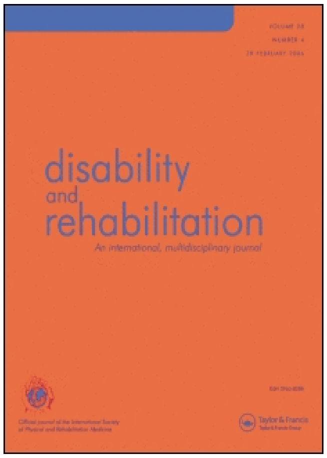

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RESEARCH PAPER

Posturographic testing and motor learning predictability in gymnasts

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Abstract

Purpose. One aim of this study was to find if there was a difference between balance and stability between elite level gymnasts and non-gymnasts. Another aim was to find if there was a relationship between dynamic posturographic scores associated with sway fatigue or adaptability and the ability to learn new gymnastic routines. The ultimate aim of the study was to improve gymnastic performance while reducing the probability of injury.

Methods. Computer dynamic posturography (CDP) provided stability scores, fatigability ratios and adaptation ratios in elite level gymnasts and non-gymnasts controls. Relationships between the postural integrity of gymnasts and non-gymnasts were calculated. The gymnasts were trained in a novel gymnastic routine and performance outcomes were compared to the CDP outcomes.

Results. Tests of postural stability have shown that gymnasts have greater postural stability than non-gymnasts. Gymnasts whose adaptability scores were higher were able to learn and perform new motor routines better than those with lower adaptability scores or high fatigability ratios.

Conclusions. While gymnasts have greater postural integrity than do non-gymnasts, CDP can identify individuals whose ability to perform new motor activities might be impaired. Methodology to improve functional stability not associated with the motor task may contribute to increased sports performance and decreased probability of injury.

Keywords: *Posturography, motor learning, gymnasts, injury prevention, vestibular rehabilitation*

Introduction

To minimize injury risk and maximize gymnastics performance, coaches, parents, and health professionals working with young gymnasts need to understand and practice safe gymnastics. Our investigations using dynamic posturography measurements aim to contribute to the practice of safe gymnastics. Gymnastics training develops strength, flexibility, concentration, balance, grace, and speed in young athletes. The intensity of practice and dedication to training at a young age is greater than most other youth sports. Gymnastic training and competition is associated with the risk of injury to an immature musculoskeletal system, and it is our duty to ensure that these risks are minimized. Strenuous physical activity is known to cause structural abnormalities in the immature vertebral body and exposure to years of intense athletic training increase the risk for developing adolescent hyperkyphosis associated with adult-onset back pain. Larger angles of thoracic kyphosis and lumbar lordosis are associated with greater cumulative training time while a lack of sports participation is associated with the smallest curves and gymnasts show the largest curves of all athletes [1]. Gymnasts must know where their body parts are in space in order to perform the complex movements associated with the sport. The control and perception of body orientation and motion are subserved by multiple sensory and motor mechanisms ranging from relatively simple, peripheral mechanisms to complex ones involving the highest levels of cognitive function and sensory-motor integration [2]. Gymnastic routines are associated with both reflexogenic and volitional motor activity. The equilibrium point hypothesis of voluntary motor control states that the control action of muscles is not explicitly computed, but arises as a consequence of interaction between moving equilibrium position, current kinematics and stiffness of

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the joint, obviating the need to explicitly specify the forces controlling limb movements [3]. Joint position and loading during a gymnastic routine are constantly changing due to the complexity of movement involved in the sport. Balance is an integral part of gymnastics and is controlled by independent canal and otolith reflexes and degrees of sway change with changes in head position [4]. Head positions in reference to the environment are constantly changing during a gymnastic routine involving rotation and inversion of the body.

Gymnastics is a sport of young people whose training customarily starts in the very early years. Progression in the sport is dependant upon many variables including the control of balance. Maintenance of postural balance requires an active sensorimotor control system with proprioceptive function maturing at 3–4 years of age and visual and vestibular afferent systems reaching adult levels at 15–16 years of age [5]. The processes underlying the maintenance of an optimal postural stability are mature at least as soon as 6 years of age [6]. Children and adolescents appear to have the nervous system development appropriate to the needs of a sport that is dependant upon such maturation. Abnormalities or pathologies in system development or postural integrity can result in decreased advancement in gymnastics performance with injury potential. The incidence and severity of injuries is relatively high, particularly among advanced level female gymnasts, establishing a need to analyse injury risk factors and to identify dependable injury preventive measures [7]. Methodology that might contribute to injury reduction and performance increases will contribute to the safety needs of the sport and individual. Gymnastic routines are associated with rapid adaptation of a variety of linked postures. Gymnastic movements demand an adaptation of sensory information processing with head position and visual conditions affecting a control of balance [8]. Often times, visual clues may be removed from the gymnast for periods of time during a routine and the role of vision on body sway is not directly linked to the difficulty or specificity of the posture in varied balance tasks [9]. Postural sway in gymnasts might therefore be tested with and without vision and compared to a variety of linked weight bearing postural moments in a routine. The relationship between control and dynamics during successive phases of weight-bearing tasks, all of which have multiple objectives, is essential for improving performance without sustaining injury. Modifications in the control logic of one motor subsystem not apparently related to the weight-bearing task may be sufficient for achieving both the global and local task objectives of weight bearing after a gymnastic routine involving landing [10]. It is obvious that unless a gymnast collides with an object that most severe injuries will occur with an improper landing or fall from an increased sway associated with a failed posture. Gymnasts must be able to generate high speeds of body movement in order to successfully complete complex routines. The ability to maintain a posture after completion of quick body movements is central to the sport. The speed of the kinematic of center of mass corresponds to a global strategic response linked to the body's posturo-kinetic capacity, and reduction of the anticipatory postural adjustments seems to be linked to the precariousness of the final equilibrium [11].

The most serious problem faced by contemporary gymnasts is injury with prevention being superior to treatment. Injury prevention ultimately requires that one can predict the outcome of certain activities and their injurious nature. Injury prevention efforts must be firmly grounded in science and medicine while making pragmatic linkages to gymnastics as it exists and is practiced [12]. A repetition of movement patterns is necessary in order to learn to incorporate such patterns in a gymnastic routine. The dynamic movements associated with the sport are variable and associated with different loading and balance requirements. For example, tumbling is a dynamic movement requiring control of the linear and angular momenta generated during the approach and takeoff phases, both of which are subject to some variability even when the gymnast is trying to perform a given movement repeatedly [13]. Experts in motor skills require a fine postural control to keep a stable upright posture while facing the task of reinserting proprioceptive information. Contrasting with non-gymnasts, gymnasts are able to rapidly take advantage of the reinsertion of proprioceptive information to decrease their center of pressure displacements suggesting that the efficiency of the integration process leading to the reweighting of sensory information can be significantly improved through a specific training [14]. The integration of sensorimotor activity in gymnastics is such that the contribution of the environment to the nervous system may be weighted differently dependent upon the type and class of receptor to the environmental stimulus. For instance, somatosensory cues are more informative than otolithic cues for the perception of body orientation, and the efficiency of otolithic and/or interoceptive inputs can be improved through a specific training to compensate for the lack of somatosensory cues [15].

Head and body positions are constantly changing during a gymnastics routine. The head extension position commonly encountered in many routine activities yields a reorganization of the control mechanisms for maintaining undisturbed upright stance [16]. Intact cervical neuromuscular function is important in postural control during quiet standing with a reweighting of sensory cues in balance control following cervical muscular fatigue occuring by increasing the reliance on the somatosensory inputs from the plantar soles, ankles and visual information if available. Cervical muscular fatigue yields increased the center of pressure displacements in the absence of vision which is more accentuated when somatosensation is degraded by standing on a foam surface [17]. One aim of our investigation was to utilize a foam perturbational surface in order to promote greater displacement and sway and to allow us to observe fatigue of muscles and sensory integration. Neck proprioceptive input and neck muscle fatigue can produce destabilizing effects on stance and locomotion with the effects of neck muscle fatigue on orientation opposite to those produced by neck proprioception. The neck represents a complex source of inputs capable of modifying our orientation in space during a locomotor task [18].

Peripheral motor events and resultant feedback parameters necessary to successfully integrate complex gymnastics routines are ultimately dependent upon brain activity. The basal ganglia contributes to balance correcting control responses and processes afferent information which is highly relevant for postural control [19]. Much of the brain activity associated with human motion and a perceptual representation of space is dependant upon an integrated sensory response from the environment. During locomotion, human subjects navigate in their environment and choose a direction of movement by means of the internal representation of space that is continuously updated by sensory input. Trunk proprioception plays a major role in the definition of locomotor trajectory and appears to be weighted against vision and whole-body kinematic information [20].

Another aim of our investigation was to ascertain if a change in postural sway during a perturbational task might be associated with learning or fatigue such that performance of new tricks or routines might be predictable. We know that balance recovery variables are not strongly or consistently correlated with postural steadiness which is not predictive of the ability to recover balance with an ankle strategy [21]. The recovery of balance, however, is not limited to ankle strategies. Stabilization of the center of mass is an important goal of the postural control system and coordination of several joints along the human "pendulum" is required to achieve this goal [22]. During a gymnastic routine there will be varied perturbations due to ground and apparatus contact and other variables. Experimentally we might induce perturbations and measure motor responses to them. Regardless of the type (voluntary versus involuntary) or direction of perturbation, the strategy employed by the central nervous system to control the body center of mass displacement concerns mainly trunk stabilization [23]. The well-known condition for standing stability in static situations is that the vertical projection of the centre of mass should be within the base of support [24]. The gymnast must constantly be aware of self-movement or stability as well as the stability or movement of the environment in order to safely perform complex motor movements. Cognitive perception of body position might differ from the reality of the situation in a gymnastics routine.

The visual channel of balance control is susceptible to cognitive influence while the vestibular system responds to acceleration of the head in space and therefore always signals self-motion [25]. A variety of dynamic motor responses to perceptual and environmental influences are necessary to maintain stability. Some muscles may not be as efficient as others in a certain plane of motion resulting in a lesser stabilizing event. For example, trunk muscles that have a lesser action of an anticipatory stabilizing reaction for pitch perturbations correct roll perturbations and pitch perturbations which are corrected by lower leg muscle activity have a minor stabilizing effect for roll perturbations [26]. Stability is important in a gymnastics routine where the athlete may be in a variety of unstable positions connected to a varied number of quasistable linked events. Sport performance during the execution of closed skills combines specific body and limb movements into codified patterns where stability and consistency may be more important than variability [27]. A variety of motor strategies are necessary to restore balance during a complex gymnastics routine. Control of the standing posture of humans involves an ankle and a hip strategy to restore the body balance in the sagittal plane such that when postural control becomes difficult, the central nervous system selectively activates the somatosensory feedback paths from the hip joint angle to the moments around the ankle and hip joints [28]. Further complicating a restoration to balance is the variety of environmental events that may facilitate or compete with balance. For instance, postural sway during quiet standing reduces when somatosensorial information is provided by an active or passive "light touch" of different body parts with a surface [29]. Physical contact with an apparatus or the ground must be compared to other receptor activation during a movement. The vestibular organs in the inner ear serve balance, gaze control, and higher spatial functions such as navigation while the brain uses this information for online error correction of planned body-movement trajectories [30]. But increases in postural instability with the head tilted from the erect position may be in part due to mechanical perturbation rather than solely vestibular disruption [31]. The gymnast must constantly modify the motor activity of the limbs in order to correctly compensate for changes in body positions. During passive self-motion, the vestibular control of arm-reaching movements essentially derives from a sensorimotor process by which arm motor output is modified on-line to preserve hand trajectory in space despite body displacement. In contrast, the updating process maintaining up-to-date egocentric representation of visual space seems to contribute little to generating the required arm compensation during body rotations [32].

The degree of body sway when maintaining a position can provide information that allows clinicians to understand the facilitation of environmental information. Both vestibular reflexes and perceptual signals appear to have a specific role in the maintenance of upright stance with acute facilitation of vestibulospinal reflexes occurring as body sway increases [33]. Different training and sports experience may be responsible for some differences in sway noticed in different athletes. The postural sway of dancers (eyes closed and on a foam surface) is less regular, less stable, less complex, and more stationary than that of track athletes [34]. Ballet dancers and controls have comparable balance ability during eyes open and eyes closed conditions but when somatosensory information alone or in combination with visual information is made unreliable, dancers are significantly less stable than controls and utilize a hip strategy to maintain postural control [35].

Athletes have been found to be superior to non-athletes in balance performance with gymnasts performing better on a dynamic balance task than all other groups [36]. Techniques that might increase balance and decrease sway might contribute to better athletic performance with a decrease of injury. The superior balance control in professional gymnasts is primarily achieved through motor training and not by learning abilities or a higher sensitivity of the vestibular system [37]. Motor training specific to one routine or trick may not be appropriate to increase balance or postural integrity associated with other routines. We know that postural ability of elite gymnasts in one posture is not transferable to their abilities in other postures [38]. Different types of training have a probability of resulting in different concomitants of postural integrity. We know that resistance training has an acute negative effect on postural control [39]. Postural control is generally viewed as a feedback loop in which sway is detected by sensory systems and appropriate motor commands are generated to stabilize the body's orientation. All individuals will demonstrate some degree of sway while attempting to maintain a given posture. Postural sway is considered to have two fundamental stochastic components, a slow non-oscillatory component shown to account for the majority of sway variance during quiet stance and a faster damped-oscillatory component. The slow component is due to errors in state estimation because state estimation is inside the feedback loop rather than a moving reference point or an exploratory process outside the feedback loop [40].

Another aim of our study was to ascertain whether fatigue in the maintenance of posture viewed as increasing sway over time was related to the level of gymnastic performance of new routines. We also desired to understand any relationships that might be associated with a decreased frequency of sway during a postural moment. In summary, the aims of this study were three-fold. To discover: (i) Is there a difference between balance and stability between elite level gymnasts and non-gymnasts? (ii) Is there a relationship between sway fatigue or adaptability and motor learning?, and (iii) Do our findings promote methodology that might improve gymnastic performance while reducing the probability of injury?

Methods

Computerized dynamic posturography outcomes were obtained on elite level gymnasts and non-gymnasts who were age matched. All gymnasts were volunteers who had qualified for the United States national competitions of the United States All Star Federation in Dallas, Texas (2005 – 2006). The skill levels of all gymnasts were considered equal in that they all could perform the routines necessary for competition at world class levels. The outcome measurement was obtained using computerized dynamic posturography, a standard diagnostic test of balance function [41 – 46]. The subject's balance was tested using a three-component force platform (CAPS test) under one sensory condition of the modified Clinical Test of Sensory Interaction on Balance (mCTSIB), the eyes closed on perturbing surface condition. This condition was chosen as studies have shown it to be the single test that best correlates with balance impairment and falls [47 – 49]. The stability score, already used in several studies by other authors [47 – 49] was used as the primary outcome measure in this research. It is defined as 1 minus the ratio between the measured sway during the test (computed as the major axis of a standard 95% confidence ellipse) and the amount of sway a normal subject of the same height as the one being tested should be able to sway before falling (also known as the theoretical maximum sway or the theoretical limit of stability, calculated using a regression formula based on the subject's height developed by NASA in 1962 and commonly used in all posturographic tests). For convenience, the stability score is expressed as a percentage. Its definition makes it a convenient and easy to understand measure to use as a subject able to stand perfectly still with no sway will have a score of 100%, whereas one that sways as much as the limit of stability will have a score of 0%. During each test, the subject's sway was determined by the force platform and its related software. The CAPS three-component force platform uses 3 load cells arranged in a triangle to measure the distribution of the vertical ground reaction force on the platform. The analog load cell signals are amplified and simultaneously sampled by the platform electronics using three synchronized individual 24-bit delta-sigma analog to digital converters sampling at 312 kHz and decimating the samples to a data rate of 64 Hz. The use of three A/D converters insures that the signals from the 3 load cells are acquired simultaneously with no timing error. The high sampling rate with the high decimation and low data rate of the sigma-delta converters eliminates aliasing and provides a resolution of about 4 parts per million. The digital load cell data was then sent via a USB connection to the PC where software uses a calibration matrix determined by the manufacturer to compute the total vertical force and the two horizontal moments acting on the platform. From these data, the software computed the point of application of the vertical force acting on the platform, commonly referred to as the Center of Pressure (CoP). The location of the CoP coincides in static conditions with the projection of the subject's Center of Mass (CoM) onto the platform, and its movement relates to the movements of the subject's CoM (sway). The determination of the actual sway required the determination of the instantaneous location of the CoM via the location and inertial properties of each body segment of the specific subject being tested. The CAPS test, like all posturographic equipment, uses the movement of the CoP as an approximation of the sway. Because it is an approximation, and because for kinetic reasons the CoP moves more than the CoM, the 95% confidence interval of the CoP motion was considered. This allowed the CAPS software to compute the ellipse that represents the location of all of the sway samples collected during the test with 95% confidence. The major axis of this ellipse represented the maximum sway of the subject in any direction during the test and it is used to compute the stability score. To assess the accuracy and resolution of the measurement chain, calibrated weights of 75 kg and 100 kg were positioned in the center of the force platform (as if it were a subject) and 20 sec acquisitions were performed: The accuracy of the weight was within the instrument's factory specifications ($\pm$2N). Therefore the accuracy for the position claimed by the manufacturer of $\pm$1 mm for a weight of 75 kg was accepted as correct as it determination would have required specialized equipment and software available only to the manufacturer. It should be noted that the overall accuracy of the position of the CoP given by the instrument is not relevant in this study as the motion of the CoP determined the sway. The sway measurement error was estimated considering the fact that during the test at both weights the dead weight did not move, but the measurement chain indicated a "sway" of less then 0.05 mm (measurement noise), therefore the resolution of the measurement chain and the sway measurement error was considered to be 0.05 mm. To verify the repeatability of the measurement chain, the same type of tests were repeated two times, obtaining similar results (within the specified accuracy and resolution). Given the sway measurement error, the measurement error in the stability score was determined. From the definition of the stability score it is clear that the least the theoretical limit of stability, the more pronounced the effect of the sway measurement error is. As the theoretical limit of stability is computed by using the formula $0.55 \times \text{height} \times 2 \times \sin(6.25°)$, the shorter the subject, the more the stability score is sensitive to the measurement errors. To estimate the stability score measurement error a subject's height of 1.6 m was considered. Such a subject would have a theoretical limit of stability of 191.6 mm. For such a subject, a sway measurement error of 0.05 mm means a stability score measurement error of 0.05/191.6 or, if the score is expressed in percentage, of 0.026%. Thus, any changes in the stability score greater than that are a consequence of the subject's sway and not of measurement errors. A CAPS dynamic posturography test in the eyes closed perturbed stance was obtained on all subjects. Subjects were instructed that they would stand on a foam platform and close their eyes while data was obtained from a computerized force plate. The subjects were all given practice sessions so that they were familiar with the test prior to the collection of data. The CAPS test occurs over 25 sec. We divided the degree of sway observed during the first half of the test and the second half of the test and obtained ratios. When subjects sway increased in the second half of the test in reference to the first half we called this a fatigability ratio. When individuals demonstrated less sway in the second half of the test we called this an adaptability ratio that we considered might be related to some type of motor learning. All gymnasts were instructed in a novel gymnastic routine which included a variety of inverted postures and ground routines unfamiliar to the subjects. The athletes were allowed to practice the routine for one hour after which they were asked to perform the routine in front of the same judge who was blinded as to the outcome measures previously obtained. The performance scores were then compared to the CDP measurements to ascertain if there would be any relationship.

The study ran from 06/01/05 thru 07/01/06 and conformed to the code of ethics of the World Medical Association (Declaration of Helsinki) and was funded by the Carrick Institute, USA ClinicalTrials.gov Identifier: NCT00374569. The funding source had no involvement in the study design or in the collection, analysis, and interpretation of data; in the writing of the report; and in the decision to submit the paper for publication.

Results

In this sample, we have 53 males and 183 females. Seventy persons are non-gymnasts and 166 persons are elite level gymnasts. Table I reports the number of subjects in each group.

Question 1: We would like to know if our subjects had any relationships between their fatigability scores and adaptability scores specific to the learning of new tricks.
Question 2: We also would like to know if there is any relationship of the stability score and the fatigability-adaptability scores and new trick acquisition.

Table II reports the descriptive statistics for stability scores, fatigue ratios, adaptability ratios, age, and new trick scores. The mean of the stability score is 69.0212 with a standard deviation of 10.086. The mean of fatigue ratio and adaptability ratio is 19.696 and 17.576 with a SD of 35.637 and 20.191, respectively. We found that the mean of fatigue ratio is higher than the adaptability ratio, but with much higher SD in this sample. The mean age in this sample is 15.27 with a SD of 4.485 and the mean of new trick score was 6.205 with SD of 2.085.

Correction analysis

Table III shows the Pearson correlation of each of the two variables of fatigue and adaptability. The first row in each cell is the correlation coefficient. The second number is the probability of obtaining a sample correlation coefficient as large as or larger than the one obtained by chance alone (i.e., when the variables in question actually have zero coefficient). The small probability indicates that it is unlikely to obtain a correlation this large by chance if the sample where taken from a population whose correlation was zero. We can see that the adaptability ratio has a significant positive relationship with the new trick score at a significant level of 0.01%. But, the fatigue ratio has a negative relationship with the new trick score at a significant level of 0.01%; however, the stability score has no significant relationship with the new trick score. We can conclude that subjects who have higher adaptability ratios and lower fatigue ratios will tend to obtain a higher new trick score. We also found the adaptability ratio and fatigue ratio have significant negative relationships at a significant level of 0.01%. This indicates that the subjects who have higher adaptability ratios tend to have lower fatigue ratios.

Multiple regression model

We can use the multiple regression equation that predicts the "new trick score" from the variables of

Table I. Number of subjects in each group.

	Value label	*n*
Gender	Female	183
	Male	53
Gym group	Non-gym	70
	Gym	166

Table II. Descriptive statistics.

	n	Minimum	Maximum	Mean	SD
SS	236	30.00	97.00	69.021	10.086
FR	236	.00	267.00	19.686	35.637
AR	236	.00	71.00	17.576	20.791
Age	236	10.00	37.00	15.266	4.485
New trick score	166	2.00	9.00	6.204	2.085
Valid *n* (listwise)	166				

SS, Stability score; FR, Fatigue ratio; AR, Adaptability ratio; Age, and New trick score.

Table III. Pearson correlation of variables.

	FR	AR	Age	New trick score
SS	−0.117 (0.072)	0.055 (0.399)	−0.152(*) (0.019)	0.043 (0.583)
FR	1	−0.469(**) (0.000)	0.111 (0.089)	−0.534(**) (0.000)
AR		1	−0.034 (0.598)	0.516(**) (0.000)
Age			1	−0.139 (0.074)

*Correlation is significant at the 0.05 level (2-tailed); **correlation is significant at the 0.01 level (2-tailed).

the adaptability ratios, fatigue ratios and stability scores as:

$$\text{Predicted new trick score} = \text{constant} + B1 \times SS + B2 \times FR + B3 \times AR$$

The regression coefficients are estimated by the method of least squares or maximum likelihood. That is, we selected the coefficients that had results in the smallest sum of squared differences between the observed and predicated values of the dependent variable. Table IV shows the coefficient estimation for this regression model.

In the multiple regression equation, the partial regression coefficient for each independent variable (SS, FR, AR) tells us how much the value of the New trick score (dependent variable) changes when the value of that Xi increase by 1 and the values of the other Xj do not change. A positive coefficient means that the predicated value of the dependent variable increases when the value of the independent variable increases. A negative coefficient means the dependent variable decreases when the value of the independent variable increases. Here, the estimated regression equation is:

$$\hat{Y} = 6.160 - 0.003 \times SS - 0.020 \times FR + 0.033 \times AR$$

The coefficient for the *AR* tells us that new trick scores are sensitive to changes in the adaptability scores. The new trick scores will increase by 0.033 for a change of 1 in the *new trick score*; but it is quite indifferent to changes in the stability scores since the coefficient is −0.003 and not significant at the usual 5% level. The fatigue ratio has a negative effect on the new trick score. The new trick score will decrease by 0.020 for a change of 1 in the new trick score. *R square* in this multiple regression model is 0.359, which means 35.8% of the observed variability in the "New trick score" (Y) is "explained" by these three independent variables. Question 4: Do the stability scores, fatigability scores and adaptability scores from our gymnasts differ from average normals that do not do gymnastics?

Table V reports the summary statistics for stability scores, fatigue ratios and adaptability ratios in gymnasts and non-gymnasts. A total of 156 persons are gymnasts and 80 persons are not. We found that the mean of stability scores and adaptability scores in gymnasts are higher than those in non-gymnasts; but, the mean of the fatigue ratio for the gymnasts group is lower than that for non-gymnasts group. Table VI shows the *t*-test results for the stability scores, fatigue ratios and adaptability ratios between gymnasts and non-gymnasts. The *t* value for the stability scores, fatigue ratios and adaptability ratios are 2.886, −0.559 and 3.098 with a *p* value of 0.005, 0.557 and 0.002, respectively. This indicates that there are significant differences in stability scores and adaptability scores between gymnasts and non-gymnasts at a significant level 0.1%, but, there is no significant difference in fatigue ratios between the two groups. Stability scores and adaptability ratios for gymnasts are significantly higher than those who were non-gymnasts.

Table IV. Multiple regression model to predict New trick score.

Model	Unstandardized coefficients B	Unstandardized coefficients SE	Standardized coefficients	*T*	*p*
(Constant)	6.160	1.042		5.911	0.000
SS	−0.003	0.014	−0.014	−0.220	0.826
FR	−0.020	0.004	−0.372	−5.152	0.000
AR	0.033	0.007	0.335	4.684	0.000
n	166	F value	31.822		
Adj. R	0.359				

Dependent Variable: New trick score: Coefficient estimation for regression model.

Discussion

There is a significant difference between both the stability scores and adaptability ratios seen in elite gymnasts and non-gymnast controls. The gymnasts are more stable and have a greater adaptability. Surprisingly, the fatigue ratios are similar between both groups. Motor learning has been shown to be significantly related to a higher adaptability score and

Table V. Summary statistics for gymnasts groups.

		n	Mean	SD	SE Mean
SS	Gym	156	70.442	9.177	0.735
	Non-gym	80	66.250	11.206	1.253
FR	Gym	156	18.756	37.157	2.975
	Non-gym	80	21.500	32.619	3.647
AR	Gym	156	20.410	21.280	1.704
	Non-gym	80	12.050	18.722	2.093

Table VI. Independent samples test for gymnasts groups.

	t-test for Equality of Means				
	t	df	*p* (2-tailed)	Mean Difference	SE Difference
SS	2.886	134.572	0.005	4.192	1.452
FR	−0.559	234	0.577	2.743	4.907
AR	3.098	178.437	0.002	8.360	2.699

a lower fatigability ratio. A previous level of athletic achievement is not representative of the ability to learn new motor skills. Elite level gymnasts considered to be at the same level of performance may have different abilities to learn new motor skills associated with their sport. Balance instabilities associated with decreased coordination and fatigue may contribute to injury when a gymnast is learning new routines. It is clear that training in the sport is associated with greater stability and adaptability of balance whereas it does not significantly change the fatigue ratios. New methodology must be developed to increase the adaptability scores and to decrease fatigability ratios demonstrated with CDP testing.

Conclusions

Elite level gymnasts may have underlying pathology of stability which can be identified by CDP testing. Changes in stability, particularly in the degree of sway over time are associated with the ability to learn new motor skills. A gymnast whose stability increases over the time of a CDP test is able to learn novel motor acts better than a gymnast of equal skill who fatigues over the time of the test. Coaches might use this information in their choice of team members whose skills appear similar but who have different abilities to learn. Athletes might use this information when contemplating training for a new routine. Physicians and trainers might test different training and treatment methodology specific to increasing the adaptability ratios of the CDP. These applications should have the probability of increasing performance and decreasing injury associated with pathology of stability. Since the adaptability ratios are numerical, any treatment, training or intervention might be measured as to its success in the change of the ratio before a gymnast might consider practicing novel routines. In order to decrease disability and increase motor learning in gymnasts, it is necessary to embrace the concept of active rehabilitation of the integrated sensory system. The practice of gymnastic routines does not appear to change the fatigue ratios. Rehabilitation should be designed to stabilize the center of mass of individuals who demonstrate fatigue ratios or low adaptability scores. Techniques involved in such stabilization are generally referred to as vestibular rehabilitation and include a variety of eye exercises and stimulations as well as modifications of the vestibular ocular responses. Rehabilitation should be designed to increase facilitation of vestibulospinal reflexes associated with sway and are common in the treatment of balance and postural problems. Our team has initiated a controlled study utilizing vestibular rehabilitation modalities in gymnasts who have demonstrated fatigue ratios and decreased motor learning skills. Our hypothesis is that vestibular rehabilitation will facilitate our abilities to prevent injury and disability by decreasing fatigue ratios and increasing adaptability scores associated with increased motor skills. The concept of rehabilitation as a method of athletic training is a novel addition to a multidisciplinary approach of service to the athlete. This study has demonstrated methodology that might identify pathology in high performance individuals and we hope that it will promote investigations of methodology specific to its treatment.

Conflict of interest statement

There are no financial or personal relationships with other people or organizations that could inappropriately influence (bias) our work. Dr Ogerro and Dr Pagnacco hold two patents on the Vestibular Technologies' Computerized Posturography Devise used in the study. I, Frederick Carrick, PhD, have had full access to all the data in the study and had final responsibility for the decision to submit for publication.

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