Scaling a motor skill through observation and practice. *Journal of Motor Behavior, 38*(5), 357–366. doi:10.3200/JMBR.38.5.357-366

Hedbávný, P., Sklenaříková, J., Hupka, D., & Kalichová, M. (2013). Balancing the handstand on the floor. *Science of Gymnastics Journal, 5*(3), 69–80.

Janelle, C. M., Champenoy, J. D., Coombes, S. A., & Mousseau, M. B. (2003). Mechanisms of attentional cueing during observational learning to facilitate motor skill acquisition. *Journal of Sports Sciences, 21*(10), 825–838. doi:10.1080/0264041031000140310

Kerwin, D. G., & Trewartha, G. (2001). Strategies for maintaining a handstand in the anterior-posterior direction. *Medicine and Science in Sports and Exercise, 33*(7), 1182–1188. doi:10.1097/00005768-200107000-00016

Kochanowicz, A., Niespodziński, B., Marina, M., Mieszkowski, J., Biskup, L., & Kochanowicz, K. (2018). Relationship between postural control and muscle activity during a handstand in young and adult gymnasts. *Human Movement Science, 58*, 195–204. doi:10.1016/j.humov.2018.02.007

Kochanowicz, A., Niespodziński, B., Marina, M., Mieszkowski, J., Kochanowicz, K., & Zasada, M. (2017). Changes in the Muscle Activity of Gymnasts During a Handstand on Various Apparatus. *Journal of Strength and Conditioning Research*. Advance online publication. doi:10.1519/JSC.0000000000002124

Laguna, P. L. (2008). Task complexity and sources of task-related information during the observational learning process. *Journal of Sports Sciences, 26*(10), 1097–1113. doi:10.1080/02640410801956569

Lam, W. K., Maxwell, J. P., & Masters, R. (2009). Analogy Learning and the Performance of Motor Skills under Pressure. *Journal of Sport and Exercise Psychology, 31*(3), 337–357. https://doi.org/10.1123/jsep.31.3.337

Magill, R. A. (2014). *Motor learning and control: Concepts and Applications* (10th ed.). Boston: McGraw-Hill.

Maleki, F., Nia, P., Zarghami, M., & Neisi, A. (2010). The Comparison of Different Types of Observational Training on Motor Learning of Gymnastic Handstand. *Journal of Human Kinetics, 26*, 13–19. doi:10.2478/v10078-010-0043-0

Malhotra, N., Poolton, J. M., Wilson, M. R., & Omuro, S. (2015). Dimensions of Movement-Specific Reinvestment in Practice of a Golf Putting Task. *Psychology of Sport and Exercise, 18*, 1–8. doi:10.1016/j.psychsport.2014.11.008

Masser, L. S. (1993). The Comparison of Different Types of Observational Training on Motor Learning of Gymnastic Handstand. *Journal of Teaching in Physical Education, 12*, 301–312.

Masters, R., & Maxwell, J. (2008). The theory of reinvestment. *International Review of Sport and Exercise Psychology, 1*(2), 160–183. doi:10.1080/17509840802287218

Post, P. G., Aiken, C. A., Laughlin, D. D., & Fairbrother, J. T. (2016). Self-control over combined video feedback and modeling facilitates motor learning.

Human Movement Science, 47, 49–59. doi:10.1016/j.humov.2016.01.014

Rohbanfard, H., & Proteau, L. (2011). Learning through observation: A combination of expert and novice models favors learning. *Experimental Brain Research, 215*(3-4), 183–197. doi:10.1007/s00221-011-2882-x

Rohleder, J., & Vogt, T. (2018a). Performance control in handstands: Challenging entrenched coaching strategies for young gymnasts. *International Journal of Performance Analysis in Sport, 4*(10), 1–15. doi:10.1080/24748668.2018.1440459

Rohleder, J., & Vogt, T. (2018b). Teaching novices the handstand: A practical approach of different sport-specific feedback concepts on movement learning. *Science of Gymnastics Journal, 10*(1), 29–42.

Schmidt, R. A., & Lee, T. D. (2011). Motor Control and Learning: A Behavioral Emphasis (5th ed.). Champaign, IL: Human Kinetics.

Sun, R., Merrill, E., & Peterson, T. (2001). From implicit skills to explicit knowledge: a bottom-up model of skill learning. *Cognitive Sciences, 25*, 203–244. doi:10.1016/S0364-0213(01)00035-0

Uzunov, V. (2008). The handstand: A four stage training model. *Gym Coach, 2*, 52–59.

Veit, J., Jeraj, D., & Lobinger, B. H. (2016). Augmented Feedback for Movement Error Correction in Gymnastics. In T. Heinen, I. Čuk, R. Goebel, & K. Velentzas (Eds.), *Gymnastics Performance and Motor Learning: Principles and Applications* (pp. 45–52). New York: Nova Science Publsihers, Inc.

Verburgh, L., Scherder, E. J. A., van Lange, P. A. M., & Oosterlaan, J. (2016). The key to success in elite athletes? Explicit and implicit motor learning in youth elite and non-elite soccer players. *Journal of Sports Sciences, 34*(18), 1782–1790. doi:10.1080/02640414.2015.1137344

Vogt, T., Kato, K., Schneider, S., Türk, S., & Kanosue, K. (2017). Central neuronal motor behaviour in skilled and less skilled novices - Approaching sports-specific movement techniques. *Human Movement Science, 52*, 151–159. doi:10.1016/j.humov.2017.02.003

Yeadon, M. R., & Trewartha, G. (2003). Control Strategy for a Hand Balance. *Motor Control, 7*(4), 421–442. doi:10.1123/mcj.7.4.421

Corresponding author:

Jonas Rohleder
German Sport University Cologne
Institute of Professional Sport Education and Sport Qualifications
Am Sportpark Müngersdorf 6
50933 Cologne
Germany
Tel: +49 (0) 221 - 4982 4160
Fax: +49 (0) 221 - 4982 8261
E-mail: j.rohleder@dshs-koeln.de

COMPARISON OF BOUNCE CHARACTERISTICS ON THREE TYPES OF TRAMPOLINES

William A. Sands[1], Madison K. Varmette[1], Gregory C. Bogdanis[2], Olyvia Donti[2], Bryce V. Murphy[3], Troy J. Taylor[1]

[1]U.S. Ski and Snowboard Association, Park City, USA
[2]School of Physical Education and Sport Science, National and Kapodistrian University of Athens, Athens, Greece
[3]U.S. Olympic Committee, Olympic Training Center, Colorado Springs, USA

Original article

Abstract

Trampoline use has skyrocketed in recent years in a variety of recreational contexts and among athletes in sports ranging from gymnastics and diving to skiing and snowboarding. The purpose of this study was to examine the bounce characteristics elicited by athletes bouncing on three types of trampolines. Tumbl Trak, Standard, and Super Tramp trampolines were assessed by 10 experienced trampoline and acrobatic athletes (5 males, 5 females). A triaxial accelerometer (250 Hz) characterized the 10 highest controlled bounces on each trampoline and each athlete. Repeated measures ANOVAs showed statistical differences in bounce characteristics: time from bounce start to peak acceleration ($p<.001$, $\eta^2=0.82$), time from peak acceleration to bounce end ($p=.030$, $\eta^2=0.40$), and total bounce time ($p<0.001$, $\eta^2=0.78$, jump height ($p<.001$, $\eta^2=0.95$) peak acceleration ($p=.015$, $\eta^2=0.37$), and flight time ($p<.001$, $\eta^2=0.97$). Average acceleration, force, and allometrically scaled average force were not statistically different ($p>.140$, $\eta^2=0.20$). The stiffest trampoline with the least time values, peak accelerations, and jump heights was the Tumbl Trak, followed by the Standard trampoline, and Super Tramp, respectively. This information may help practitioners and others to understand the bounce behaviors of athletes on these types of trampolines.

Keywords: trampoline, comparison, acceleration, jumping.

INTRODUCTION

Trampolines have been used in various forms from the early 1900s (Horne, 1968). The modern trampoline dates from 1936 and was developed by George Nissen and Larry Griswold (Ladue & Norman, 1954). The characteristics that make a trampoline are a flexible surface (i.e., bed) attached to dozens of springs which are in turn connected to a large round, square, or rectangular metal frame. The trampoline has undergone a number of designs that include different sizes, shapes, beds, and spring configurations for different purposes. Trampoline is an Olympic competitive event (International Gymnastics Federation, 2018).

In spite of the relatively long history of trampolines, there is a paucity of scientific information about the mechanical behavior of the trampoline and the interactions of athletes with these apparatuses. Trampolines are used for recreation (Fisher, 2010), spatial orientation (Heinen, 2011), fitness exercise (Atterbom & MacLean, 1983; Cugusi et al., 2018), gymnastics (Heinen, 2011;

Hondzinksi & Darling, 2001), diving (Kimball, 1999), medical treatment (Giagazoglou et al., 2013; Hahn, Shin, & Lee, 2015; Sahlberg & Strandvik, 2005), and as a competitive event (Esposito & Esposito, 2009; Jensen, Scott, Krustrup, & Mohr, 2013). A recent *New York Times* posting described a new activity called "Gtramp" which involves backyard and other trampoline use arising from skateboard, parkour, and youth social media activities (Kettler, 2018).

Trampolines offer athletes the ability to rise as high as five or more meters in the air with minimal physical effort (Eager, Chapman, & Bondoc, 2012). The flight time of trampoline jumping enhances an athlete's ability to practice difficult skills, gain spatial awareness, and land on a soft trampoline bed. Trampoline beds are assumed to be soft and flexible. However, the "softness" of a trampoline bed represents a flawed understanding (Farquharson, 2012). The energy required to project the athlete high in the air is considerable and on descending and landing the energy from the flight should be absorbed and returned by the athlete's musculoskeletal system and the trampoline bed. Understanding how bouncing on trampolines may affect timing, acceleration, height, and energy exchange is largely unknown with the exception of some physics modeling (Blajer & Czaplicki, 2001; Chen et al., 2016; Yeadon & Hiley, 2017).

A recent study of circus acrobats used a wearable three-dimensional accelerometer to measure accelerations in seven male acrobats during training and show performances. The results revealed that accelerations were statistically greater during training than shows. Moreover, accelerations were classified into categories of magnitude from approximately 1 g to more than 12 g (Barker, Burnstein, & Mercer, 2018). A conference presentation on trampoline measurements showed average peak accelerations of approximately 5 g (49 m/s^2) and flight times ranging from 0.50 s to 0.54 s (Eager et al., 2012). The values from the Eager and colleagues (Eager et al., 2012) measurements are astonishingly low. The corresponding jump height for these values would be approximately 31 cm to 36 cm which is easily attainable in a vertical jump from the floor (Simons & Bradshaw, 2016b). A thesis investigating the relationship between trampoline bouncing and the countermovement vertical jump found no statistically significant relationship (Briggs, 2014). A study by the National Aeronautics and Space Administration (NASA) showed that trampoline bouncing by eight males at four heights with accelerometers on the ankle, forehead, and back resulted in accelerations of 3.0-7.0 g, 3.9-6.0 g, 3.0-5.6 g, respectively (Bhattacharya, McCutcheon, Shvartz, & Greenleaf, 1980).

Trampolining has received considerable attention in terms of injury and injury prevention in Australia, Germany, New Zealand, and the U.S. (Ashby, Pointer, Eager, & Day, 2015; Chalmers, Hume, & Wilson, 1994; Hammer, Schwartzbach, & Paulev, 1981; Lewald, 1979; Sandler et al., 2011; Torg & Das, 1984). Moreover, studies of the benefits of trampolining include aerobic fitness, convenience, and balance (Atterbom & MacLean, 1983; Butler, 1969; Da Roza, Brandao, Mascarenhas, Jorge, & Duarte, 2015; Giagazoglou et al., 2013; Guillot & Collet, 2004; Hardy, Mullen, & Martin, 2001; Heitkamp, Horstmann, Mayer, Weller, & Dickhuth, 2001; Katch, Villanacci, & Sady, 1981; Ladue & Norman, 1954). However, analyses of bounce characteristics have seldom been addressed. In addition, there appear to be only a few studies comparing backyard trampolines, mini-trampolines, and full-size or competitive trampolines in terms of injury incidence and rates (Council On Sports & Fitness, 2012; Sands, Hondzinski, Shultz, & George, 1995; Torg & Das, 1985). It is our belief that the lack of information on the characteristics of bouncing on different trampolines has been ignored and merits research.

The Center of Excellence facility of the U.S. Ski and Snowboard Association headquarters is unusual in that there are three different types of trampolines, expert trampolinists (i.e., national team Aerial, Moguls, and Half-Pipe Skiers along with Half-Pipe and Big-Air Snowboard), and expert coaching. Many of these athletes are former gymnasts and trampolinists. Moreover, these athletes regularly perform skills on trampolines that are equal or more difficult than competitive trampolinists. These athletes regularly perform quad-twisting triple somersaults (Aerials) and quadruple somersaults (Big-Air Snowboard). These skills are performed on unpredictable terrain, a variety of weather conditions, and landings on snow.

Trampoline use has skyrocketed in recent years in a variety of recreational contexts and among athletes in sports ranging from gymnastics and diving to skiing and snowboarding (Ashby et al., 2015; Chalmers et al., 1994; Esposito & Esposito, 2009; Fisher, 2010). However, scientific understanding of the behavior of trampolines has not kept pace. Characterizing the interaction of trampoline-related activities and athletes may assist practitioners, scientists, and medical professionals in encouraging or discouraging use of trampoline bouncing for acrobatic athletes and others.

The purpose of this study was to characterize the bounce behaviors elicited by three types of trampolines to determine the relative accelerations, durations, average forces and other factors. In spite of a relatively long history of trampoline use, and the fact that many catastrophic injuries occur in the center of the trampoline bed by highly-trained athletes (Torg, 1985; Torg & Das, 1984), it should be imperative to derive a more complete understanding of the workings of trampoline-athlete interactions while bouncing. We hypothesized that all of the trampoline types would show statistically different bounce characteristics.

METHODS

Participants: Ten experienced trampoline athletes from the U.S. Ski and Snowboard Aerials Team volunteered to participate in this study. The anthropometric information for the athletes was: five males (Mean ± SD; age 22.6 y ± 3.4 y; height 174.0 cm ± 5.0 cm; mass 73.2 kg ± 9.2 kg) and five females (Mean ± SD; age 19.8 y ± 2.8 y; height 160.2 cm ± 5.0 cm; mass 57.9 kg ± 4.8 kg).

Equipment: Bounce accelerations provided by the athletes were obtained from three types of trampolines: Tumbl Trak (bed size = 1.52 m x 11.89 m, solid black bed, Tumbl Trak, Mount Pleasant, MI, USA), a standard competitive trampoline (bed size = 2.14 m x 4.27 m, two-string bed, Rebound Products, Thornhill, Ontario, Canada), Super Tramp (bed size = 3.05 m x 6.10 m, one-string bed, Rebound Products, Thornhill, Ontario, Canada). See Figures 1-3.

Instrumentation: Accelerations were obtained from a PASCO Scientific triaxial accelerometer (PASCO Scientific, Roseville, CA, USA PS-3202) attached rigidly to a waist belt that was worn snugly about the waist of the athlete placing the accelerometer posterior to the lumbar spine at approximately the level of lumbar vertebrae L3 to L4 (Simons & Bradshaw, 2016a). Accelerometer placement has varied widely in experiments because of potential threats to stability from skin movement, subcutaneous fat, breathing, tissue inertia and many other factors (Simons & Bradshaw, 2016a). Placement of accelerometers on the upper back has been compared to the lower back among female participants in bilateral hopping and drop landings (Simons & Bradshaw, 2016a, 2016b) with better correlations with drop landings on a force platform arising from an upper back placement and better inter-day reliability arising from a low back placement (Simons & Bradshaw, 2016a, 2016b). Acceleration data were transmitted via Bluetooth to a laptop computer. Data were captured, displayed, and stored using the PASCO Capstone software (PASCO Scientific, Roseville, CA, USA, V1.11.1). The sampling rate was 250 Hz. Calibration was performed using gravitational vertical.

Calibration was ensured by rotating the accelerometer systematically such that one of the three axes of the accelerometers was oriented to the line of gravity approximately 9.806 m/s^2, while the remaining axes measured approximately 0 m/s^2.

Figure 1. Tumbl Trak trampoline.

Figure 2. Standard trampoline.

Procedures: The athletes were fitted with the belt and accelerometer and then asked to perform 10 or more consecutive bounces on each of the three trampolines. The athletes were instructed to bounce as high as they could control. A self-selected number of initial bounces were undertaken and the athlete announced verbally when he or she was bouncing maximally. Sampling was undertaken throughout all bounces similar to previous procedures (Briggs, 2014; Harden & Earnest, 2015). The ten bounces with the highest and most consistent sequence of accelerations were used as the bounce trials to characterize each trampoline's acceleration profile.

Figure 3. Super Tramp trampoline.

Data analysis: Following data capture and storage, PASCO Capstone software was used to extract relevant information from each bounce (Figure 4) (Shanahan, 2004). A bounce was defined as the period from trampoline bed contact to departure. The variables of interest for this study were:

- time from start of a bounce to the peak acceleration,
- time from peak acceleration to the end of the bounce,
- total time of the bounce,
- jump flight time,
- jump height,
- peak acceleration,
- average acceleration,
- average force and allometrically scaled force.

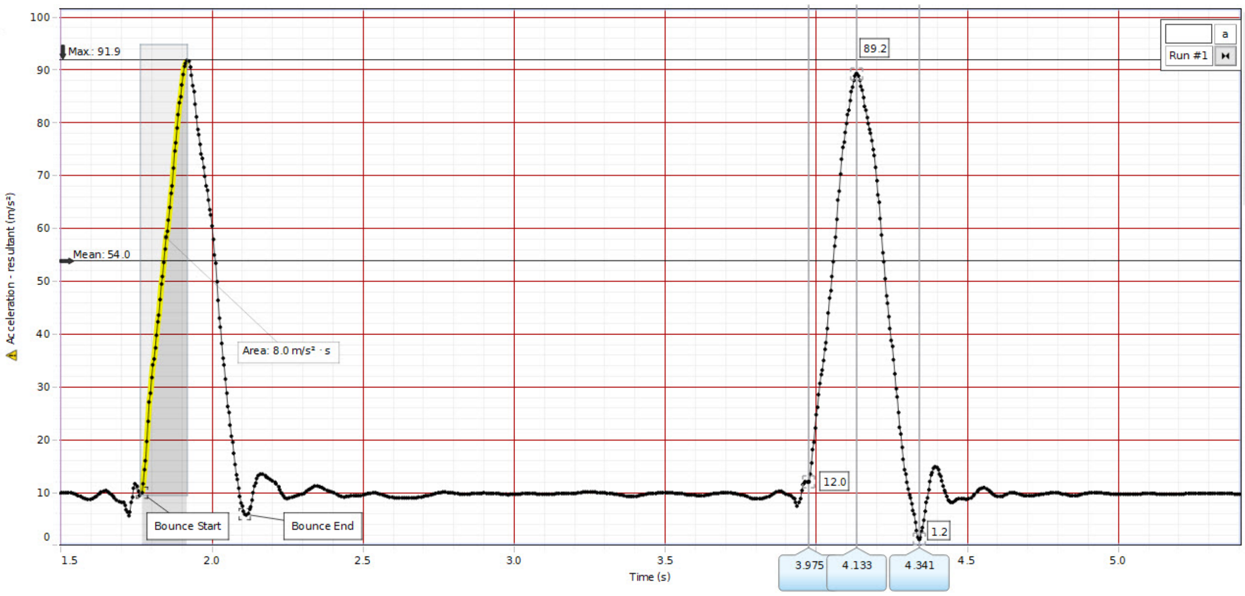


Figure 1. Example of the data and variables that were extracted from the bounce accelerations.

The multiple trials (i.e., bounces) were displayed using the Capstone software and a cursor was passed through the data to acquire the timing of the start of the bounce, time of the end of the bounce, peak acceleration time and peak acceleration value. Resultant accelerations were used for all analyses. The trials data were assessed for reliability via trends across trials (Henry, 1950, 1967). The means of the trend-free trials were calculated for each athlete collapsing the ten trials per trampoline-type to a single mean value which was later used for magnitude-based inference and hypothesis testing (Henry, 1950, 1967; Hopkins, Hawley, & Burke, 1999). The large number of performance trials (10 per athlete per trampoline-type) led to using Cronbach's alpha procedures to calculate an intraclass correlation coefficient (ICC) – alpha (Atkinson & Nevill, 1998). Additionally, one-way repeated measures ANOVAs were calculated across the ten trials along with coefficients of variation (CV) for each variable obtained from each trampoline-type (Table 1). Nine variables showed extremely high ICCs while also indicating some statistical differences across trials (Table 1). Closer inspection of these data showed no consistent pattern of variability such as increasing values indicative of learning or decreasing values indicative of fatigue. Therefore, because the ICCs were extremely high, CVs were low or modest, a reluctance to discard data (Henry, 1950), and no apparent pattern of variations across trials, all data were retained and means were calculated utilizing all ten trials for each athlete and each trampoline-type.

Our initial assessment involved calculating reliability and trends across trials values and coefficients of variation with sex as a group factor. After reliability assessments, multiple 9 (variables) by 2 (sexes) by 3 (trampoline-types) repeated measures ANOVAs (RMANOVA) were calculated. The data showed that there were no main effect statistical differences attributable to sex (all $p > 0.05$). Following these uniform results, the data were collapsed across sex and further analyses involved multiple (9 variables) one-way RMANOVAs. All data were analyzed using IBM SPSS software (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY:

IBM Corp). Effect size estimates were calculated as partial eta^2 (η^2) values: ≤ 0.02 = small, 0.02 to 0.13 = medium, 0.13 to 0.26 = large (Cohen, 1988).

Table 1
Trials Reliability.

Variable	Trampoline	Chronbach's Standardized Item Alpha	RMAnova $F_{(9,81)}$	p	Coefficient of Variation Mean (SD)
Time Start to Peak	Tumbl Trak	.96	1.15	.34	18.88 (1.18)
	Standard	.97	1.69	.11	11.82 (11.09)
	Super Tramp	.96	0.50	.87	9.76 (0.76)
Time Peak to End	Tumbl Trak	.99	0.91	.53	10.16 (4.96)
	Standard	.97	1.17	.32	10.93 (5.47)
	Super Tramp	.96	1.06	.37	11.46 (6.26)
Total Time	Tumbl Trak	.98	0.68	.73	11.33 (3.73)
	Standard	.96	1.06	.40	10.13 (2.79)
	Super Tramp	.94	0.72	.79	8.97 (2.87)
Flight Time	Tumbl Trak	.99	0.50	.85	4.10 (2.52)
	Standard	.98	4.47	<.001	3.42 (1.97)
	Super Tramp	.99	0.95	.48	2.71 (1.02)
Jump Height	Tumbl Trak	.99	0.50	.85	8.13 (4.92)
	Standard	.99	4.95	<.001	6.82 (5.40)
	Super Tramp	.99	0.88	.54	5.39 (2.02)
Peak Acceleration	Tumbl Trak	.97	1.55	.14	8.14 (4.92)
	Standard	.99	7.97	<.001	6.83 (3.91)
	Super Tramp	.99	2.72	.008	5.40 (2.02)
Average Acceleration	Tumbl Trak	.97	3.12	.003	6.11 (2.07)
	Standard	.98	1.13	.36	5.24 (2.52)
	Super Tramp	.99	2.64	.010	3.80 (2.14)
Average Force	Tumbl Trak	.99	3.40	.001	6.12 (2.07)
	Standard	.98	1.23	.29	5.24 (2.52)
	Super Tramp	.99	2.48	.015	4.01 (2.26)
Average Force Allometrically Scaled	Tumbl Trak	.97	3.12	.003	6.11 (2.07)
	Standard	.98	1.13	.36	5.23 (2.52)
	Super Tramp	.99	2.64	.01	4.01 (2.26)

RESULTS

Table 2
One-way Repeated Measures ANOVA.

Variable	F	df	p	Effect Size $\eta^2_{partial}$	Power
Time Start to Peak	43.10	2,18	<.001	0.82	1.00
Time Peak to End	6.00	1.17,10.49	.030	0.40	.64
Total Time	31.35	1.27,11.40	<.001	0.78	1.00
Flight Time	248.72	1.38,12.41	<.001	0.97	1.00
Jump Height	159.65	1.27,11.43	<.001	0.95	1.00
Peak Acceleration	5.34	2,18	.015	0.37	.77
Average Acceleration	2.20	2,18	.140	0.20	.39
Average Force	2.19	2,18	.140	0.20	.39
Average Force Allometrically Scaled	2.20	2,18	.140	0.20	.39

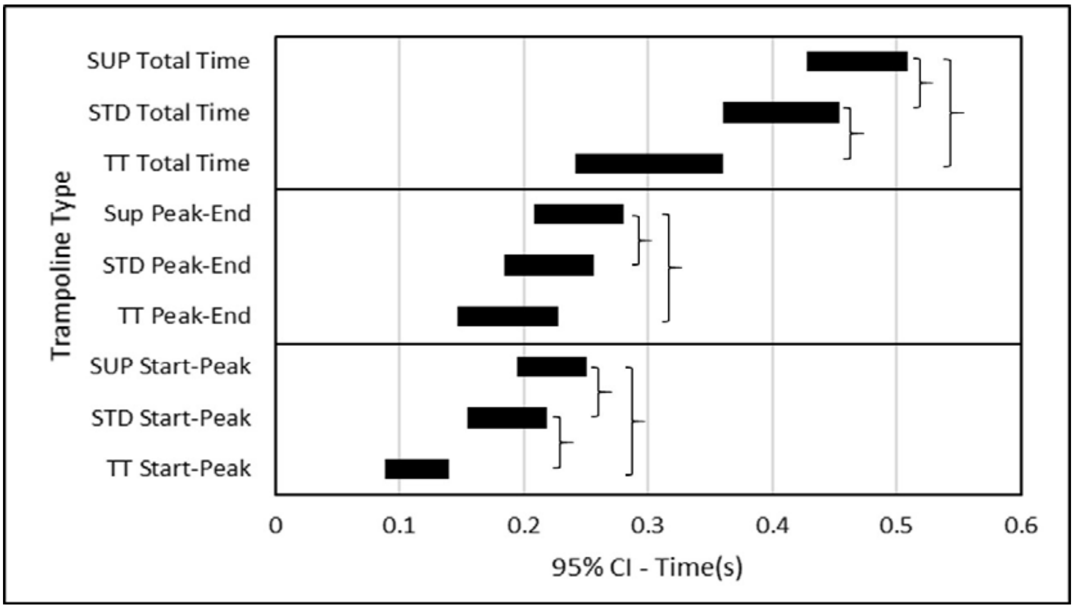


Figure 5. 95% Confidence intervals for time variables on all trampolines. Pairwise statistical differences (p<.05) are shown via brackets. SUP = Super Tramp, STD = Standard Trampoline, TT = Tumbl Trak.

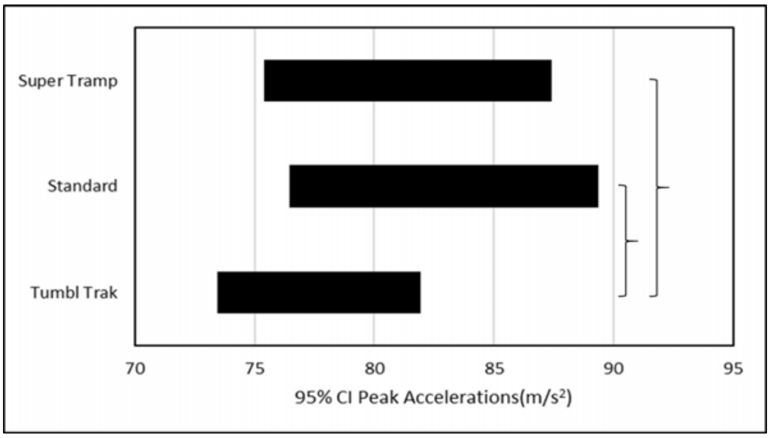


Figure 6. 95% Confidence intervals for peak accelerations on all trampolines. Pairwise statistical differences ($p<.05$) are shown via brackets.

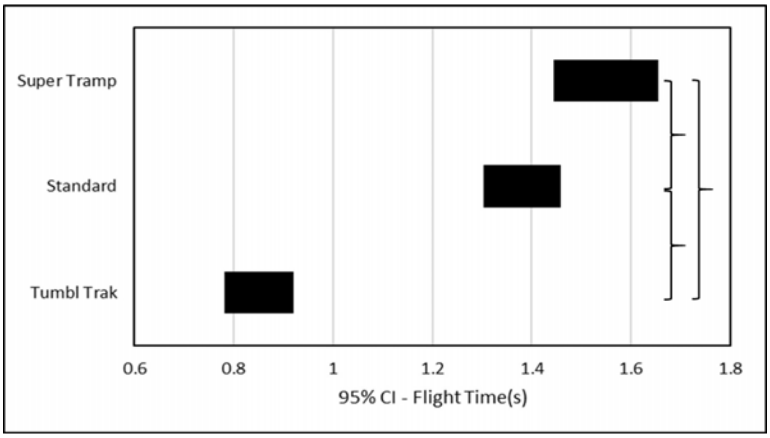


Figure 7. 95% Confidence intervals for flight times on all trampolines. Pairwise statistical differences ($p<.05$) are shown via brackets.

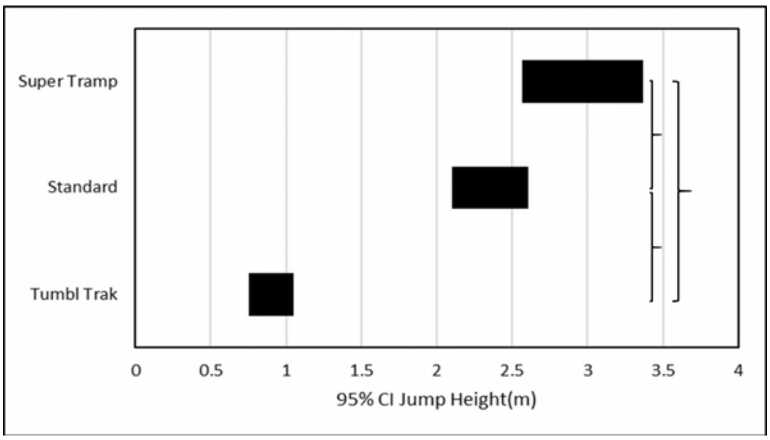


Figure 8. 95% Confidence intervals for jump height on all trampolines. Pairwise statistical differences ($p<.05$) are shown via brackets.

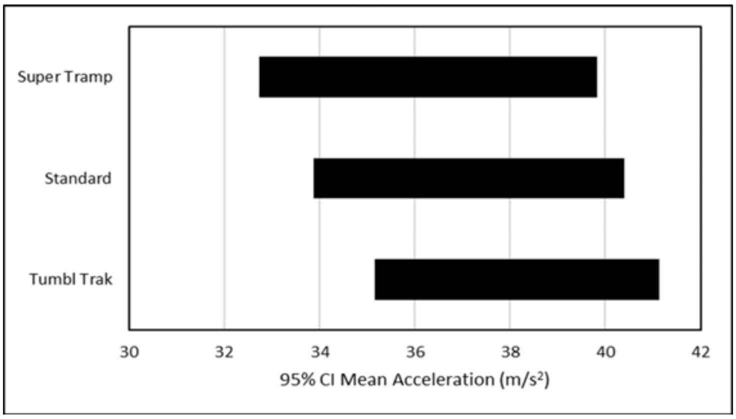


Figure 9. 95% Confidence intervals for mean acceleration on all trampolines. None of the pairwise comparisons were statistically different (all p>.05).

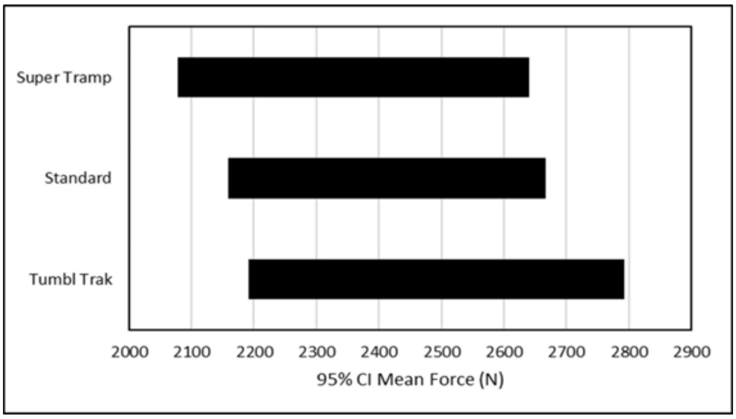


Figure 10. 95% Confidence intervals for mean force values on all trampolines. None of the pairwise comparisons were statistically different (all p>.05).

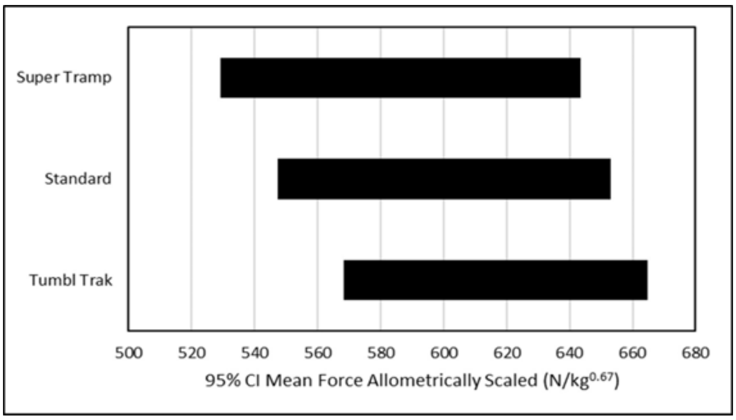


Figure 11. 95% Confidence intervals for mean force allometrically scaled on all trampolines. None of the pairwise comparisons were statistically different (all p>.05).

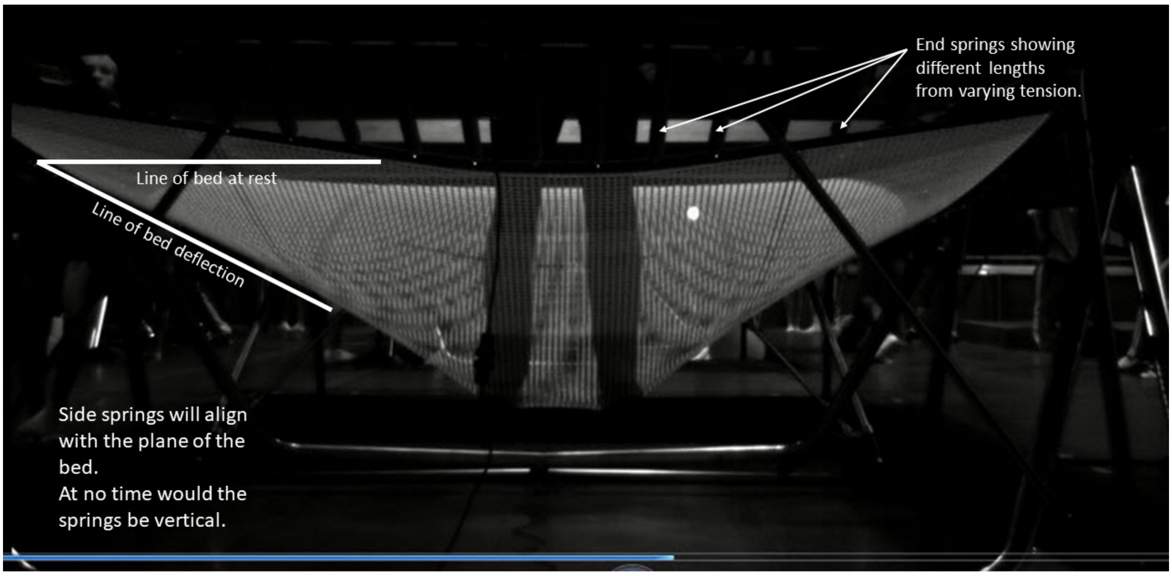


Figure 12. Frame grab from video of bouncing on a Standard trampoline. The string-bed allows a limited view of the legs of the athlete, in this case at the lowest position of the depression of the trampoline.

DISCUSSION

Hypotheses were supported for all "non-average" variables and all variables showed large effect sizes. The Tumbl Trak trampoline showed a larger number of differences from the Standard and Super Tramp apparatuses. The Tumbl Trak is designed to encourage horizontally directed tumbling skills more than vertical cyclic bouncing, but Tumbl Trak trampolines are commonly used for teaching stationary jumps and saltos (Sands, 2002). The larger trampolines were able to propel the athletes higher and with greater accelerations than the Tumbl Trak. The Super Tramp was capable of propelling the athletes the highest and with the greatest flight times. Flight times were mirrored by longer bed contact times.

Our data indicated greater peak accelerations, flight times, and trampoline bed contact times than most previous studies. A similar study involving three trampoline types (unidentified manufacturers) showed lower peak accelerations although the instructions to the athletes were not specified and may have been less aggressive than the instructions in this study (Eager et al., 2012). The Eager and colleagues (Eager et al., 2012) study involved three trampolines with different spring mechanisms and designs which may have influenced the bounce characteristics they observed. Given the unknown nature of the trampolines, and the varying dimensions of the trampolines in the present study, comparisons are difficult. The size of the trampoline, arrangement of springs, and fabric of the bed are likely to interact with bounce characteristics (Kraft, 2001).

A study contesting the existing mechanical models of trampoline bouncing showed that the normal application of a vertical ideal spring model based on Hooke's Law is not correct because of the horizontal orientation of the trampoline springs and bed, the involvement of a subset of the total springs, and the weight of the athlete (Kraft, 2001). In fact, the springs of a modern trampoline act at varying angles to the body of the bouncer rather than co-vertical (Kraft, 2001). Figure 12 shows an athlete's bounce at the lowest position of trampoline bed depression. Differential tension on the springs visible near the top of the image is shown by the middle springs' greater elongation than those farther from the middle. The side springs (not visible) follow the line of the string-bed as shown by the white bed area visible through the net-like structure of the strings. Note that at no time are the springs oriented vertically in line with the bouncer's body or the line of gravity. Typical Hooke's Law models of trampoline bouncing indicate a sinusoidal acceleration result that is lower in magnitude (approximately 10 m/s^2) than that obtained by Kraft's model and experimentation (Kraft, 2001). The alternative model developed by Kraft showed that heavier athletes will always have longer contact times with the trampoline bed when controlled for the distance of descent of the preceding flight and depth of the depression of the trampoline bed (Kraft, 2001). The study by Eager and colleagues (Eager et al., 2012) used a vertical spring model.

The present study recorded flight times corresponding with peak accelerations ranging from slightly less than 0.8 s to greater than 1.6 s. However, the relationship between bed contact time and height of flight can be nonlinear with height of the previous jump, weight of the athlete, musculoskeletal skill application, and nature of the trampoline can all interact to effect bounce characteristics (Glitsch & Henrichs, 1993; Kraft, 2001). For example, higher flights can be achieved following shorter trampoline bed contact times (Briggs, 2014; Glitsch & Henrichs, 1993; Kraft, 2001).

Given that all terrestrial animals vary muscle stiffness while running and jumping to compensate for the characteristics of landing and take-off surfaces, trampoline bouncing is likely to invoke the same mechanisms. Perception, skill, and prior knowledge of the stiffness of the landing surface has been shown to influence motor control strategies of the lower extremity (Ferris & Farley, 1997; McNitt-Gray, 1991a, 1991b; McNitt-Gray, 1993; McNitt-Gray, 1999; Moritz & Farley, 2004). McNitt-Gray demonstrated the importance of individual motor control strategies when handling a drop landing (McNitt-Gray, 2000). Leg muscle stiffness is varied when jumping on sprung surfaces to compensate for the nature of the surface (Arampatzis, Bruggemann, & Klapsing, 2001). Children also show similar adaptations to an elastic jumping surface by varying their lower extremity muscular stiffness (Arabatzi, 2018). Based on athlete feedback, the three trampolines, in order of stiffness would be Tumbl Trak, Standard, and Super Tramp.

CONCLUSIONS

Measured differences were observed in the acceleration behavior of three types of trampolines and the interactions of the trampolines with male and female athlete bouncers. Peak acceleration values were statistically different while average accelerations were not. The Tumbl Trak trampoline was the stiffest with the lowest accelerations and flight times. The Standard trampoline showed middling acceleration and related behaviors while the Super Tramp showed the greatest. This information may prove useful when prescribing trampoline training and rehabilitation protocols for athletes and others who use trampolines. Those with compromised motor control skills may be at more risk when bouncing than healthy and experienced athletes. Future research should expand on these findings along with the influence muscle stiffness and motor control.

REFERENCES

Arabatzi, F. (2018). Adaptations in movement performance after plyometric training on mini-trampoline in children. *Journal of Sports Medicine and Physical Finess, 58*(1-2), 66-72. doi:10.23736/s0022-4707.16.06759-1

Arampatzis, A., Brüggemann, G. P., & Klapsing, G. M. (2001). Leg stiffness and mechanical energetic processes during jumping on a sprung surface. *Medicine & Science in Sports & Exercise, 33*(6), 923-931.

Ashby, K., Pointer, S., Eager, D., & Day, L. (2015). Australian trampoline injury patterns and trends. *Australian and New Zealand Journal of Public Health, 39*(5), 491-494. doi:10.1111/1753-6405.12404

Atkinson, G., & Nevill, A. M. (1998). Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Medicine, 26*(4), 217-238.

Atterbom, H. A., & MacLean, T. A. (1983). Aerobic benefits of rebound jogging. *Annals of Sports Medicine, 1*(3), 113-114.

Barker, L., Burnstein, B., & Mercer, J. (2018). Acceleration profile of an acrobatic act during training and shows using wearable technology. *Sports Biomech*, 1-12. doi:10.1080/14763141.2018.1460394

Bhattacharya, A., McCutcheon, E. P., Shvartz, E., & Greenleaf, J. E. (1980). Body acceleration distribution and O2 uptake in humans during running and jumping. *J Appl Physiol Respir Environ Exerc Physiol, 49*(5), 881-887. doi:10.1152/jappl.1980.49.5.881

Blajer, W., & Czaplicki, A. (2001). Modeling and inverse simulation of somersaults on the trampoline. *Journal of Biomechanics, 34*(12), 1619-1629.

Briggs, K. (2014). *The relationship between strength, power and trampoline jump height* (BS (Honors) Dissertation), Cardiff Metropolitan University, Cardiff, Wales, UK.

Butler, K. N. (1969). The effect of instant replay videotape television on improving performance of selected trampoline skills. *International Gymnast, 11*(10), 13.

Chalmers, D. J., Hume, P. A., & Wilson, B. D. (1994). Trampolines in New Zealand: a decade of injuries. *British Journal of Sports Medicine, 28*(4), 234-238.

Chen, J., Guo, H., Gao, Z., An, M., Wang, X., & Chen, W. (2016). Optimal kicking of a trampolinist. *Hum Mov Sci, 48*, 54-61. doi:10.1016/j.humov.2016.04.005

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Council On Sports, M., & Fitness. (2012). Trampoline Safety in Childhood and Adolescence. *Pediatrics*. doi:10.1542/peds.2012-2082

Cugusi, L., Manca, A., Serpe, R., Romita, G., Bergamin, M., Cadeddu, C., . . . Mercuro, G. (2018). Effects of a mini-trampoline rebounding exercise program on functional parameters, body composition and quality of life in overweight women. *Journal of Sports Medicine and Physical Finess, 58*(3), 287-294. doi:10.23736/s0022-4707.16.06588-9

Da Roza, T., Brandao, S., Mascarenhas, T., Jorge, R. N., & Duarte, J. A. (2015). Volume of training and the ranking level are associated with the leakage of urine in young female trampolinists. *Clinical Journal of Sport Medicine, 25*(3), 270-275. doi:10.1097/jsm.0000000000000129

Eager, D., Chapman, C., & Bondoc, K. (2012, 9-12 December 2012). *Characterisation of trampoline bounce using acceleration* Paper presented at the 7th Australasian Congress on Applied Mechanics, ACAM 7 Adelaide, Australia.

Esposito, P. W., & Esposito, L. M. (2009). The reemergence of the trampoline as a recreational activity and competitive sport. *Current Sports Medicine Reports, 8*(5), 273-277. doi:10.1249/JSR.0b013e3181b8f60a

Farquharson, R. (2012). The demands of gymnastic trampolining from touch down to take off: a physical preparation perspective. *SportEx Medicine, Jul 2012*(53), 14.

Ferris, D. P., & Farley, C. T. (1997). Interaction of leg stiffness and surface stiffness during human hopping. *Journal of Applied Physiology, 82*(1), 15-22.

Fisher, A. (2010). Extreme Trampoline. *Time, 176*(7), 48-48.

Giagazoglou, P., Kokaridas, D., Sidiropoulou, M., Patsiaouras, A., Karra, C., & Neofotistou, K. (2013). Effects of a trampoline exercise intervention on motor performance and balance ability of children with intellectual disabilities. *Research in Developmental Disabilities, 34*(9), 2701-2707. doi:10.1016/j.ridd.2013.05.034

Glitsch, U., & Henrichs, B. (1993). Pressure distribution under the foot during take-off in trampolining. In G.-P. Brüggemann & J. K. Ruhl (Eds.), *Biomechanics in Gymnastics* (pp. 301-307). Koln, Germany: Bundesinstitut fur Sportwissenschaft.

Guillot, A., & Collet, C. (2004). Field dependence-independence in complex motor skills. *Perceptual Motor Skills, 96*(2), 575-583.

Hahn, J., Shin, S., & Lee, W. (2015). The effect of modified trampoline training on balance, gait, and falls efficacy of stroke patients. *J Phys Ther Sci, 27*(11), 3351-3354. doi:10.1589/jpts.27.3351

Hammer, A., Schwartzbach, A., & Paulev, P. E. (1981). Trampoline training injuries - one hundred ninety-five cases. *British Journal of Sports Medicine, 15*(3), 151-158.

Harden, M., & Earnest, C. P. (2015). The effect of warm-up modalities on trampoline flight time performance. *Central European Journal of Sport Sciences and Medicine, 10*(2), 33-43.

Hardy, L., Mullen, R., & Martin, N. (2001). Effect of task-relevant cues and state anxiety on motor performance. *Perceptual and Motor Skills, 92(3)*, 943-946.

Heinen, T. (2011). Evidence for the spotting hypothesis in gymnasts. *Motor Control, 15*(2), 267-284.

Heitkamp, H.-C., Horstmann, T., Mayer, F., Weller, J., & Dickhuth, H.-H. (2001). Gain in strength and muscular balance after balance training. *International Journal of Sports Medicine, 22*, 285-290.

Henry, F. M. (1950). The loss of precision from discarding discrepant data. *The Research Quarterly, 21(2)*, 145-152.

Henry, F. M. (1967). "Best" versus "Average" individual scores. *The Research Quarterly, 38*(2), 317-320.

Hondzinksi, J. M., & Darling, W. G. (2001). Aerial somersault performance under three visual conditions. *Motor Control, 3*, 281-300.

Hopkins, W. G., Hawley, J. A., & Burke, L. M. (1999). Design and analysis of research on sport performance enhancement. *Medicine and Science in Sports and Exercise, 31*(3), 472-485.

Horne, D. E. (Ed.) (1968). *Trampolining: A complete handbook*. London, England: Faber and Faber.

International Gymnastics Federation, F. I. G. (2018). Qualification System - Games of the XXXII Olympiad, Trampoline Gymnastics. Retrieved from https://cdn.dosb.de/user_upload/Olympische_Spiele/Tokio_2020/internationale_Qualifikationskriterien/FIG_-_Gymnastics_Trampoline_20180315.pdf

Jensen, P., Scott, S., Krustrup, P., & Mohr, M. (2013). Physiological responses and performance in a simulated trampoline gymnastics competition in elite male gymnasts. *Journal of Sports Sciences, 31*(16), 1761-1769. doi:10.1080/02640414.2013.803591

Katch, V. L., Villanacci, J. F., & Sady, S. P. (1981). Energy cost of rebound-running. *Research Quarterly for Exercise and Sport, 52*(2), 269-272.

Kettler, J. (2018). The Next Big Thing Goes Up and Down, and Sometimes

Sideways. *New York Times,* p. SP7. Retrieved from https://www.nytimes.com/2018/08/07/well/kaboom-cody-rudi-young-flippers-embrace-gtramp-a-new-sport-for-the-instagram-set.html

Kimball, D. (1999). Part 7. Diving Training Stations and Spotting Rigs for Trampoline, Dry Board, Dry Platform and Wet Board. In J. L. Gabriel (Ed.), *U.S. Diving safety training manual* (2nd ed., pp. 81-88). Indianapolis, IN: United States Diving, Inc.

Kraft, M. (2001). *A simple approach for the vertical force of the trampoline bed* Retrieved from Braunschweig, Ger: http://www.digibib.tu-bs.de/?docid=00001214

Ladue, F., & Norman, J. (Eds.). (1954). *Two seconds of freedom*. Cedar Rapids, IA: Nissen Corporation.

Lewald, R. (1979). German schools ban trampolines. *The Physician and Sportsmedicine, 7*(4), 18-19.

McNitt-Gray, J. L. (1991a). The influence of joint flexion, impact velocity, rotation, and surface characteristics on the forces and torques experienced during gymnastics landings. *FIG Scientific/Medical Symposium Proceedings, 1*(1), 17-18.

McNitt-Gray, J. L. (1991b). Kinematics and impulse characteristics of drop landings from three heights. *International Journal of Sport Biomechanics, 7*(2), 201-224.

McNitt-Gray, J. L. (1993). Kinetics of the lower extremities during drop landings from three heights. *Journal of Biomechanics, 26*(9), 1037-1046.

McNitt-Gray, J. L. (1999). Neuromuscular control and performance of landings in gymnastics. In M. Leglise (Ed.), *Symposium Medico-Technique* (pp. 55-66). Lyss, Switzerland: International Gymnastics Federation.

McNitt-Gray, J. L. (2000). Subject specific coordination of two- and one-joint muscles during landings suggests multiple control criteria. *Motor Control, 4*(1), 84-88; discussion 97-116.

Moritz, C., & Farley, C. T. (2004). Passive dynamics change leg mechanics for an unexpected surface during human hopping. *Journal of Applied Physiology, 97*(4), 1313-1322.

Sahlberg, M., & Strandvik, B. (2005). Trampolines are useful in the treatment of cystic fibrosis patients. *Pediatric Pulmonology, 40*(5), 464; author reply 465. doi:10.1002/ppul.20281

Sandler, G., Nguyen, L., Lam, L., Manglick, M. P., Soundappan, S. S., & Holland, A. J. (2011). Trampoline trauma in children: is it preventable? *Pediatric Emergency Care, 27*(11), 1052-1056.

Sands, W. A. (2002). *Gymnastics Risk Management: Safety Handbook 2002 Edition*. Indianapolis, IN: USA Gymnastics.

Sands, W. A., Hondzinski, J. M., Shultz, B. B., & George, G. S. (1995). A comparison of subtalar joint maximal eversion while jogging on the minitrampoline and floor. *Journal of Orthopaedic and Sports Physical Therapy, 22*(2), 65-72.

Shanahan, D. F. (2004). *Human Tolerance and Crash Survivability*. Paper presented at the Pathological Aspects and Associated Biodynamics in Aircraft Accident Investigation, Madrid, Spain.

Simons, C., & Bradshaw, E. J. (2016a). Do accelerometers mounted on the back provide a good estimate of impact loads in jumping and landing tasks? *Sports Biomech*. doi:10.1080/14763141.2015.1123765

Simons, C., & Bradshaw, E. J. (2016b). Reliability of accelerometry to assess impact loads of jumping and landing tasks. *Sports Biomech, 15*(1), 1-10. doi:10.1080/14763141.2015.1091032

Torg, J. S. (1985). Epidemiology, pathomechanics, and prevention of athletic injuries to the cervical spine. *Medicine and Science in Sports and Exercise, 17*(3), 295-303.

Torg, J. S., & Das, M. (1984). Trampoline-related quadriplegia: Review of the literature and reflections on the American Academy of Pediatrics' Position Statement. *Pediatrics, 74*(5), 804-812.

Torg, J. S., & Das, M. (1985). Trampoline and minitrampoline injuries to the cervical spine. *Clinics in Sports Medicine, 4*(1), 45-60.

Yeadon, M. R., & Hiley, M. J. (2017). Twist limits for late twisting double somersaults on trampoline. *Journal of Biomechanics, 58*, 174-178. doi:10.1016/j.jbiomech.2017.05.002

Corresponding author:

William A Sands, PhD, FACSM
U.S. Ski and Snowboard Association
1 Victory Lane, Park City
UT 84060
USA
E-mail: wmasands@hotmail.com

COMPARISON OF ACTUAL AND PREDICTED ANTHROPOMETRIC CHARACTERISTICS OF CZECH ELITE GYMNASTS

Miriam Kalichová, Petr Hedbávný, Barbora Pyrochtová, Jana Příhonská

Faculty of Sport Studies, Masaryk University, Brno, Czech Republic

Original article

Abstract

In context of artistic gymnastics, the influence of intense training on the growth and development of male and female gymnasts is often discussed. The aim of this work is to compare the attained and predicted body height and length of body segments in 11 elite male gymnasts from the Czech Republic who have undergone intense trainings for 12 years or more. The average age of the research sample was 33 ± 11.5 years, body height 174.9 ± 4.1 cm and weight 71.5 ± 5.13 kg. Using standardized anthropometric measurements, we obtained the body height (BH) and length of the trunk, upper and lower limbs, arms, forearms, thighs, and calves. Using the t-test (p .05) <, a comparison of the actual and predicted body height was made using three different predictive equations. The results were also compared with relative lengths of body segments as reported by Chaffin & Andersson and Brugsch. In most cases, the results indicated lower actual body height than predicted body height, this difference was statistically significant in two of the three predictive equations. The relative predicted length of the upper limbs (0.442BH), arms (0.189BH), lower limbs (0.515BH), thighs (0.257BH) and calves (0.251BH) corresponds with the predicted length of these segments. Actual trunk length (0.544BH) and forearm length (0.166BH) is longer than the predicted length. Based on the analysis of the body segments of the gymnasts we can say that the gymnasts have a longer trunk, medium long upper limbs and shorter lower limbs.

Keywords: *artistic gymnastics, body height, body segments, predictive equations.*

INTRODUCTION

Physical activity has a significant effect on the human body. Physical activity can lead to the development of physical abilities and skills, the overall physical condition and morphological structure of our body. Athletes train for several hours a day. This, along with the early specialization in sport, leads to concerns about the negative effects of high intensity movement load on physical function and construction. One of the ways to monitor these potential changes is to use prediction or estimation of the body height, which is vital for assessing the growth process or detecting any growth abnormalities. Furthermore, we can observe the impact of the external environment (e.g. physical activity, high physical load, etc.) or predict the final height and the level of somatic development.

The most commonly used methods for predicting the body height are the developmental morphographs and the correlation and regression analysis of the relationships between the values of the variables found in different periods of the ontogenesis. There are many variants of these two basic methods (Lebl & Krásničanová, 1996). Some variants combine the actual height at a given age by the biological or bone age to calculate the most accurate body height prediction (Tanner, Healy, Goldstein, & Cameron, 2001). The prediction of the body height can also be attained using the parental body height. This method was first used in 1889 by Galton, who came up with the concept of so-called parental middle height or Mid-parental height/MPH (Riegerová, Přidalová, & Ulbrichová, 2006). This concept was later further developed by Gray's equation, which was then modified by Kališová and Riegerová (1988) in order to correspond with the secular trend. Another variant of the calculation is the so-called adjustable Mid-parental height (Tanner, Goldstein, & Whitehouse, 1970). This equation includes the difference between a male and female body height, which represents the number 13 in the equation. The ± 10 cm range indicates the endpoints of the offspring, with an accuracy of 95%. Due to the calculation accuracy, it is appropriate to combine several methods for predicting the body height. Attaining the same or similar results with the maximum deviation of 5%, it is possible to consider the calculated final height as correct (Lébl & Krásničanová, 1996; Riegerová et al., 2006).

In relation to artistic gymnastics, the influence of intense training and the development of the male and female gymnasts is often being discussed. Gymnasts are trained up to 35 hours per week (Chrenko, 2017). Daly, Rich, Klein, and Bass (1999) calculated that during one gymnastic training the gymnasts perform on average 102 landings on their upper extremities and 217 landings on their lower extremities, with the impact force ranging between 3.6 and 10.4 times of body weight.

Riegerová et al. (2006) explains that genetic factors affect the body height by 80%, while the environment affects it only by 20%. Although most of the studies focus on the question how the body development and body height are affected by intense mechanical stress in female gymnasts (Havlíčková, 1993, Weimann, Witzel, Schwidergall, & Böhles, 1998), the same trends can also be observed in male gymnasts. Previous studies support that the typical figure of a gymnast is of lower growth and leaner compared to the normal population (Georgopoulos et al., 2012; Richet al., 1992).

Based on a comparison of somatic characteristics of the best gymnasts with lower-level gymnasts, Cleassens et al. (1991) found that the best ones differed in their lower height and lower weight and had shorter forearms. In relation to the lower body height, body weight and the tendency towards an ectomorphic body type of the gymnasts, Pavlík (2003) presented a comparison of somatometric parameters of Czech gymnasts competing in 1969, 1993 and 1996. The body height of the gymnasts dropped to 166 cm from the previous 170.2 cm and the body weight dropped from previous 67 kg to 62.1 kg. The authors suggested that the change in somatic parameters reflects the demand for more difficult and more dynamic routines. However, more recent results showed the average body height of the gymnasts somewhat higher than 170 cm (n = 101). Nevertheless, those values are still low compared to the values of the general European population (Šibanc, Kalichová, Hedbávný, Čuk, & Pajek, 2017).

Even the most recent sources (Burt, Green, & Naughton, 2017; Malina et al., 2013) report that there is much less knowledge of the load and growth of male gymnasts than there is of female gymnasts. Malina et al. (2013) note that with regards to the segmental structure of the body of the gymnasts, the findings are very limited.

They recapitulate that most authors only state that the lower limbs of the legs tend to be shorter, or mention the information about the sitting height. More detailed information about the lower limb segments is missing, same applies to the upper limbs. Siatras, Skaperda, and Mameletzi (2010) proved high reliability of anthropometric measurements such as segment lengths, breadths, circumferences, and skinfold thickness using portable and easy-to-use instruments. Therefore, they recommend this method as a suitable method for monitoring the growth of individual body segments of artistic gymnasts.

The aim of our study is to contribute to these findings and based on the analysis of anthropometric measures to find out whether the attained body height of elite artistic gymnasts from the Czech Republic corresponds with the predicted body height. Also, the objective is to compare the actual length of selected body segments with their predicted lengths.

METHODS

The sample was comprised of eleven male gymnasts (n = 11) aged 19 to 53 with average age of 33 ± 11.5 years, body height 174.9 ± 4.1 cm and weight 71.5 ± 5.13 kg (Table 1). Gymnasts included in the sample had to meet the following criteria: 1. finished physical growth, 2. intense gymnastic training 5 times a week for at least 12 years, 3. participation in competitions at international level. Most gymnasts started specializing and training intensively between the ages of 5 and 7 and their active gymnastic career ended mostly between the ages of 22 and 25. The weekly workload of the test subjects (TS) was between 15 and 30 hours.

Table 1
Characteristics of test subjects (TS).

TS	Age	Start gym.	End gym.	Time gym.	Mother's	Father's
TS 1	37	7	27	20	166	174
TS 2	52	6	24	18	172	176
TS 3	26	10	22	12	159	162
TS 4	27	7	24	17	168	180
TS 5	22	7	22	15	168	174
TS 6	19	6	19	13	160	175
TS 7	27	5	25	20	165	180
TS 8	38	7	22	15	165	177
TS 9	41	5	30	25	167	180
TS 10	53	5	33	28	158	178
TS 11	21	4	21	17	158	175
average	33.0	6.3	24.2	18.2	164.2	175.5
SD	11.47	1.54	3.94	4.65	4.51	4.83
x min	19	4	19	12	158	162
x max	53	10	33	28	172	180

A questionnaire and anthropometric measurement were used to collect the necessary data. The questionnaire served to collect personal data in respect of training and parental height. As for the anthropometric measures, the actual body height and the lengths of the following segments were obtained: trunk, upper limbs, arms, forearms, lower limbs, thighs, calves. The gymnasts were measured using a standardized anthropometric devices (anthropometer for measuring the vertical dimensions of the human body, sliding caliper featuring a double sided measuring scale and sitting chair). A standardized methodology was used to determine the length dimensions (Riegerová et al., 2006; Steward et al., 2011). M23 – M56a = segment specification according to Riegerová et al. (2006).

The measured anthropometric parameters were the following:

1. Physical Height (PH): The default position was standing up straight with the back, buttock, and heels touching the wall. The head was held up straight (so-called Frankfurt Horizontal) and did not touch the wall. The height was measured from the ground to the vertex.

2. Sitting height/trunk length (M23): The vertical distance of the vertex (v) from the sitting area was measured. The trunk was held up straight, the head in Frankfurt Horizontal; the thighs resting on the sitting area, knees bent at right ankles.

3. Length of the entire upper limb (M45): The direct distance of the acromial point from the dactylion point of the limb (a-da) was measured.

4. Arm length (M47): The direct distance of the acromial point from the radial point was measured.

5. Forearm length (M48): The direct radial point distance from the stylion point (r-sty) were measured.

6. Length of the entire lower limb (M53): The direct distance of the iliospinal point from the foot was measured.

7. Thigh Length (M55): The direct distance of the iliospinal point from the tibial point (ti) to the external lateral knee joint was measured.

8. Legs length (M56a): The direct distance of the tibial point spacing from the sphyrion point was measured.

To predict the body height, three different equations were used, all of which were based on the parental body height.

PH1 is predictive equation according to Gray (1988).

PH2 is predictive equation according to Kališová and Riegrová (1988).

PH3 is predictive equation calculating with the adjusted parental height (Tanner, Goldstein, & Whitehouse, 1970).

PH1: Son = (1.08 · Father's height + Mother's height) / 2

PH2: Son = (111.1 % Mother's height + 102.4 % Father's height) · 0.5

PH3: Son = [Father's height + (Mather's height + 13)] / 2 ± 10 cm

Due to our research being focused on men only, we always used the equation to calculate the height of the son.

To compare the measured lengths of individual body segments, the relative lengths of the segments (= ratio of segment length to body height) were calculated and compared with relative lengths of segments as reported by Chaffin and Andersson (CHA) (in Herman, 2007) (Table 2). The actual relative lengths of the segments were also compared with the anthropometric indexes by Brugsch (B) (Schmeister, 2011) (Table 3). Brugsch defined the values limiting the mid-lengths of the trunk, lower, and upper limbs. For statistical comparison the average value $\bar{x}$ of this range was used.

Table 2
Relative lengths of body segments (ratio of segment length to body height) in general population according to Chaffin and Andersson (in Herman, 2007).

Segment	Length of
Trunk	0.520
Upper limb	0.440
Arm	0.186
Forearm	0.146
Lower limb	0.530
Calve	0.246
Thigh	0.245

Table 3
Classification of anthropometric indexes of relative segment lengths (ratio of segment length to body height) for men in the general population according to Brugsch (edited by Schmeister, 2011). x̄ Men = the mean value of the range.

Classification by Brugsch	Men	x̄ Men
Metriocormic (Medium long trunk)	(0.511–0.520)	0.516
Brachycormic (Medium long upper limbs)	(0.441–0.445)	0.443
Metrioscelic (Medium long lower limbs)	(0.536–0.540)	0.538

The collected data was processed in Microsoft Excel 2016 and Statistics 12. Based on the results of the normality tests, for further statistical data processing parametric tests, namely the t-test at the level of probability 5% were used.

RESULTS

Anthropometric measurements results

The results of the anthropometric measurements of the research sample are summarised in Table 4.

Results of body height prediction

To calculate the predicted height (PH) of the probands three different equations - PH1, PH2, and PH3 were used. The calculated predicted heights (PH) were subsequently compared with the measured actual body height (BH) of the test subjects (Table 5, Figure 1).

As seen in Figure 1, it is apparent that using certain prediction equations, the actual BH of some tested subjects (TS) corresponds with the predicted body height or is even higher (TS 1, TS 2, TS 3, TS 9, TS 10 and TS 11). In TS 4 – TS 8 the body height is lower than all predicted values. The biggest difference between the PH and BH can be seen in TS 4 and TS 5, where the predicted body height obtained using the prediction equations PH2 is up to 14 cm higher than the actual body height.

The measured lengths of individual body segments, except from the absolute values (Table 4), are also given in the relative values, i.e. in relation to the BH (Table 6), in order to provide better interindividual comparison. Even Chaffin and Andersson (In Herman, 2007), as well as Brugsch (In Schmeister, 2011), whom our data was compared with, indicate the relative lengths of body parts. Brugsch only specifies the lengths of the trunk, lower limbs and upper limbs, and not the individual segments. For this reason they are missing from in Table 6.

Table 4
Results of anthropometric measurements of test subjects - the length of body segments (cm).

TS	Body	Sitting	Upper	Arm	Forearm	Lower	Thigh	Calf
TS 1	176	97.7	79	34.5	31	96.9	43	47
TS 2	181	99	78	32	30	101.6	45.5	49
TS 3	172.2	93.6	75	32	27	91.7	40.5	44.5
TS 4	171.7	94	76.6	35	29	93.2	41	45.5
TS 5	168.5	94.5	76	33.5	28	96.4	45.3	44.5
TS 6	172.5	95	74.4	30	30	89.2	42.2	40.3
TS 7	176	96	77.2	35.4	29	94.2	45	42.3
TS 8	174	96.5	73.5	31.4	27	93.8	45	42
TS 9	183.4	99	83	35.5	32	106.7	54	45.5
TS 10	176	92	78	32	27	92.9	45	41
TS 11	173	90	79	33	30.5	96.7	48	42
average	174.9	95.2	77.2	33.1	29.1	95.7	45	44
SD	4.1	2.7	2.5	1.7	1.7	4.6	3.6	2.6
x min	168.5	90	73.5	30	27	89.2	40.5	40.3
x max	183.4	99	83	35.5	32	106.7	54	49

Table 51
Actual Body Height (BH) and Predicted Body Height (PH1 - according to Gray (1988), PH2 – according to Kališová and Riegrová (1988), and PH3 – according to Tanner, Goldstein, & Whitehouse, 1970) of the gymnasts.

TS	BH (cm)	PH1 (cm)	PH2 (cm)	PH3 (cm)
TS 1	176.0	177.0	181.3	176.5
TS 2	181.0	181.0	185.7	180.5
TS 3	172.2	167.0	171.3	167.0
TS 4	171.7	181.2	185.5	180.5
TS 5	168.5	178.0	182.4	177.5
TS 6	172.5	174.5	178.5	174.0
TS 7	176.0	179.7	183.8	179.0
TS 8	174.0	178.1	182.3	177.5
TS 9	183.4	180.7	184.9	180.0
TS 10	176.0	175.1	178.9	174.5
TS 11	173.0	173.5	177.4	173.0
average	174.9	176.9	181.1	176.4
SD	4.1	4.0	4.1	3.9
x min	168.5	167.0	171.3	167.0
x max	183.4	181.2	185.7	180.5

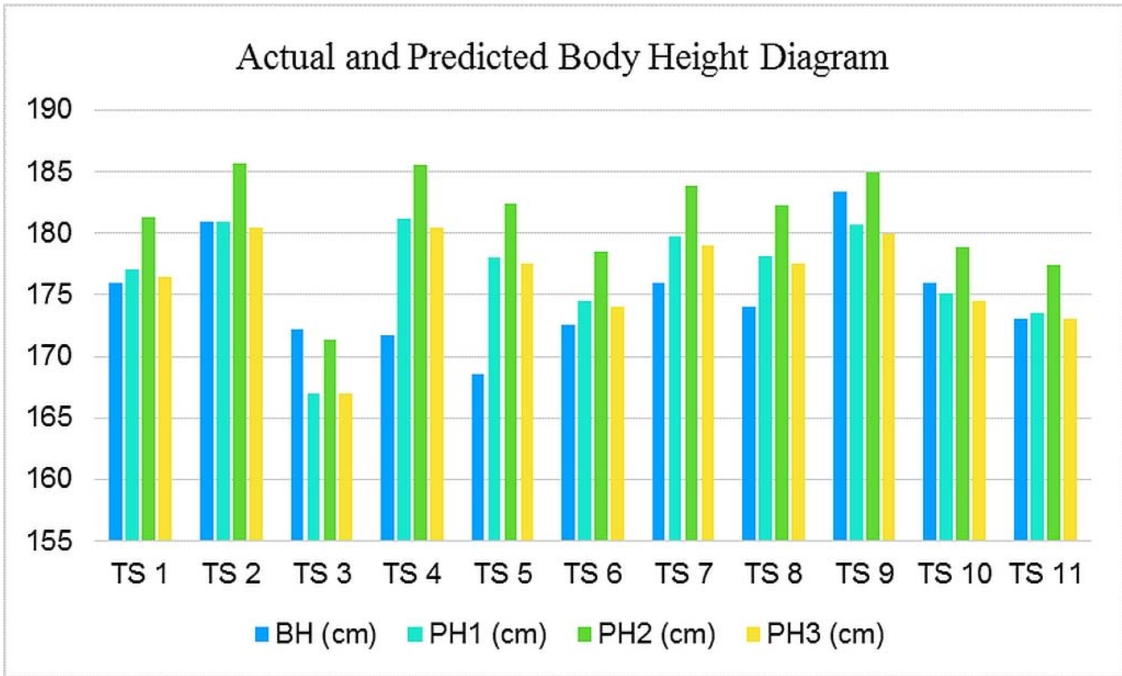


*Figure 1.*Comparison of the Actual Body Height (BH) and Predicted Body Height, (PH1 - according to Gray (1988), PH2 – according to Kališová and Riegrová (1988), and PH3 – according to Tanner, Goldstein, & Whitehouse, 1970) in test subjects (TS)

Table 62

Actual relative length of the body segments of gymnasts (ratio of segment length to body height); CHA = Predicted Relative Length of Segments according to Chaffin – Andersson, B = Predicted Relative Length of Segments according to Brugsch. M23 – M56a = segment specification by Riegerová et al., (2006) - length of Body Segments/Body Height.

TS	Trunk (M23)	Upper limb (M45)	Arm (M47)	Forearm (M48)	Lower limb (M53)	Thigh (M55)	Calf (M56a)
TS 1	0.555	0.449	0.196	0.176	0.506	0.244	0.267
TS 2	0.547	0.431	0.177	0.166	0.525	0.251	0.271
TS 3	0.544	0.436	0.186	0.157	0.508	0.235	0.258
TS 4	0.547	0.446	0.204	0.169	0.507	0.239	0.265
TS 5	0.561	0.451	0.199	0.166	0.504	0.269	0.264
TS 6	0.551	0.431	0.174	0.174	0.484	0.245	0.234
TS 7	0.545	0.439	0.201	0.165	0.497	0.256	0.24
TS 8	0.555	0.422	0.18	0.155	0.484	0.259	0.241
TS 9	0.54	0.453	0.194	0.174	0.452	0.294	0.248
TS 10	0.523	0.443	0.182	0.153	0.58	0.256	0.233
TS 11	0.52	0.457	0.191	0.176	0.618	0.277	0.243
average	0.544	0.442	0.189	0.166	0.515	0.257	0.251
SD	0.012	0.010	0.010	0.008	0.044	0.017	0.013
CHA	0.520	0.440	0.186	0.146	0.530	0.245	0.246
B	0.515	0.443	-	-	0.538		-

Table 7

T-test for the Actual Body Height (BH) and Predicted Body Height (PH1 - according to Gray (1988), PH2 – according to Kališová and Riegrová (1988), and PH3 – according to Tanner, Goldstein, & Whitehouse, 1970).

Variable	T-test for dependent samples, Differences significant at the level p <.05000									
	Average	SD	N	Dif.	SD (dif.)	t	sv	p	Int. reliab. (-95.000%)	Int. reliab. (+95.000%)
BH	174.936	4.065								
PH1	176.886	4.235	11	-1.949	4.569	-1.415	10	0.188	-1.121	5.019
BH	174.936	4.065								
PH2	181.082	4.330	11	-6.146	4.626	-4.406	10	0.001	3.038	9.254
BH	174.936	4.065								
PH3	176.364	4.063	11	-1.427	4.482	-1.056	10	0.316	-1.584	4.438

Table 83

T-test for the actual and predicted lengths (PL) of individual segments according to Chaffin and Andersson (PL1) and Brugsch (PL2), M23 – M56a = segment specification by Riegerová et al., (2006).

Variable	T-test for dependent samples, Differences marked at the significance level p <.050									
	Average	SD	N	Dif.	SD (dif.)	t	sv	p	Int. reliab. (-95.00%)	Int. reliab. (+95.00%)
Trunk length (M23)	95.209	2.815								
PL1- trunk	90.967	2.217	11	4.242	2.189	6.429	10	0.000	-5.713	-2.772
Trunk length (M23)	95.209	2.815								
PL2- trunk	90.180	2.198	11	5.029	2.185	7.634	10	0.000	-6.497	-3.561
Upper limb length (M45)	77.245	2.637								
PL1–Upper limb	76.972	1.876	11	0.273	1.872	0.484	10	0.638	-1.531	0.984
Upper limb length (M45)	77.245	2.637								
PL2–Upper limb	77.497	1.889	11	-0.251	1.872	-0.445	10	0.666	-1.006	1.509
Lower limb length (M53)	90.064	7.941								
PL1–Lower limb	92.716	2.259	11	-2.653	8.151	-1.079	10	0.306	-2.823	8.129
Lower limb length (M53)	90.064	7.941								
PL2–Lower limb	94.116	2.294	11	-4.052	8.159	-1.647	10	0.131	-1.429	9.534
Arm length (M47)	33.118	1.814								
PL1-Arm	32.538	0.793	11	0.580	1.782	1.080	10	0.306	-1.777	0.617
Forearm length (M48)	29.136	1.733								
PL1-Forearm	25.541	0.622	11	3.596	1.492	7.991	10	0.000	-4.598	-2.593
Thigh length (M55)	44.955	3.720								
PL1-Thigh	42.859	1.044	11	2.095	3.156	2.202	10	0.052	-4.216	0.025
Calf length (M56a)	43.964	2.694								
PL1-Calf	43.034	1.049	11	0.929	2.463	1.251	10	0.239	-2.584	0.726

It is apparent from the results that the actual trunk length in probands is higher than the predicted length. The average trunk length of the research sample is 4 to 5 cm greater than the average predicted length.

The average actual length of the upper limbs is higher than the predicted length according to CHA, but is lower than the predicted length according to B. In some probands, the actual length of the upper limbs is higher than both predicted lengths.

The average actual length of the lower limbs is lower than the predicted length according to both CHA and B. The average predicted length of the lower limbs is 2.66 – 4.06 cm greater than the actual lengths. However, it is obvious that the research sample also includes gymnasts whose length of the lower limbs is longer than both predicted ones.

To answer the question whether the actual body height of Czech elite artistic gymnasts corresponds with the predicted height, a statistical comparison using the t-test was performed (Table 7).

The statistically significant difference ($p <.05$) between the actual and predicted body height, which was calculated using the PH2 equation, was proved.

The calculation of the statistical significance of the differences (Table 8) was chosen to evaluate the question of how the length of the individual body segments corresponded to their predicted lengths (PL) according to Chaffin and Andersson (PL1) and Brugsch (PL2).

DISCUSSION

As the results showed, there is no significant difference between the predicted body height PH1, PH3, and the actual body height. The body height of the probands mostly corresponds with the Mid-parental height PH3. Considering the deviation of the predicted body height of ± 10 cm, which is given by this equation, it is evident that the body height of the gymnasts lies within this limit. These results correspond with the findings of Georgopoulos et al. (2012), according to which gymnasts reach lower body height than their genetic predispositions determine, however the final body height is still within the norm.

When comparing the obtained results with the results from other authors, who focused on the same topic, the present study revealed that the average body height of our tested gymnast (174.9 ± 4.1 cm) was higher than the average body height of the gymnasts in other studies. When comparing the results with a study by Cleassens et al. (1991) that included a larger number of tested subjects (n = 165), the average height of sample group is 7.9 cm higher. Latest results from the World Cup 2015 (Šibanc et al., 2017) show that the current gymnastic elite is by average 5 cm shorter than our research sample. In accordance with Malina et al. (2013), it can be assumed that the differences in the average body height of gymnasts in the studies can be affected by the number of tested subjects, their age, level of performance and their nationality, which is associated with their genotype.

Due to the fact that the research group consisted of Czech gymnasts, their height was compared with the average body height of the Czech population. The current average body height of Czech men is 178.8 cm, according to Kopecký, Kikalová and Charamza (2016). This average body height of men was determined on the basis of the body height measurement in 973 males aged between 19 and 94 years, which was implemented between 2013 and 2015. The average body height of the sample group is therefore 3.9 cm lower than the current average of the Czech male population.

When comparing the average body height of the fathers of the tested gymnasts (175 cm) with the average body height of the male Czech population (178.8 cm), results showed that the fathers' body height was below average. Baxter Jones, Helms, Maffulli, Baines-Preece and Preece

(1995) also found that the parents of gymnasts have lower body height than the parents of i.e. swimmers or tennis players.

When evaluating the validity of the predictive equations, we came to the same conclusions as Caska (2016), who showed a better match between the predicted and the achieved body heights when using the equation with the adjusted mid-parental height (PH3). This method of predicting body height is also mentioned in Malina et al. (2013). According to Lebl and Krasničanová (1996), the predictive calculation can be considered correct if the results match with the deviation of 5%. This condition corresponds with the results of PH1 and PH3. Therefore, it can be assumed that these predictive equations are more accurate than the equations by Kališová and Riegrová (PH2). However, it is advisable to verify the accuracy of the used calculations on a larger sample and control groups, or use different methods to perform to predict body height to verify the accuracy of the calculations.

As regards the anthropometric characteristics of the individual segments, a statistically significant difference between the actual and predicted length was found in the trunk. The actual length of the segment in gymnasts is greater than the predicted length according to CHA ($p = .000$) and B ($p = .000$).

There was no statistically significant difference between the actual and predicted length of the upper limbs (CHA: $p = .639$; B: $p = .666$). The same was found for the actual and predicted length of the lower limbs (CHA: $p = .306$). The difference in the average length of lower limbs and the predicted length according to B is higher (4.05 cm), yet no statistically significant difference was found ($p = .131$).

The data provided by Chaffin and Andersson allowed us for even more detailed comparison of the individual segments of the upper and lower limbs. No statistically significant difference was found in the actual arm length when compared to the predicted arm length PL1 (CHA: $p = .306$). On the other hand, a statistically significant difference was found when comparing the forearm lengths (CHA: $p = .000$). In this case, the average actual length of the forearm was 4.4 cm longer than the predicted length PL1.

For the lower limb segments, the actual length of the calves and the thighs was moderately higher than the predicted lengths. However, this difference was not statistically significant (CHA calf: $p = .239$; CHA thigh: $p = .052$). The fact that the total length of the lower limb was 2.7 - 4.1 cm less than the predicted length could be explained by the specific measurement methodology. The length of the lower limb included the ankle-floor distance, which could have been different in the tested persons but we did not measure it separately. The results could also be affected by individual differences within the relatively small research sample, as shown by the standard deviations in the lengths of lower limbs, thighs and calves.

When comparing our data regarding the body length parameters of gymnasts with previous studies, it is obvious the similarity of some results. Daly, Rich, Klein, & Bass (2000) focused on body length parameters of prepubertal and early pubertal male gymnasts (n = 31), that they compared with a control group. The authors reported a lower overall body height of gymnasts given by the shorter lower limbs, because the trunk length of the gymnasts corresponded with the trunk length of the control group. Even Rich et al. (1992) and Buckler et al. (1977) came to the same conclusion when they stated that the smaller figure is due to the shorter lengths of the lower limbs, not the length of the trunk. These results correspond with our results of shorter lower limbs in relation to the body height.

The lengths of the humerus, radius, femur and tibia bones were shorter in gymnasts than in the control group (Daly et al., 2000). Siatras, Skaperda, and Mameletzi (2009) found that the arms and legs of gymnasts were shorter compared to swimmers and non-athletes. Our results showed that the lengths of these segments correspond to the predicted lengths, according to Chaffin and Andersson, with only the forearm being significantly longer than assumed. These different results can be attributed to a relatively small sample of our research as well as to the choice of a control group that has been set up by Chaffin and Andersson.

The different proportions of the body parts of gymnasts in relation to their total body height may be associated with the different intensity of loading of the different body parts. Compressive load is applied to the musculoskeletal system during floor exercises, vault, and pommel horse. Parallel bars are a combination of compression and tension, horizontal bar and still rings exercises load the body primarily in tension (Chrenko, 2017). During floor exercises the highest values of compression force were recorded as follows: up to 3.6 times body weight (BW) in the upper limbs, and 10.4 BW in the lower limbs (Daly, Rich, Klein & Bass, 1999). In male gymnastics, the upper limbs, especially the wrists, are loaded on the pommel horse at around 1.85 BW (Fujihara, 2011). High-tension forces were recorded during exercises on still rings (Serafin, Golema, & Siemeński, 2008) and reported up to 11 BW. In regards to the different bone adaptation rates, Dowthwaite and Scerpella (2009) state that *"the mode of diaphyseal adaptation (endocortical expansion versus contraction) may be a function of the skeletal site, varying from bone to bone and within a single bone. High variability in the diaphyseal endocortical dimensions also suggests the potential for genetic influence."*

Lower body height in gymnasts is often associated with the negative effects of high-intensity mechanical loading. The main cause of this is primarily a high energy expenditure in comparison to poor nutrition, lower body fat mass and lower hormone levels. However, it should be noted that these results come mainly from research of female gymnasts. Studies on female gymnasts show that the levels of insulin-like growth factor 1 (IGF-1) and thyrixin are not different from that of other athletes or non-athletes due to intense training during pre-puberty and/or puberty (Daly et al., 1999; Daly et al., 2000; Weimann, Witzel, Schwidergall & Böhles, 2000). Some results show late maturation with lower growth rates in gymnasts (Georgopoulos et al., 2010; Weimann et al., 1998). However, according to Daly et al., (1999), Daly et al. (2000) and Ward, Roberts, Adams, Lanham-New & Mughal (2007), the growth rate of gymnasts was comparable to the growth rate of the controls. Canda (2016) in his case study followed the development of the anthropometric profile in two gymnasts. His measurements also showed that the gymnasts remained in their percentile growth curve during their long-term intensive training. Daly et al. (2000) suggest that bone growth may be affected by other factors as well, such as recurrent stress or acute bone injury.

Burt, Greene, Ducher, and Naughton (2013) claim that gymnastic training up to 30 hours per week and more has negative effects, but also positive effects as well. Even according to Jürimä, Gruodyte-Raciene, & Baxter-Jones (2018), these negative effects, which can result in lower bone accrual, are balanced by the positive effects of the gymnastic stress that has positive effects on bone development, primarily greater bone density and bone content. Dowthwaite and Scerpella (2009) specify the adaptive changes of the skeletal system of gymnasts during their growth as follows: enlargement of total and cortical bone geometry (+10 to 30 %) and elevation of trabecular density (+ 20 %) in the forearm, yielding elevated indexes of skeletal strengths (+20 to +50 %). Other sites exhibit more moderate geometric and densitometric adaptations (5 to 15 %). Burt et al. (2013) observed that these positive adaptations towards load are greater at the radius than tibia. Especially in the distal radius, with 10% to 12% more of the total bone density and content in pre-pubertal gymnasts than in controls. These results are supported by the results of comparable studies on other sports athletes. Heinonen, Sievänen, Kyröläinen, Perttunen, and Kannus (2001), who focused on the effects of extreme impact loading on the structure of lower limbs in triple jumpers, came to similar conclusions. It was found that this load improved the mechanical properties of the tissues, namely the mineral mass, size, and gross structural properties.

Based on findings, the authors (Daly et al., 2000) are of the opinion that lower body height of gymnast is rather the result of selection, as the body height deficit didn’t increase with the higher workload. Natural selection bias, where physical predisposition plays an unavoidable role, can be commonly observed in sports (basketball, swimming, etc.) and it is also very important in artistic gymnastics. When monitoring the growth of gymnasts, the control groups often consists of non-athletes or swimmers (Siatras et al., 2009). It can be assumed that different anthropometric values will be found in swimmers as their performance depends on a quite different somatotype than of the gymnasts. The implementation of complex space-time movement structures is advantageous for smaller and lighter gymnasts (Burt et al., 2017). Therefore, it can be assumed that athletes with these physical characteristics will achieve excellent performances more easily and will be more successful. Individual gymnastic disciplines require different predispositions, which may be the somatotype or the anthropometric characteristics of the athlete. In today's gymnastics there is noticeable trend of gymnasts’ specialization. Therefore, it is possible that among the elite gymnasts the variability of these physical factors will increase according to their specialization in different events. However, any relationship between the anthropometric characteristics of the segments or the somatotype of the gymnasts and their success individual disciplines in gymnasts competing in the World Cup 2015 was not confirmed (Hedbávný & Kalichová, 2015, unpublished).

Although gymnasts are usually smaller in size, our research sample was above average in comparison with the gymnasts from similar research. The cause of this result may be the fact that Czech men and women generally belong to the very tallest in the world (Grasgruber & Hrazdíra, 2013). The present study further revealed that the gymnasts surpassed the predicted body height and length of certain segments, and it was very individual. In our opinion, this fact is primarily due to their genetic dispositions, which were not significantly affected by the training. In any case, it is important to follow certain principles during high intensity training. It is necessary to monitor the level of training load and its consequences, especially fatigue, which can have negative effects on physiological functions of the body and thus both on the performance and the health of an athlete (Bernacikova, Čechovská & Novotný, 2018). As reported by Daly et al. (2007), exercises should be dynamic, diverse, applied rapidly and intermittently. The boundary load, when high-intensity exercises have still positive effects, is difficult to determine; several factors such as type of exercise and its intensity, duration, dietary intake, and other athlete-related variables such as age, gender, or maturity should be taken into account (Klentrou, 2016).

CONCLUSIONS

Unfortunately, due to the lack of publications dealing with anthropometric characteristics of artistic gymnasts and the lack of specification of the measurement methodology in these publications, it is not possible to compare our results further. In addition to this, the impact of intense gymnastic training on growth is mostly measured in female gymnasts rather than male gymnasts. The limitation of our study is primarily in a small research sample. However, its size corresponds with the possibilities of Czech gymnastics. A study with a larger sample group would be needed to generalize the results. Another limiting factor is the relatively large age range of our research sample. The results can be affected by the fact that some gymnasts competed 20 years ago when the Code of Points was different. With the development of the demands of the gymnastics in the course of two decades, changes in the optimal somatotype of the gymnast may be observed. Another limitation is the fact that the published studies often differ from each other in the methodology of both measuring and evaluating the results. It should also be kept in mind that the present research was conducted as a cross-sectional study. The results point to certain contexts, however a longer-term study following the changes in anthropometric characteristics in gymnasts and the control group would better demonstrate the extent to which intense training affects the body growth of gymnasts.

The results of this study can be briefly summarized as follows:

- The actual body height of gymnasts corresponds with the predicted body height, which was calculated using two different predictive equations: PH1 equation by Gray (1988) and PH3 equation with the adjusted mid-parental height; the highest match was in the case of PH3.
- The actual body height of gymnasts was lower than the predicted body height, which was calculated using the predictive equation PH2 by Kališová and Riegrová (2006).
- The actual length of segments corresponded with the predicted length of the upper limbs, arms, lower limbs, thighs and calves.
- The actual length of the trunk and forearms was significantly longer than the predicted length.
- The results indicated longer trunk, moderate upper limbs, and shorter lower limbs in gymnasts.

REFERENCES

Baxter-Jones, A. D. G., Helms, P., Maffulli, N., Baines-Preece, J. C., & Preece, M. (1995). Growth and development of male gymnasts, swimmers, soccer and tennis players: A longitudinal study. *Annals of Human Biology, 22*(5), 381-394.

Bernaciková, M., Čechovská, I. & Novotný, J. (2018). Questionnaire method in the diagnosis of fatigue of 14 and 16 years old sports gymnasts. *Studia sportiva*, *12*(1), 6-13.

Buckler, J. M. H., & Brodie, D. A. (1977). Growth and maturity characteristics of schoolboy gymnasts. *Annals of Human Biology, 4*(5), 455-463.

Burt, L. A., Green, D. A., & Naughton, G. A., (2017). Bone Health of Young Male Gymnasts: A Systematic Review. *Pediatric Exercise Science, 29*(4), 456-464 .

Burt, L. A., Greene, D. A., Ducher, G., & Naughton, G. A. (2013). Skeletal adaptations associated with pre-pubertal gymnastics participation as determined by DXA and pQCT: A systematic review and meta-analysis. *Journal of Science and Medicine in Sport, 16*(3), 231-239.

Canda, A. S. (2016). Anthropome tric profile of gymnast from childhood to maturity sport: Report of 2 cases. *Archivos de Medicina del Deporte*, *33* (6), 375-381.

Caska, J. (2016). *Porovnání předpokládané a reálné tělesné výšky u sportovních gymnastů.* Diplomová práce. Masarykova univerzita, Brno.

Claessens, A. L., Veer, F. M., Stijnen, V., Lefevre, J., Maes, H., Steens, G., & Beunen, G. (1991). Anthropometric characteristics of outstanding male and female gymnasts. *Journal of Sports Sciences, 9*(1), 53-74.

Daly, R. M., Rich, P. A., Klein, R., & Bass, S. L. (2000). Short stature in competitive prepubertal and early pubertal male gymnasts: The result of selection bias or intense training? *Journal of Pediatrics, 137*(4), 510-516.

Daly, R. M., Rich, P. A., Klein, R., & Bass, S. (1999). Effects of high-impact exercise on ultrasonic and biochemical indices of skeletal status: A prospective study in young male gymnasts. *Journal of Bone and Mineral Research, 14*(7), 1222-1230.

Daly, R. (2007). The effect of exercise on bone mass and structural geometry during growth. *Medicine and Sport Science*, *51*, 33-49.

Dowthwaite, J. N., & Scerpella, T. A. (2009). Skeletal geometry and indices of bone strength in artistic gymnasts. *Journal of Musculoskeletal Neuronal Interactions, 9*(4), 198-214.

Fujihara, T. (2011). *Biomechanical Evaluation of Circles with a Suspended Aid*. Doctoral thesis. Faculty of Physical Education and Recreation. University of Alberta.

Georgopoulos, N. A., Roupas, N. D., Theodoropoulou, A., Tsekouras, A., Vagenakis, A. G., & Markou, K. B. (2010). The influence of intensive physical training on growth and pubertal development in athletes. *Annals of the New York Academy of Sciences, 1205*(1), 39-44.

Georgopoulos, N. A., Theodoropoulou, A., Roupas, N. D., Armeni, A. K., Koukkou, E., Leglise, M., & Markou, K. B. (2012). Final height in elite male artistic gymnasts. *Journal of Pediatric Endocrinology and Metabolism, 25*(3-4), 267-271.

Grasgruber, P. & Hrazdíra, E. (2013). Anthropometric characteristics of the young Czech population and their relationship to the national sports potential. *J. Hum. Sport Exerc.*, *8*(2), 120-134.

Havlíčková, L. (1993). *Fyziologie tělesné zátěže. II, Speciální část*. Praha: Karolinum, 238 p.

Heinonen, A., Sievänen, H., Kyröläinen, H., Perttunen, J., & Kannus, P. (2001). Mineral mass, size, and estimated mechanical strength of triple jumpers' lower limb. *Bone, 29*(3), 279-285.

Herman, I. P. (2007). Physics of the human body (3rd, corr. print). Berlin: Springer, 857 p.

Chrenko, S. (2017). *Mechanické zatížení juniorů během tréninku ve sportovní gymnastice*. Diplomová práce. Masarykova Univerzita, Brno.

Jürimäe, J., Gruodyte-Raciene, R., & Baxter-Jones, A. D. G. (2018). Effects of gymnastics activities on bone accrual during growth: A systematic review. *Journal of Sports Science and Medicine, 17*(2), 245-258.

Kališová, M., & Rigerová, J. (1988). *Dědičnost některých antropometrických znaků*. Teor. Praxe těl. Vých., Praha.

Klentrou, P. (2016). Influence of exercise and training on critical stages of bone growth and development. *Pediatric Exercise Science, 28*(2), 178-186.

Lebl, J., & Krásničanová, H. (1996). *Růst dětí a jeho poruchy*. Praha: Galén, 157 p.

Kopecký, M., Kikalová, K., & Charamza, J. (2016). Sekulární trend v tělesné výšce a hmotnosti dospělé populace v České republice. *Časopis lékařů českých*, *155*(7), 357-364.

Malina, R. M., Baxter-Jones, A. D. G., Armstrong, N., Beunen, G. P., Caine, D., Daly, R. M., . . . Russell, K. (2013). Role of intensive training in the growth and maturation of artistic gymnasts. *Sports Medicine, 43*(9), 783-802.

Pavlík, J. (2003). *Tělesná stavba jako faktor výkonnosti sportovce*. Brno: Masarykova univerzita, 57 p.

Riegerová, J., Přidalová, M., & Ulbrichová, M. (2006). *Aplikace fyzické antropologie v tělesné výchově a sportu: (příručka funkční antropologie).* (3. vyd). Olomouc: Hanex, 262 p.

Rich, P. A., Fulton, A., Ashton, J., Bass, S., Brinkert, P., Brown, P. et al. (1992). Physical and functional characteristics of highly trained young male gymnasts. *Excel, 8*, 93-100.

Serafin, R., Golema, M., & Siemieński, A. (2008). Mechanical loading of the gymnast's motor system during swings on rings. *Biology of Sport, 25*(4), 351-360.

Schmeister, P. (2011). *Tělesné složení žáků 8. tříd v regionu Slovácko a Horňácko*. Diplomová práce. Univerzita Palackého, Olomouc.

Siatras, T., Skaperda, M., & Mameletzi, D. (2009). Anthropometric characteristics and delayed growth in young artistic gymnasts. *Medical Problems of Performing Artists, 24*(2), 91-96.

Siatras, T., Skaperda, M., & Mameletzi, D. (2010). Reliability of anthropometric measurements in young male and female artistic gymnasts. *Medical Problems of Performing Artists, 25*(4), 162-166.

Steward, A. D., & Marfell-Jones, M. (2011). *International standards for anthropometric assessment*. New Zeland: International society for advancement of kinanthropometry. 115 p.

Šibanc, K., Kalichová, M., Hedbávný, P., Čuk, I., & Pajek, M. B. (2017). Comparison of morphological characteristics of top level male gymnasts between the years of 2000 and 2015. *Science of Gymnastics Journal, 9*(2), 201-211.

Tanner, J. M., Goldstein, H., & Whitehouse, R. H. (1970). Standards for children's height at ages 2-9 years allowing for height of parents. *Archives of Disease in Childhood, 45*(244), 755-762.

Tanner, J. M., Healy, M. J. R., Goldstein, H, & Cameron, N. (2001). *Assessment of Skeletal Maturity and Prediction of Adult Height (TW3 Method)*. 3rd ed. London: W.B.Saunders, 110 p.

Ward, K. A., Roberts, S. A., Adams, J. E., Lanham-New, S., & Mughal, M. Z. (2007). Calcium supplementation and weight bearing physical activity: do they have a combined effect on the bone density of pre-pubertal children? *Bone*, *41*, 496–504.

Weimann, E., Witzel, C., Schwidergall, S., & Böhles, H. J. (1998). Effect of high performance sports on puberty development of female and male gymnasts. *Wiener Medizinische Wochenschrift, 148*(10), 231-234.

Weimann, E., Witzel, C., Schwidergall, S., & Böhles, H. J. (2000). Peripubertal pertubations in elite gymnasts caused by sport specific training regimes and inadequate nutritional intake. *International Journal of Sports Medicine, 21*(3), 210-215.

Corresponding author:

Miriam Kalichová
Faculty of Sports Studies - Kinesiology
Kamenice 5 , Brno 62500
Czech Republic
E-mail: kalichova@fsps.muni.cz

PERSONALITY OF GYMNASTS AND COPING STRATEGIES TO MANAGE STRESS

Adriana Kaplánová

Faculty of Physical Education and Sport, Comenius University in Bratislava, Slovakia

Original article

Abstract

The reason why some gymnasts give an excellent performance and others are barely able to give average performance in competition may be embedded in the sphere of personality structure. Stress is the body's response to the imbalance between the demands of the external environment and the body's ability to meet those requirements. Therefore, the aim of our study is to investigate the relationship between personality structure of gymnasts and coping strategies to manage stress. The study sample consisted of 56 elite Slovak gymnasts (16 men and 40 women) aged from 15 to 26, with an average age of 19.34 ± 3.15 years. The personality structure of gymnasts was investigated by the NEO-FFI inventory (Ruisel & Halama, 2007). Coping strategies to manage stress were investigated by the Athletic Coping Skills Inventory ACSI-28 (Smith et al., 1995). The correlational research design was used. The results of our study showed that 6 of the 7 subscales of coping strategies to manage stress are in relation to personality structure of the gymnasts, namely emotional lability/stability, extroversion/introversion and openness to experience. We also found that none of subscales of coping strategies to manage stress is in relationship to an agreeableness and conscientiousness of gymnasts. A better understanding of the personality traits and coping strategies to manage stress may help coaches and sports psychologists to develop effective interventions and assist gymnasts to attain optimal performances in competition.

Keywords: *coping strategies, personality traits, stress, gymnasts, sports psychology.*

INTRODUCTION

Competition is associated with a multitude of various feelings, athletes feel excitement or enthusiasm and believe in achieving valued goals which bring them coveted happiness and satisfaction with performance (Skinner & Brewer, 2004). Sometimes athletes feel also scared due to which they become nervous, their muscles get tense, their stomach pains, body becomes tight, hands become clammy, and negative thoughts predominate them and hence they start believing that they will never win a big competition (Bhambri, Dhillon & Sahni, 2005). These feelings can be accompanied by a stress response. The stress is defined as a physical and mental demand, which tends to disturb the homeostasis of the human body (Bali, 2015).

There are only few studies investigating stress and coping strategies to manage stress that monitors seven of subscales of psychological skills in sports (Bebetsos, 2015; Bebetsos & Antoniou, 2003; Daroglou, 2011; Christensen & Smith, 2016; Jooste, Steyn & Van den Berg, 2014; Skourtanioti & Bebetsos, 2008; Young & Knight, 2014). Whether athletes are able to remain calm, even when things are going badly, monitors subscale of coping with adversity. Good sports performance in competition is also dependent on concentration, confidence and achievement motivation which evaluates subscale of concentration and subscale of confidence and achievement motivation. Athletes should be mentally prepared for performance and have stress under control during the competition. The level of these skills monitors subscale of goal setting and mental preparation and subscale of peaking under pressure. Sometimes it happens that athletes worry about what others will think if they perform poorly. These worries assess subscale called freedom from worry. The last subscale is coachability which evaluates openness and ability to listen to the coach's instructions what to improve the physical and mental skills of athletes (Smith, Schutz, Smoll & Ptacek,1995).

In high-risk sports (rock climbing, parachuting, bungee-jumping) athletes achieved the highest scores in subscale of confident and motivation achievement, as well as subscale of concentration. It seems that stay calm and know to focus on the tasks even when adverse or unexpected situations occur, is necessary for these high-risk sports (Young & Knight, 2014). In other sports, such as golf, athletes achieved the highest scores in subscales of coachability, confidence, and peaking under pressure. It seems that golfers used to accept constructive criticism without taking it personally and becoming upset what predispose them to be positively motivated and give maximum during competition (Christensen & Smith, 2016). The results indicated that psychological skills change depending on requirements in sport what also confirmed previous studies in basketball (Skourtanioti & Bebetsos, 2008), badminton (Bebetsos & Antoniou, 2003) or archery (Young & Knight, 2014).

Using the closed-skill sport of gymnastics, they found different cognitive patterns for U.S. Olympic qualifiers and nonqualifiers. The successful gymnasts were more self-confident, had a higher frequency of gymnastic dreams, and were more open to talking with coaches compared to unsuccessful gymnasts (Mahoney & Avener, 1977). Similar findings were found in case of archery where experienced athletes achieved a higher score in subscale of confidence and concentration, as well as subscale of freedom from worry compared to inexperienced athletes (Bebetsos, 2015). It seems that coping strategies to manage stress are not the same and vary according to athletic experiences in sport (Bebetsos, 2015; Bebetsos & Antoniou, 2003; Mahoney & Avener, 1977; Skourtanioti & Bebetsos, 2008).

Sports performance is often greatly influenced by the intensity of the athletes' emotions as well as their entry and stay in optimal zones. If emotions are in optimal zones, athletes are capable of good or excellent sports performance. If emotions get into dysfunctional zones, athletes feel negative emotions that weaken their performance (Hanin, 2000; Robazza, 2006; Robazza, Pellizzari, Bertollo & Hanin, 2008). It was found that psychological skill help athletes maximize their physical skills (Smith et al., 1995). Using coping strategies to manage stress in competition, it is possible to increase sports performance, which declared studies investigating the relationship between coping strategies and sports performance in various sports, such as golf (Christensen & Smith, 2016), baseball (Kimbrough, Debolt & Balkin, 2007), basketball (Karamousalidis, Bebetsos & Laparidis, 2006; Vidic, Martin & Oxhandler, 2017), cricket (Jooste, Van Wyk & Steyn, 2013), football (Jooste et al., 2014) or volleyball (Schellenberg, Gaudreau & Crocker, 2013).

There are inventories that help sports psychologists categorize athletes into groups according to a level of personality traits. One of them is Five-factor Personal Inventory NEO-FFI which evaluates 5 dimensions of athlete´s personality (Costa & McCray, 1992). The conscientiousness factor describes individual's task orientation and goal-orientation behaviors as well as their level of impulse control (Trninic, Barancic & Nazor, 2008). An individual's level of adventurous and self-seeking qualities assesses openness to experience factor (McCrae & Sutin, 2007). The agreeableness factor accounts for the quality of relationships with others and explains how individual acts towards others (Trninic et al., 2008). This inventory evaluates two ambivalent items of introversion and extroversion, as well as emotional lability and emotional stability. In case that athletes achieve a high score in these items it means that they are extroverted and emotionally labile. Otherwise, when athletes score low means they are introverted and emotionally stable (Costa & McCray, 1992; Ruisel & Halama, 2007). This inventory has been used in various sports, such as tennis (Kaplánová, 2018), rhythmic gymnastics (Lazarević, Petrović & Damnjanović, 2012), football (Mirzaei, Nikbakhsh & Sharififar, 2013) or ice hockey (Conway, 2016).

In general, sports such as gymnastics puts high demands on gymnasts already at an early age. It was found that elite gymnasts who spent long hours exercising and developing physical skills scored higher in personality inventory in comparison to amateur gymnasts, specifically in items of openness, agreeableness and consciousness (Lazarević et al., 2012). It seems that gymnasts who were more organized, responsible, imaginative and artistically based achieved better results in comparison to gymnasts who were irresponsible, careless and narrow interests. It was also found that young gymnasts achieved a low score in item monitoring extroversion and introversion. It means that gymnasts are more introverted, quiet, reserved (Lazarević et al., 2012) compared to other sports, such as ice hockey, where hockey players achieved a higher score in the same item. It seems that hockey players are more active, energetic, enthusiastic, talkative what may be due to the nature of team sport (Conway, 2016). These findings provide valuable knowledge which may help coaches develop psychological skills athletes which declared many studies in sports (Kaplánová, 2018; Lazarević et al., 2012; Mirzaei et al., 2013).

Although there is study investigating personality traits of children from perspective five-factor model of personality in rhythmic gymnastics (Lazarević et al., 2012), as well as study monitoring psychological skills of gymnasts (Daroglou, 2011). Our study is an exploratory study because there is no study investigating personality traits of adolescents and adults of gymnasts from perspective five-factor model of personality, as well as there is no study investigating the tightness of relationship between personality traits and coping strategies to manage stress in gymnastics. The aim of our study is to investigate the relationship between personality structure of gymnasts, namely emotional lability/stability, extroversion/introversion, conscientiousness, agreeableness and openness to experience and coping strategies to manage stress. Based on previous findings, we have formulated a research question. Are there any relationships between five-factors personality traits of gymnasts, namely emotional lability/stability, extroversion/introversion, conscientiousness, agreeableness and openness to experience, and all subscales of psychological skills, namely coping with adversity, coachability, concentration, confidence and achievement motivation, goal setting and mental preparation, peaking under pressure, as well as subscale of freedom from worry?

METHODS

The study sample consisted of 56 elite Slovak gymnasts (16 men and 40 women) aged from 15 to 26, with an average age of 19.34 ± 3.15 years. All gymnasts were registered in the Slovak Gymnastics Federation (SGF) and had experiences with national or international competitions in categories: sport aerobics (n = 12), rhythmic gymnastics (n = 10), women artistic gymnastics (n = 10), men artistic gymnastics (n = 6) and gymnastics for all (n=18). The gymnasts trained in average for 25 hours a month (SD = 5.24).

Athletic Coping Skills Inventory (ACSI-28) is a validated tool that commonly used to discover the level of coping skills among athletes. It is composed of 28 items and 7 sport specific sub-scales, which are used to reflect a multidimensional construct of psychological skills. Each statement in the inventory describes experiences of other athletes, which prompts the participant to indicate the frequency of similar experiences. The response format for each item consists of a linear 4-point scale ranging from 0 (almost never) to 3 (almost always). Scores range from a low of 0 to a high of 12 on each subscale, with higher scores indicating greater strengths on that subscale. The score for the total scale ranges from a low of 0 to a high of 84, with higher scores signifying greater strength. Description of sub-scales of Athletic Coping Skills Inventory ACSI-28 (Smith et al., 1995) we present in table 1.

Table 1
Description of sub-scales of Athletic Coping Skills Inventory ACSI-28 (Smith et al., 1995).

Sub-scales	Athletic Coping Skills Inventory ACSI-28
1 Coping with Adversity	This subscale assesses if an athlete remains positive and enthusiastic even when things are going badly, remains calm and controlled, and can quickly bounce back from mistakes and setbacks.
2 Coachability	Assesses if an athlete is open to and learns from instruction and accepts constructive criticism without taking it personally and becoming upset.
3 Concentration	This subscale reflects whether an athlete becomes easily distracted or is able to focus on the task, even when adverse or unexpected situations occur.
4 Confidence and Achievement Motivation	Measures if an athlete is confident and positively motivated, consistently gives 100% during practices and competition, and works hard to improve his/her skills.
5 Goal Setting and Mental Preparation	Assesses whether an athlete sets and works toward specific performance goals, plans and mentally prepares for competition, and clearly has a future plan for performing well.
6 Peaking under Pressure	Measures if an athlete is challenged rather than threatened by pressure situations and performs well under pressure.
7 Freedom from Worry	Assesses whether an athlete puts pressure on him- or herself by worrying about performing poorly or making mistakes; worry about what others will think if he or she performs poorly.

Table 2
Description of dimensions of Five-factor personal inventory NEO-FFI(Ruisel & Halama, 2007).

Five-factor personal inventory NEO-FFI		
People with high scores	*Dimensions*	*People with low scores*
Anxious, Touchy, Unstable, Worrying	Emotional Lability vs. Stability	Stable, Calm, Contented, Unemotional
Active, Energetic, Enthusiastic, Talkative	Extroversion vs. Introversion	Quiet, Reserved, Silent, Withdrawn
Artistic, Original, Imaginative, Insightful	Openness to Experience	Narrow Interests, Commonplace, Simple, Shallow
Appreciative, Forgiving, Generous, Kind	Agreeableness	Cold, Thankless, Stingy, Unkind
Organized, Responsible, Reliable, Planful	Conscientiousness	Disorderly, Irresponsible, Forgetful, Careless

The personality structure of gymnasts was investigated by Slovak version of Five-factor Personal Inventory NEO-FFI (Costa & McCray, 1992) revised by Ruisel and Halama (2007). The inventory was translated into more than 30 languages across the world, what ensures wider comparability of results even in different areas of sport. It is composed of 60 items and 5 dimensions which are used to describes the structure of personality. The inventory monitors personality dimensions: (1) emotional lability/stability, (2) extroversion/introversion, (3) openness to experience, (4) agreeableness and (5) conscientiousness. Each statement in the inventory describes experiences of other people, which prompts the participant to indicate the frequency of similar experiences. The gymnasts recorded the answer on a linear 5-point scale (0 – strongly disagree, 1 – disagree, 2 – neutral, 3 – agree, 4 – strongly agree). Scores range from a low of 0 to a high of 48 on each dimension, the score for the total scale ranges from a low of 0 to a high of 240. Descriptive characteristics of people with high/low scores in Five-factor Personal Inventory NEO-FFI (Ruisel & Halama, 2007) we present in table 2.

Out of respect for research ethics data were collected anonymously with informed consent of the respondents or their legal representatives. Slovak Gymnastic Federation (SGF) and gymnasts involved in the research, were informed about the goals and objectives of data collection and their use for research purposes. Data were collected and administered by sports psychologist. The study used the correlational research design in order to assess the closeness of relationships between the personality structure of gymnasts and coping strategies to manage stress. We used a correlation analysis with Spearman correlation coefficient, which is used in the non-parametric distribution of data (Daniel, 1990). The tightness of relationship was assessed for 5% and 1% of the level of statistical significance. Cronbach's alpha indices were calculated for both measures employed in the study to ensure the reliability of these inventories for the particular data-set (Cronbach, 1951). The data were analyzed using the SPSS statistical program (Version 23 for Windows, IBM, Armonk, NY, USA).

RESULTS

The internal consistency of Five-factor personal inventory NEO-FFI reached the following values: emotional lability/stability $\alpha = .87$; extroversion/introversion $\alpha = .76$; agreeableness $\alpha = .74$, conscientiousness $\alpha = .82$ and openness to experience $\alpha = .67$. Although item of openness to experiences reached internal consistency below .70, we consider this value of reliability as acceptable because is 0.1 higher than the average for the Slovak sample in the standard version of Five-factor personal inventory NEO-FFI (Ruisel & Halama, 2007). The internal consistency of Athletic coping skills inventoryACSI-28 reached the following values: coping with adversity α = .78, coachability α = .77, concentration α = .70, confidence and achievement motivation α = .72, goal settings and mental preparation α = .72, peaking under pressure α = .75 and freedom from worry α = .78.

Descriptive statistics were used to give an indication of mean scores on subscales of psychological skills, as well as five-factor of personality structure of gymnasts. The descriptive statistics also included a range of both scales and standard deviations. The results of descriptive statistic suggested that it is impossible to determine exactly whether the adolescent and adult gymnasts are more emotionally labile or stable because they on average scored exactly at the border of emotional lability and stability what we presented in table 3.

Table 3
Descriptive statistics of gymnasts.

	Range of the scale	M	SD
Five-factor Personal Inventory NEO-FFI			
1 Emotional Lability/Stability	0-48	23.96	9.94
2 Extroversion/Introversion	0-48	16.79	7.03
3 Openness To Experience	0-48	19.89	6.82
4 Agreeableness	0-48	19.66	7.23
5 Conscientiousness	0-48	13.73	7.48
Total Score	0-240	94.04	17.84
Athletic Coping Skills Inventory ACSI-28			
1 Coping With Adversity	0-12	7.14	2.28
2 Coachability	0-12	8.70	2.56
3 Concentration	0-12	7.32	2.05
4 Confidence and Achievement Motivation	0-12	7.54	1.98
5 Goal Setting and Mental Preparation	0-12	7.52	2.31
6 Peaking Under Preassure	0-12	5.93	2.59
7 Freedom From Worry	0-12	5.82	3.21
Total Score	0-84	49.96	9.12

Table 4
Results of correlation analysis between Five-factor personal inventory NEO-FFI and Athletic Coping Skills Inventory ACSI-28.

	Five-factor personal inventory NEO-FFI				
Athletic Coping Skills Inventory ACSI-28	Emotional Lability/Stability	Extroversion/ Introversion	Openness to Experiences	Agree-ableness	Conscien-tiousness
1 Coping with Adversity	.41**	**-.32***	.22	-.19	-.26
2 Coachability	.10	**-.37****	.02	-.03	-.25
3 Concentration	.26	-.18	**.39****	-.08	-.04
4 Confidence and Achievement Motivation	.20	**-.32***	**.33***	.05	-.16
5 Goal Setting and Mental Preparation	-.08	-.15	.14	-.05	-.04
6 Peaking under Pressure	.23	-.25	**.29***	.08	-.12
7 Freedom from Worry	.46**	.15	.10	-.01	-.20

Note: *p<.05, **p<.01

In table 3 also we can see that in other items they achieved low scores which indicate a preference for introversion, less openness to experiences, as well as less agreeableness and conscientiousness. In second inventory gymnasts achieved the highest score in subscale of coachability. They also have higher scores also in items coping with adversity, concentration, confidence and achievement motivation, as well as goal setting and mental preparation. In last items called peaking under pressure and freedom from worry gymnasts achieved low scores. In table 3 are also presented mean of total scores which adolescent and adult gymnasts achieved in both inventories. The results of correlation analysis between the personality structure of gymnasts and their coping strategies to manage stress are presented in table 4.

The results of our study showed that there is the closeness of relationships between the personality structure of gymnasts and coping strategies to manage stress. We found a positive significant correlation between coping with adversity and emotional lability/stability (r_s = .41; p = .002) and negative significant correlation between coping with adversity and extroversion/introversion (r_s = -.32; p = .018). We also found a negative significant correlation between coachability and extroversion/introversion (r_s = -.37; p = .005). Other negative statistically significant correlations were found between concentration and openness to experience (r_s = -.39; p = .003), as well as between peaking under pressure and openness to experience (r_s = -.29; p = .032). Positive statistically significant correlations were also found between freedom from worry and emotional lability/stability (r_s = .46; p = .000). Negative statistically significant correlations were also found between confidence and achievement motivation and extroversion/introversion (r_s = -.32; p = .016) and positive significant correlation between confident and achievement motivation and openness to experience (r_s = .33; p = .014). We found that 6 of the 7 subscales of coping strategies to manage stress are in relationship to personality structure of the gymnasts, namely emotional lability/stability, extroversion/introversion and openness to experience. We also found that none of subscales of coping strategies to manage stress is in relationship to an agreeableness and conscientiousness of gymnasts.

DISCUSSION

In present, there are only few studies investigating personality traits of elite athletes from perspective five-factor model of personality (Kaplánová, 2018, Mirzaei et al., 2013). Although there is a study of personality traits of children in rhythmic gymnastics (Lazarević et al., 2012) until now there is no study monitoring personality traits of elderly gymnasts in adolescence or adulthood. Our study is one of the first which monitor a level of personality traits of elderly gymnasts from perspective five-factor model of personality. Analysis of this model showed that gymnasts achieved very low scores in items of extroversion/introversion and agreeableness what means that adolescent and adult gymnasts are more introverted, quieter and reserved compared to athletes of team sports. The preference of extroversion and agreeableness in team sports, such as football or ice hockey, may also be caused by the nature of this type of sport where there is a need for player cooperation (Mirzaei et al., 2013; Conway, 2016). Low level of conscientiousness and openness to experience suggests the needs for developing self-seeking qualities, as well as self-disciplined and ambitious of gymnasts (McCrae & Sutin, 2007). The results of our study also showed that still is not possible to interpret clearly that adolescent and adult gymnasts are more emotionally labile or stable because they on average scored exactly at the border of this item which is consistent with findings in tennis (Kaplánová, 2018). This is mainly due to a wide range of responses monitoring emotional lability/stability which in the case of football players is more uniform (Mirzaei et al., 2013).

Previous research showed that psychological skills change according to requirements in sport what confirmed studies in basketball (Skourtanioti & Bebetsos, 2008), badminton (Bebetsos & Antoniou, 2003) or archery (Young & Knight, 2014). Therefore, it is necessary to monitor coping strategies to manage stress not only for children´s gymnasts (Daroglou, 2011) but also for elderly elite gymnasts. The results of our study showed that adolescent and adult gymnasts scored higher in items of coachability, coping with adversity, concentration, confident and achievement motivation, goal setting and mental preparation, peaking under pressure, as well as freedom from worry compared to young elite gymnasts competed at the Hellenic Championship of Rhythmic Gymnastics (Daroglou, 2011). The highest differences between young gymnasts and elderly gymnasts were recorded in subscale of coachability. On the contrary, the smallest difference was recorded in subscale of freedom from worry. It seems that adolescent and adult gymnasts are more openness and ability to listen to coach´s instructions than young gymnasts, but they still worry about others will think if they perform poorly. On the basis of previous findings, there is a well-founded need for a better understanding to develop of the psychological skills which can reduce stress in competition and increase sports performance of gymnasts (Smith et al., 1995).

Our study is one of the first which found out a relationship between personality traits of adolescent and adult gymnasts and coping strategies to manage stress. It seems that there are some personality traits who predispose athletes to achieve better results in competition (Christensen & Smith, 2016; Jooste et al., 2014; Kaplánová, 2018). Analysis of a five-factor model of personality showed that is very important to focus on three personality traits of gymnasts, mainly emotional lability/stability, extroversion/introversion and openness to experience. Ability to remain calm in stressful situations and also know to quickly bounce back from mistakes or setbacks is one of the important factor successful performance in competition (Smith et al., 1995). We found out that a high level of this psychological skill is in relation to a high level of emotional lability, as well as a high level of introversion of gymnasts. It seems that gymnasts who are more reserved, silent, focus on subjective experiences and trusting their intuition can be more resistant against mistakes or failures. High level of introversion also predisposes adolescent and adult gymnasts to listen to coach and accepts constructive criticism without taking it personally and becoming upset. The results of our study also showed that gymnasts with a high level of openness to experience are probably able to focus on the task better, even when adverse or unexpected situations occur. This may be due to the fact that adolescent and adult gymnasts are more artistically gifted, their life is full of experiences that survive more markedly. Good sports performance in competition is also depending on confidence and achievement motivation (Smith et al., 1995). We found out that gymnasts who have a high level of introversion and a high level of openness to experiences are probably able to be positively motivated and works hard to improve their skills. High level of openness to experience also predispose adolescent and adult gymnasts a good stress management and they are able to give better performance compared to athletes with a low level of openness to experience. We also found that gymnasts with a high level of emotional lability are probably less worried about the bad things that could happen to them.

Based on previous research findings, we can formulate the following recommendations for practice. The results of our study showed that adolescent and adult gymnasts are more introverted, quieter and more reserved what is probably necessary given the requirements of this type of sport. Introverted people are more inclined to keep their feelings to themselves and deal with issues alone compared to extroverted people (Leary & Buckley, 2000). Introverted people also prefer a few close relationships compared to extroverted people who spend a lot of time interacting with people in social situations (McCrae & Sutin, 2007). It seems gymnasts are capable to create a close relationship with another person but it takes them for a while. The introverted people may give off the impression that they do not want to receive attention from others (Leary & Buckley, 2000). Therefore, the coach should be patient in building a relationship with the gymnast. A close confidential relationship between a coach and a gymnast based on honesty, openness and understanding can be one of the ways how to create the emotional comfort of a gymnast not only during the training but also in competition. Furthermore, we also found that a higher level of openness to experience correlate with concentration, confidence and achievement motivation. Thus, it is necessary to work on an individual's level of adventurous and self-seeking qualities of gymnasts which can improve sports performance of gymnasts under pressure. The results suggest that a higher level of openness to experience can help the gymnast easier to cope with the pressure in the competition.

The results of Spearman correlation also showed a tightness relationship between emotional lability and subscales coping with adversity and freedom from worry. It seems that the dose of emotion and impulsivity inserted into performances helps to quickly bounce back from mistakes or setbacks. Gymnasts probably are able to remember emotional performances longer and thus avoid repeated mistakes.

Limits

Although our study sample of elite gymnasts considered as representative for the conditions of Slovakia. In the future, we recommend exploring a wider research sample and compare results with findings in other countries.

CONCLUSIONS

The results of our study showed that coping strategies to manage stress vary according to levels of emotional lability/stability, extroversion/introversion and openness to experience of gymnasts. A better understanding of the personality traits and coping strategies to manage stress to extend knowledge of sports psychology and may help coaches and sports psychologists to develop effective interventions and assist athletes to attain optimal performances in competitions.

REFERENCES

Bali, A. (2015). Psychological factors affecting sports performance. *International Journal of Physical Education, Sports and Health, 1*(6), 92-95.

Bebetsos, E. (2015). Psychological skills of elite archery athletes. *Journal of Human Sport and Exercise, 10*(2), 623-628.

Bebetsos, E., & Antoniou, P. (2003). Psychological skills of Greek badminton athletes. *Perceptual and Motor Skills, 97*(3), 1289 – 1296.

Bhambri, E., Dhillon, P.K., & Sahni, S.P. (2005). Effect of psychological interventions in enhancing mental toughness dimensions of sports persons. *Journal of the Indian Academy of Applied Psychology, 31*(1-2), 63-68.

Conway, B. H. (2016). *Investigating the relationship between personality traits and athletic performance among elite hockey players.* EWU Masters Thesis Collection. 347.

Costa Jr, P. T., & McCrae, R. R. (1992). *Revised NEO Personality Inventory (NEO-PI-R) and NEO Five-Factor Inventory (NEO-FFI) professional manual.* Odessa, FL: Psychological Assessment Resources.

Cronbach, L. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika, 16*(3), 297 – 334.

Daniel, W.W. (1990). *Spearman rank correlation coefficient. Applied nonparametric statistics*. Boston: PWS-Kent.

Daroglou, G. (2011). Coping skills and self-efficacy as predictors of gymnastic performance. *Sport Studies and Sport Psychology, 14*(1), 1-6.

Hanin, Y. L. (2000). *Emotions in sport*. Champaign, IL: Human Kinetics.

Christensen, D. S., & Smith, R. E. (2016). Psychological coping skills as predictors of collegiate golf performance: Social desirability as a suppressor variable. *Sport, Exercise, and Performance Psychology, 5*(1), 67-80.

Jooste, J., Steyn, B. J. M., & Van Den Berg, L. (2014). Psychological skills, playing positions and performance of African youth soccer teams. *South African Journal for Research in Sport, Physical Education and Recreation, 36*(1), 85-100.

Jooste, J., Van Wyk, J. G. U., & Steyn, B. J. M. (2013). The relationship between mental skills and level of cricket participation. *African Journal for Physical Health Education, Recreation and Dance, 19*(1), 254-265.

Kaplánová, A. (2018). Individual differences of sensitivity of tennis players to injustice situations from the perspective of the five-factor model of personality Big Five Theory. *Acta Gymnica, 48*(1), 21-26.

Karamousalidis, G., Bebetsos, E., & Laparidis, K. (2006). Psychological skills of Greek basketball players. *Inquiries in Sport & Physical Education, 4*(3), 442 – 448.

Kimbrough, S. K., Debolt, L., & Balkin, R. (2007). Use of the Athletic Coping Skills Inventory for prediction of performance in collegiate baseball. *The Sport Journal, 10*(1).

Lazarević, L. B., Petrović, B., & Damnjanović, K. (2012). Personality traits of young gifted rhythmic gymnasts. *Physical Education and Sport, 10*(2), 115-126.

Leary, M. R., & Buckley, K. E. (2000). Shyness and the pursuit of social acceptance. In W.R. Crozier (Ed.), *Shyness: Development, consolidationa and change* (pp. 139-153). New York: Routledge.

Mahoney, M., & Avener, M. (1977). Psychology of the elite athlete: An exploratory study. *Cognitive Therapy and Research, 1*(2), 135 – 141.

McCrae, R. R., & Sutin, A. R. (2007). New frontiers for the five-factor model: A preview of the literature. *Social and Personality Psychology Compass, 1*, 423-440.

Mirzaei, A., Nikbakhsh, R., & Sharififar, F. (2013). The relationship between personality traits and sport performance. *European Journal of Experimental Biology, 3*(3), 439 – 442.

Robazza, C. (2006). Emotion in sport: An IZOF perspective. In S. Hanton & S. D. Mellalieu (Eds.) *Literature Reviews in Sport Psychology* (pp. 127 – 158). New York: Nova Science.

Robazza, C., Pellizzari, M., Bertollo, M., & Hanin, Y. L. (2008). Functional impact of emotions on athletic performance: Comparing the IZOF model and the directional perception approach. *Journal of Sports Sciences, 26*(10), 1033-1047.

Ruisel, I., & Halama, P. (2007). *NEO Päťfaktorový osobnostný inventár*. Praha: Testcentrum-Hogrefe.

Schellenberg, B. J., Gaudreau, P., & Crocker, P. R. (2013). Passion and coping: Relationships with changes in burnout and goal attainment in collegiate volleyball players. *Journal of Sport & Exercise Psychology, 35*(3), 270-280.

Skinner, N., & Brewer, N. (2004). Adaptive approaches to copetition: Challenge appraisals and positive emotion. *Journal of Sport & Exercise Psychology, 26*, 283-305.

Skourtanioti, G., & Bebetsos, E. (2008). Measurement of athletic coping skills among Greek thrower athletes. 16th International Congress of Physical Education and Sport, 16 - 18 May Komotini, Greece. Congress Proceedings. University Press.

Smith, R. E., Schutz, R. W., Smoll, F. L., & Ptacek, J. (1995). Development and validation of a multidimensional measure of sport-specific psychological skills: The Athletic Coping Skills Inventory – 28. *Journal of Sport and Exercise Psychology, 17*, 379 – 398.

Trninic, V., Barancic, M., & Nazor, M. (2008). The five-factor model of personality and aggressiveness in prisoners and athletes. *Journal of Kinesiology, 40*(2), 170-181.

Vidic, Z., Martin, M. S., & Oxhandler, R. (2017). Mindfulness intervention with a U.S. women's NCAA Division I basketball team: Impact on stress, athletic coping skills and perceptions of intervention. *The Sport Psychologist, 31*(2), 147-159.

Young, P.R., & Knight, E.L. (2014). Use of psychological skills by risk sport athletes. *Journal of Human Performance in Extreme Enviroments. 11*(2), 1-9.

Corresponding author:

Adriana Kaplánová
Faculty of Physical Education and Sport
Comenius University in Bratislava
Nábrežie armádneho generála Ludvíka Svobodu 42e98/9,
814 69 Bratislava-Staré Mesto
Slovakia
E-mail: kaplanova8@uniba.sk

SHORT HISTORICAL NOTES XV

Anton Gajdoš, Bratislava, Slovakia & Michal Babela, Faculty of Physical Education and Sports, Bratislava, Slovakia

Ph.D. Anton Gajdoš born on 1.6.1940 in Dubriniči (today Ukraine) lives most of his life in Bratislava (ex TCH, nowadays SVK). He comes from gymnastics family (his brother Pavel have world championship medals) and he devoted his life to gymnastics. His last achievement is establishment of Narodna encyklopedia športu Slovenska (www.sportency.sk). Among his passion is collecting photos and signatures of gymnasts. As we tend to forget old champions and important gymnasts, judges and coaches, we decided to publish part of his archive under title Short historical notes. All information on these pages is from Anton's archives and collected through years.

ALBERT VAGARŠAKOVIČ AZARJAN (February, 11 1929 Kirovakan, Armenia, ex-Soviet Union)

Armenian Azarjan was born in hard times during WWI and WWII. Lucky he was young enough to miss combats of the WWII, but he had to survive as his father died when Albert was 14. He started to work to support his family, and again something bad is not necessary so negative for future life. He worked as ironsmith and it is no wonder how he became so strong in arms. Comparing to nowadays-young gymnasts, who start with gymnastics at age of 5 or 6, he started with gymnastics at age of 17. In addition, he became gymnast by pure luck. Armenian gymnasts had a performance at his town and after exhibition Albert and friend tried to perform what they saw. As Albert was excellent in repeating movements on rings, gymnasts invited him to join at Erevan (Armenia capitol). After three years of training, he won Armenian championship on rings.

The first international competition he participated was World Championship 1954 in Roma (Italy). Already at the first attempt he won the title on rings, and with Soviet Union team, besides he was also very good in all around, placed to 4^{th} – 5^{th} and 4^{th} on vault.

At European championship in 1955 (Frankfurt, Germany) he won rings, parallel bars and took silver on horizontal bar.

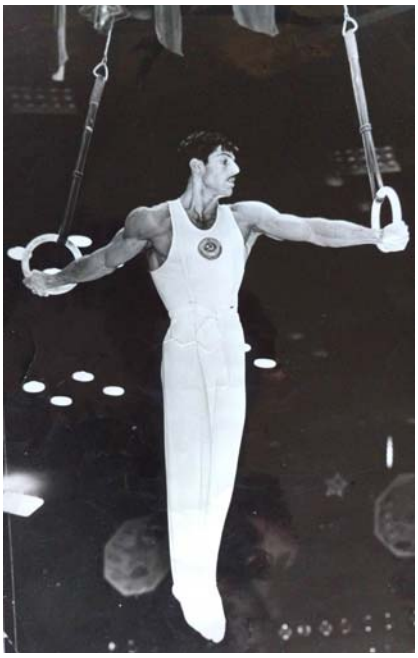
Next year at OG in Melbourn (1956, Australia) he won rings and team title. Melbourn he left with another two good results as he was 5^{th} on parallel bars and 7^{th} in all around.

In Albert's time two major comeptitions OG and WC were organized in four years timespan and between two OG were WC. So in a row of Albert's competitions WC 1958 in Moscow

(Russia, ex-Soviet Union) he was the best on rings and with team, and improved his high bar gymnastics to the second place.

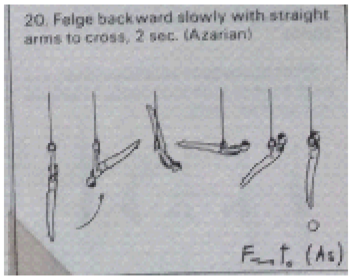
OG in Rome (1960, Italy) were Albert's last major competition, and again he was the best on rings, and with team he won silver.

Albert left to the international gymnastics two major inventions on rings, which remained even up to day as something very difficult.



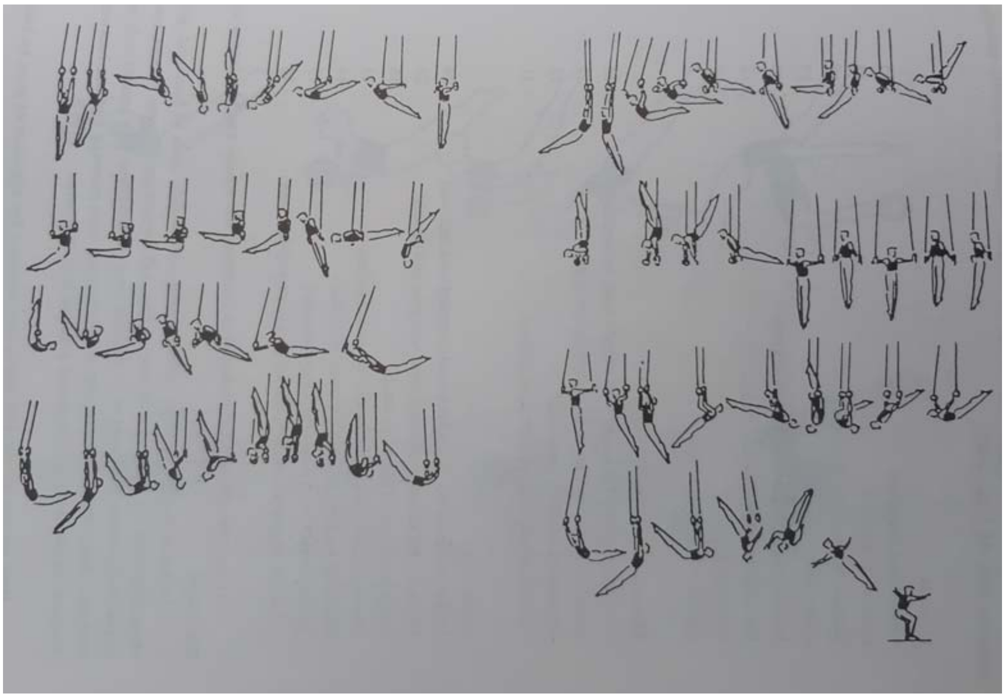
First time he showed his cross (Azarjan cross) at Soviet Union championship in 1953, his exercise was not evaluated as his exercise consisted of something which was declared as "unprecedented". Up to now, no other gymnast tried to search new elements with such arms position (forward and backward, despite there are possibilities).

His second invention was slow felge backward with straight arms to cross, and he performed this element at WC 1954 for the first time at major competitions.



His son Eduard (he had also two daughters) followed his steps in gymnastics and was a member of wining team at OG 1980 in Moscow.

Armenian Sport Journalists Federation declared Albert Azarjan as the top Armenian athlete of 20th century. He was also decorated by Armenian Prime Ministers and Presidents at his anniversaries (70th, 75th, 80th).



Albert Azarjan winning exercise on rings at 1954 WC in Rome as draw from Tadamiki Mori in Akitomo Kaneko book: Exercises on Rings, Fumaido, Tokyo, 1971, page 127

Happy 90th birthday!

Slovenski izvlečki / Slovene Abstracts

Sarita Bacciotti, Adam D.G., Baxter-Jones, Adroaldo Gaya, José Maia

GIBALNA UČINKOVITOST BRAZILSKIH ORODNIH TELOVADK: VPOGLED V VEČSTOPENJKO RAZČLENJENOST

Namen raziskave je bil raziskati spremenljivke, ki pojasnjujejo razlike v gibalnih sposobnostih telovadk (MP). Vzorec je sestavljalo 249 telovadk (68 vrhunskih; 181 srednje dobrih), starih od 9 do 20 let, razdeljenih v štiri starostne kategorije: 9-10 let (n = 98); 11-12 let (n = 72); 13-15 let (n = 64) in 16 in več (n = 15). Telovadke so članice iz 26 brazilskih društev iz šestih različnih brazislkih zveznih držav. Celotni rezultat meritev sposobnosti nadarjenih je bil uporabljen za oceno telovadk, ki temelji na sklopu sedmih meritev: držanje stoje na rokah, odkolebi v opori, plezanje po vrvi, skleki v stoji na rokah, gibljivost v medeničnem obroču, dviganje nog in 20 metrski tek. Zbrani so bili tudi podatki o sestavi telesa, biološki zrelosti in podatki o zgodovini vadbe, pa tudi značilnosti društva, njegove opreme, tekmovanja, vaditeljih in razpoložljivosti programov za izbor nadarjenih. Podatki so bili razčlenjeni s pristopom modeliranja na več ravneh. Posamezne značilnosti telovadk so razložile 39% spremenljivosti ocene gibalnih sposobnosti, od katere je bilo 32% povezanih z neodvisnimi učinki starosti, tekmovalne ravni, maščobne mase, pojavljanja menarhe in ur vadbe na teden ($p <0,05$). Značilnosti društva pojasnjujejo 61% celotne spremenljivosti gibalne sposobnosti telovadk; 96% od tega je bilo povezanih s klubskimi značilnostmi, vaditelji in izborom nadarjenih. Ti rezultati krepijo pomembno vlogo sočasnih učinkov in poudarjajo potrebo po vlaganju v opremo društev, idealno v strokovnem znanju vaditeljev in učinkovitih izbirnih vadbah. Takšne naložbe bi morale omogočiti izboljšanje in razvoj telovadne poti med njihovo življenjsko pot.

Ključne besede: telesna pripravljenost, gibalne sposobnosti, telovadno društvo.

George Dallas, Alkmini Savvathi, Konstantinos Dallas, Maria Maridaki

VPLIV 6-TEDENSKE VADBE ZIBANJA CELEGA TELESA NA MIŠIČNO UČINKOVITOST MLADIH NETEKMOVALNIH TELOVADK

Namen je bil raziskati učinke 6-tedenskega zibanja celotnega telesa na delovanje mišic in gibljivost telovadk. Dvaindvajset mladih zmerno uspešnih telovadk, ki so se prostovoljno odločili za sodelovanje v študiji, so se ločili na skupino, ki je sodelovala pri zibanju ali skupino brez zibanj glede na njihovo vadbo. Izvedeno je bilo 6-tedensko zibanje celotnega telesa, 3-krat na teden in so vključevale ekscentrične in koncentrične čepe na zibajoči plošči, pri čemer so udeleženke izvajali tri vaje na zibajoči plošči, medtem ko je bila pri nadzorni skupini zibajoča plošča izključena. Na začetku in po koncu 6-tedenske vadbe je bilo izvedenih pet meritev učinkovitosti (hitrost 20 m, predklon, skok is čepa, skok iz stoje na stegnjenih nogah, in skok z ene noge (desna noga in leva noga). Glede na rezultate je bil ugotovljen pomemben medsebojni učinek med skupino in hitrostjo ter skoka iz čepa. Nasprotno, ugotovljen je bil pomemben glavni učinek hitrost teka, skoka iz čepa, skoka iz stoje na stegnjenih nogah, in skoka z ene noge. Zaključno je bilo ugotovljeno, da so zibanja celega telesa učinkovita metoda za izboljšanje uspešnosti skočne moči mladih telovadk.

Ključne besede: eksplozivna moč, vadba, poskus, orodna telovadba.

Ole H. Hansen, Lars G. Hvid, Per Aagaard, Kurt Jensen

MEHANIČNE ZNAČILNOSTI MIŠIC NOG PRI VRHUNSKIH AKROBATIH SKUPINSKIH AKROBATSKIH SESTAV

Skupinske akrobatske sestave (TG) se razlikuje od orodne telovadbe, saj se izvaja v skupinah, ki vključujejo 6-12 udeležencev, ki tekmujejo v akrobatskih predstavah v treh disciplinah: skakanje z male prožne ponjave, skakanje na akrobatski stezi in sestavo na parterju. Telesne zahteve, ki jih zahtevajo športniki TG, večinoma ostajajo neznane in jih verjetno narekujejo posebne discipline in uporabljena oprema. Namen študije je bil opisati fiziološke zmožnosti z raziskovanjem mehanske funkcije mišic spodnjih okončin in povezanostjo z delovanjem TG pri 24 vrhunskih (12 moških, 12 ženskih) akrobatov. Metode: izmerjene so bile telesne značilnosti, 25m tek, ponavljajoči se skoki (RJ), skok iz stoje na stegnjenih nogah (CMJ), globinski skok z višine 48 cm (DJ48), maksimalna izometrična mišična moč noge (MVC) in hitrost razvoja sile (RFD)). Rezultati: Za vse spremenljivke, razen MVC, so bile opažene pomembne spolne razlike (p <0,05). Skupni časi sprinta je bil pri moških 3,36 ± 0,1s v primerjavi s 3,70 ± 0,1 s pri ženskah, višina CMJ 0,51 ± 0,05 v primerjavi s 0,41 ± 0,03 metra, višina odriva DJ48 0,43 ± 0,06 v primerjavi z 0,34 ± 0,06 m, brez razlike v koncentričnem vrhu proizvodnja energije med CMJ in DJ48. MVC je bil pri moških 38,3 ± 9,9 N / kg, pri ženskah pa 36,4 ± 9,2 N / kg. Pri ženskah gimnastiki so bile ugotovljene korelacije (r2 = 0,41-0,46, p <0,05) med skoki z male prožne ponjave in skoki na akrobatski stezi z zmožnostjo hitrega teka. Pri moških so se pojavile povezave (r2 = 0,44, p <0,05) med skoki z male prožne ponjave in relativno RFD (% MVC / s). Sklep: ugotovljena je zmerna povezanost med uporabo mišic spodnjih okončin in tehničnim znanjem, kar kaže na to, da se uspešnost v vrhunski skupini akrobatov opira tudi na druge dejavnike, kot je izolirana mehanska mišična uporaba.

Ključne besede: skupinske akrobatske sestave, največja moč, tek, skok.

Stefan Kolimechkov, Iliya Kiuchukov, Iliya Janev, Lubomir Petrov, Albena Alexandrova, Dilyana Zaykova, Emil Stoimenov

VPLIV TELOVADBE NA ZDRAVJE IN TELESNO PRIPRAVLJENOST MLADIH TELOVADK IN TELOVADCEV

Orodno telovadbo lahko vadimo že od zgodnjega otroštva in razvijamo glavne sestavine telesne pripravljenosti. Cilj te študije je bil oceniti telesno pripravljenost mladih telovad-cev/-k iz Bolgarije. Skupaj jih je bilo 161 (81 žensk in 80 moških), ki so bili razdeljeni v tri starostne skupine (od 5-8, 9-11 in 12-15 let), s športnimi izkušnjami od 12 do 180 mesecev. Vsi udeleženci so izpolnili razširjeno različico sklopa za meritev gibalnih sposobnosti Alpha-Fit, pri čemer so se evropske norme uporabile za izračun percentilnih rezultatov za vsako meritev. Delež rezultatov v odstotkih glede na starost v starostni skupini 9-11 in 12-15 je bil bistveno nižji od 50. stotina mednarodnih norm za moške in ženske telovadke. Telovdci so pokazali bistveno nižje telesne maščobe, le en telovadec je bil ocenjen s prekomerno telesno težo, dva sta bila razvrščena kot debela. Ocenjevanje stotinov skoka v daljino in 4x10 m teka v skupinah je bilo bistveno večje od 50. stotina. V vseh ženskih skupinah so bili rezultati VO2max višji od 50. stotina, medtem ko se moški niso razlikovali od 50. stotina, razen v starostnem razponu 5-8 let. Orodna telovadba izboljšuje gibalne sposobnosti in pozitivno vpliva na telesni razvoj otrok. Telovadci in telovadke so imele v večini parametrov boljšo telesno pripravljenost v primerjavi z vrstniki.

Ključne besede: telesna pripravljenost, orodna telovadba, Alpha-Fit.

Toshiyuki Fujihara, Pierre Gervais, Gareth Irwin

RAZDALJA MED GLAVO IN PRSTI STOPALA KOT PREPROSTA MERA RAZPONA ODBOČNIH KOLES NA KONJU Z ROČAJI

Za razvoj znanstveno veljavnih orodij za spremljanje uspešnosti v praksi je ključno vprašanje, kaj meriti. Pomembnost temeljnih veščine, ki jo imenujemo odbočno kolo, je na konju z ročaji nesporna in ena od ključnih lastnosti koles je razpon gibanja. Prejšnje študije so uporabile kote med sklepi ali velikost poti dela telesa za ovrednotenje razpona, vendar smo domnevali, da razdalja med dvema točkama, in sicer glavo in prsti na stopalih, lahko nadomesti ostale kljub njeni enostavnosti. Ta študija je preučevala uporabo razdalje med glavo in prsti na stopalih, ki jo je normalizirala telesna višina telovadca, kot preprosto spremenljivko, ki bi lahko ovrednotila razpon koles. Kinematične podatke koles, ki jih je izvedlo 18 vrhunskih telovadcev, smo zbrali s sistemom za zajem gibanja Qualisys, ki deluje pri 100 Hz. Razdalja med glavo in prsti na stopalih (HTD) in njen vodoravni del (HTDh), so bili izračunani skupaj z njihovimi razmerji z rezultati rezultatov, ki so jih podali uradni sodniki, in drugimi spremenljivkami amplitude: vodoravni premeri ramen in gleženj; kot upogibanja telesa; in v oporni zadaj, kot podaljška ramen in položaj glave. Rezultati so podprli HTDh in ne HTD za njegovo potencialno uporabo kot eno samo spremenljivko za ovrednotenje razpona koles. Prednost HTDh v primerjavi z drugimi spremenljivkami so v potencialni veljavnosti, kljub relativni enostavnosti ocenjevanja. Ker računalništvo HTDh zahteva le položajne podatke glave in prstov, ima lahko več uporabe kot orodje za vrednotenje.

Ključne besede: kakovost, vrednotenje, vadba, ocenjevanje.

Lucija Milčić, Kamenka Živčić, Tomislav Krističević

RAZLIKE V ZALETNIH HITROSTIH NA PRESKOKU PRI VRHUNSKIH TELOVADCIH IN TELOVADKAH

Namen študije je bil primerjati razlike v hitrosti zaleta med skoki vrste premet, cukahara in jurčenko. Vzorec je sestavljalo 48 skokov, izvedenih na tekmovanju, od tega je bilo, 19 premetov, 17 cukahar in 12 jurčenkov. Podatki so bili zbrani na tekmovanju svetovnega pokala v Osijeku, 2017. Hitrost zaleta je bila izmerjena s hitrostnim radarjem (Stalker ATS, S PRO II). Opisna statistika je bila izračunana za vse spremenljivke in razlike v hitrosti naraščanja so bile določene z enosmerno ANOVA in Bonferronijevim preverjanjem na ravni pomembnosti pri p <.05. Povprečna hitrost zaleta pri premetu je bila 8,06 m / s, cukahari, 8,06 m / s in jurčenku 7,66 m / s. ANOVA je pokazala, da obstajajo pomembne razlike v hitrosti zaleta med premetom in jurčenkom ter med cukarao in jurčenkom. Rezultati te študije so pokazali, da ima drugačna vrsta skoka drugačno hitrost pri zaletu, kar bo vaditeljem in raziskovalcem pomagalo izboljšati tehniko preskoka.

Ključne besede: orodna telovadba, preskok, hitrost, tek.

Jonas Rohleder, Tobias Vogt

UČINKOVITOST VADBE STRATEGIJE ZAPESTJA PRI STOJI NA ROKAH PRI ZAČETNIKIH

Pri orodni telovadbi je osrednja vadba namenjena stoji na rokah, pri čemer pogosto uravnavano ravnotežni položaj v zapestju ter je prepuščeno učenju le-tega posameznemu vadečemu. Vendar pa raziskave učenja gibanja, povezane z veščinami, kažejo, da zapestja prispevajo predvsem k nadzoru drže stoje na rokah. Glede na nedavne raziskave, ki razkrivajo gibalno obnašanje, odvisno od izkušenj, je cilj te študije preučiti učinke učenja gibanja s poudarkom na zavestnem nadzoru položaja stoje na rokah izkušenih in manj izkušenih telovadcih. Petindvajset študentov prostovoljcev so izvedli tri tedensko usposabljanje, ki je izključno in izrecno obravnavalo uspešno uporabo zapestja med stojo na rokah. Video-vadnica, ki je udeležence seznanjala s strategijo nadzora ravnotežja pred petimi vadbami, so vsi zanemarjali, čeprav je nudila izrecno svetovanje o drži. Udeleženci so pred vadbo in po zaključku izvedli tri stoje na rokah na blazini. Standardizirani video posnetki vsakega preskušanja so omogočili dodelitev v skupino (izkušeni in manj izkušeni) na podlagi povprečnih časov drže stoje na rokah pred preskusom. S tem so časi ravnotežja, strokovne ocene (drža, izvedba in strategije za uravnavanje ravnovesja) in analize kotov ramenskega in kolčnega sklepa služili za odkrivanje sprememb v nadzoru. Za manj izkušene (p <0,05) so razkrili povečan čas ravnotežja kot tudi povečane ocene za strategijo nadzora izvajanja in uravnavanja ravnovesja, vendar ne tudi za izkušene (p> 0,05). Poleg tega se pri obeh skupinah spremembe v kotih ramenskega in kolčnega sklepa niso spremenile.

Ključne besede: pridobivanje spretnosti, ravnotežje, nadzor drže, opazovanje modela.

William A. Sands, Madison K. Varmette, Gregory C. Bogdanis, Olyvia Donti, Bryce V. Murphy, Troy J. Taylor

PRIMERJAVA ODRIVNIH ZNAČILNOSTI TREH VRST PROŽNIH PONJAV

Uporaba prožnih ponjav je v zadnjih letih močno narasla v telesni vzgoji in med športniki v športu, od orodne telovadbe in potapljanja do smučanja in deskanja na snegu. Namen te študije je bil preučiti značilnosti odrivov, ki jih izvedejo športniki, ki skačejo na treh vrstah ponjav: akrobatska steza, tekmovalna velika prožna ponjava in povečana velika prožna ponjava. Skoke so izvajali akrobatski (5 moških, 5 žensk). Triosni merilnik pospeška (250 Hz) je označil 10 najvišje nadzorovanih skokov na vsaki ponjavi in vsakega športnika. Ponavljajoče se analize ANOVA so pokazale značilne razlike v odrivih: čas od začetka odriva do največjega pospeševanja (p <.001, =2 = 0.82), čas od pospeševanja do največjega dosega do konca (p = .030, =2 = 0.40) in skupni čas odriva (p <0,001, =2 = 0,78, višina skoka (p <.001, =2 = 0,95) največji pospešek (p = .015, =2 = 0,37) in čas letenja (p <.001, =2 = 0,97). , sila in povprečna sila nista bili statistično različni (p>140, =2 = 0,20). Najtrajša ponjava z najnižjimi časovnimi vrednostmi, pospeški vrhov in višinami skoka je bila akrobatska steza, ki mu je sledila tekmovalna velika ponjava in povečana velika ponjava, ti podatki lahko pomagajo uporabnikom in drugim, da razumejo vedenje športnikov pri skakanju.

Ključne besede: ponjava, primerjava, pospešek, skoki.

Miriam Kalichová, Petr Hedbávný, Barbora Pyrochtová, Jana Příhonská

PRIMERJAVA MED DEJANSKO IN NAPOVEDANO TELESNO VIŠINO ČEŠKIH VRHUNSKIH TELOVADCEV

V okviru orodne telovadbe se pogosto obravnava vpliv intenzivne vadbe na rast in razvoj telovadcev in telovadk. Cilj tega dela je primerjati doseženo in napovedano telesno višino in dolžino telesnih delov v 11 vrhunskih telovadcev iz Češke republike, ki so bili 12 let ali več podvrženi intenzivni vadbi. Povprečna starost telovadcev je bila 33 ± 11,5 let, telesna višina 174,9 ± 4,1 cm in masa 71,5 ± 5,13 kg. Z uporabo standardiziranih telesnih meritev smo dobili telesno višino (BH) in dolžino trupa, zgornje in spodnje okončine, roke, podlakti, stegna in goleni. S pomočjo t-testa ($p< .05$) smo primerjali dejansko in napovedano telesno višino s pomočjo treh različnih napovednih enačb. Rezultate smo primerjali tudi z relativnimi dolžinami telesnih segmentov, kot so poročali Chaffin & Andersson in Brugsch. V večini primerov so rezultati pokazali nižjo dejansko telesno višino od napovedane telesne višine, ta razlika je bila statistično pomembna v dveh od treh napovednih enačb. Relativna predvidena dolžina zgornjih okončin (0.442BH), rok (0.189BH), spodnjih okončin (0.515BH), stegen (0.257BH) in telet (0.251BH) ustreza predvideni dolžini teh segmentov. Dejanska dolžina trupa (0,544BH) in dolžina podlakti (0,166BH) je daljša od predvidene dolžine. Na podlagi rezultatov telesnih segmentov telovadcev lahko rečemo, da imajo telovadci daljši trup, srednje dolge zgornje okončine in krajše spodnje okončine.

Ključne besede: orodna telovadba, telesna višina, telesni deli, napovedne enačbe.

Adriana Kaplánová

OSEBNOST TELOVADCEV IN NAČIN SPOPADANJA S TEŽAVAMI

Razlog, zakaj nekateri telovadci izvedejo odličen nastop, drugi pa so komaj sposobni izvesti srednje uspešen nastop na tekmovanju, je lahko s področja osebnostne strukture. Spopadanje s težavami je odziv telesa na neravnovesje med zahtevami zunanjega okolja in sposobnostjo telesa, da izpolni te zahteve. Zato je cilj naše raziskave raziskati razmerje med strukturo osebnosti telovadcev in strategij obvladovanja težav. Vzorec študije je sestavljalo 56 vrhunskih slovaških telovadcev (16 moških in 40 žensk), starih od 15 do 26 let, s povprečno starostjo 19,34 ± 3,15 let. Struktura osebnosti telovadcev je bila raziskana z vprašalnikom NEO-FFI (Ruisel & Halama, 2007). Strategije obvladovanja težav so bile preučene z Atletskim popisom sposobnosti spopadov ACSI-28 (Smith et al., 1995). Rezultati so pokazali, da je 6 od 7 podsklopov strategij za obvladovanje težav v povezavi z osebnostno strukturo telovadcev, in sicer čustveno labilnost / stabilnost, ekstrovertiranost/introvertiranost in odprtost do izkušenj. Ugotovili smo tudi, da nobeden od podsklopov strategij obvladovanja težav ni v odnosu do sprejemljivosti in vestnosti telovadcev. Boljše razumevanje osebnostnih lastnosti in strategij obvladovanja težav za pomoč pri njih obvladovanju lahko pomaga vaditeljm in športnim psihologom pri razvoju učinkovitih vplivov pomoči telovadcem za doseganje najboljših rezultatov na tekmovanju.

Ključne besede: strategije premagovanja, osebnostne lastnosti, športna psihologija.