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ESCOLA DE EDUCAÇÃO FÍSICA E ESPORTE

Biomechanical analysis of cross on training and competition rings

Paulo Daniel Sabino Carrara

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RESUMO

CARRARA, P. D. S. **Análise Biomecânica do crucifixo em argolas de treino e competição**. 2015. 77 p. Tese (Doutorado em Ciências) - Escola de Educação Física e Esporte, Universidade de São Paulo, São Paulo. 2015.

O crucifixo é um elemento chave na prova das argolas na Ginástica Artística Masculina. A posição anatômica durante a sua execução requer a abdução do ombro em 90° no plano frontal, o que provoca grande solicitação mecânica nas articulações do ombro. Em condição de treino, um aparelho modificado é mundialmente utilizado para diminuir as cargas no ombro e permitir maior numero de repetições do crucifixo. Estudos sugerem que há diferenças na ativação muscular no ombro entre a situação de treino e competição. Entretanto, ainda não há conhecimento sobre a especificidade dos aparelhos de treino no âmbito da biomecânica, considerando a cinemática, cinética e eletromiografia em bases individuais. O objetivo geral desta tese projeto é investigar a biomecânica do crucifixo com o uso das argolas de competição e de treinamento. Doze ginastas brasileiros de alto nível foram testados em dinamômetro isocinético para verificação de assimetria na força de ombros e eletromiografia. Após intervalo de uma semana, os participantes realizaram, em seus ginásios de treinamento, três crucifixos nas argolas de competição e no aparelho de treino em ordem aleatória. Foi utilizada uma câmera de vídeo digital, uma célula de carga acoplada em cada cabo das argolas e eletromiografia de superfície em nove músculos do membro superior. Os resultados foram comparados por testes paramétricos, não paramétricos e estatística descritiva. A assimetria nas forças de ombro foi de 9,9±6,4%. Os ângulos do ombro no aparelho de treino tiveram menor desvio da posição alvo com 90° de abdução do que nas argolas para o ombro direito e esquerdo, e menores valores de simetria. As forças nos cabos foram semelhantes em ambos os aparelhos, como também a simetria. Não houve diferença na eletromiografia de nove músculos e valores de co-contração entre os dois aparelhos. As argolas de treino permitiram aos ginastas um melhor desempenho do crucifixo sem alterar o padrão de ativação muscular do ombro das argolas de competição. A orientação individualizada é necessária para que os ginastas realizem o crucifixo no aparelho de treino da mesma maneira que realizam nas argolas de competição, para que as equivalentes características biomecânicas sejam mantidas.

Palavras-chave: Ombro; Assimetria; Ginástica Artística; Força.

ABSTRACT

CARRARA, P. D. S. **Biomechanical analysis of cross on training and competition rings.** 2015. 77 p. Thesis (Doctoral in Sciences) - School of Physical Education and Sport, University of São Paulo, São Paulo, 2015.

The cross is a key element in Male Artistic Gymnastics rings routines. The anatomical position during its execution requires 90° of shoulder abduction in frontal plane, which implies a large mechanical demand of shoulder joints. For training condition, a modified rings apparatus is worldwide used to decrease shoulder load and allow more repetitions of cross. Studies suggest that there is different shoulder muscle activation between training and competition conditions. However, is not clear the training apparatuses specificity regarding biomechanics, considering kinematics, kinetics and electromyography in an individual basis. The aim of this thesis is to investigate the biomechanics of the cross using training and competition rings devices. Twelve Brazilian elite gymnasts were tested on isokinetic dynamometer for shoulder strength asymmetry and electromyography assessment. Within one week interval, participants performed in their training place, three crosses in rings and in training apparatus randomly. One digital video camera, one strain gauge in each cable and surface electromyography of nine shoulder muscles were used. Statistical analyses were performed by parametric and non-parametric tests and descriptive statistics. Shoulder strength asymmetry RMS values were 9.9±6.4%. The asymmetry of shoulder strength and cross performance on rings had an individual basis relation. Shoulder angles on training device had less deviation from target 90° of abduction on training apparatus than on rings and smaller asymmetry value. Cable forces had similar values in both apparatuses, as the asymmetry values. Electromyography of nine muscles and co contraction values differences were not different between the types of rings. The training rings allowed the gymnasts to better perform the cross without changing shoulder muscle activation patterns. An individual orientation for gymnasts to perform the cross on training apparatus within the same way they perform in competition rings, it is necessary for the maintenance of equivalent biomechanical characteristics.
Keywords: Shoulder; Asymmetry; Gymnastics; Strength.

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LIST OF ACRONYMS AND SYMBOLS

BI	Biceps Brachii
CP	Code of Points
CV	Coefficient of Variation
DE	Deltoid medial
DLT	Direct Linear Transformation
DM	Deltoid Medial
EMG	Electromyography
FIG	Fédération Internationale de Gymnastique (FIG)
IF	Infraspinatus
LT	Latissimus Dorsi
MAG	Male Artistic Gymnastics
MVIC	Maximum voluntary isometric contraction
PE	Pectoralis major
RMS	Root Mean Square
RMSD	Root Mean Square Difference
SE	Serratus
SENIAM	Surface EMG for Non-Invasive Assessment of Muscle
SLAP lesion	Superior labral anterior-posterior lesion
TB	Triceps brachii
TM	Teres major
TZ	Trapezius

SUMMARY

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1 INTRODUCTION

Male Artistic Gymnastics (MAG) is a sport which gymnastic motor skills are evaluated on six apparatuses: floor, pommel horse, rings, vault, parallel bars and high bar, where the mechanical demands to perform the routines (sequence of gymnastic movements) occur mainly on the upper limbs (FIG, 2013). Specifically on the rings apparatus, the support of gymnast body is not stable, requiring more strength to postural control (BORRMANN, 1980).

On the rings, the cross (Figure 1A) is one of the most performed strength elements[1] during routines, isolated or combined with other strength elements or swing movements; therefore, it is one of the most trained elements (ARKAEV; SUCHILIN, 2009; SMOLEVSKIY; GAVERDOVSKIY, 1996). Currently, the cross can be showed itself in a routine or combined with 22 elements described at MAG code of points (CP) (FIG, 2013). During the cross, the shoulders should be kept in abduction at 90° in the frontal plane with straight elbows for at least two seconds (FIG, 2013).

The scoring penalties depend on how much deviation from 90° occurs at the shoulder joints whilst the skill is performed (Figure 1B) (FIG, 2013). Small, medium or large errors are defined at each amount of 15° of angular deviations from the perfect hold position, and non element recognition for more than 45° of angular deviation is applied. Thus, the measurement of shoulder angles would increase the understanding of its successful performance, but no shoulder angle data were found regarding the kinematics of cross. How large is deviation from the ideal shoulder angle at the cross during the competition rings?

The cross requires from postural control the stability of the shoulder at a position that involves the extension of passive structures of the joint, causing instability (GRAICHEN et al., 2005; LUDEWIG et al., 2009). The auxiliary rings is usually applied to practice the cross in order to decrease the mechanical load to the body and reduce the efforts of the postural control to support the body weight and stabilize the joints. One training method to develop the skill of cross uses a support (Figure 2) attached to the rings, to sustain the gymnast' forearms and assist the training of the skill (BORRMANN, 1980). Using such training apparatus, the gymnast is able to repeat the cross several times, by reducing the load on the upper limbs (ARKAEV; SUCHILIN, 2004; READHEAD, 1997); thus, he could improve the execution of the cross. The subjective hypothesis is that such practice would reduce the shoulder angle

[1] Any movement described in gymnastics code of points is called as an element.

deviations from 90°. However, no shoulder angle data were found regarding the kinematics of this drill on training rings. Therefore, it is not clear whether the training device contributes to reduce the deviation from the required 90° of shoulder abduction. How large is deviation from the ideal shoulder angle at the cross during those training rings?

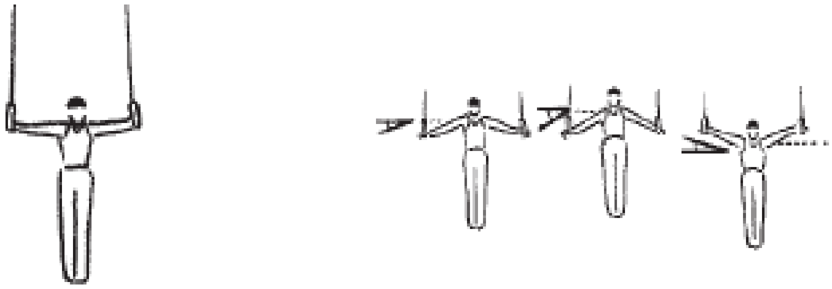

FIGURE 1 – A) Cross on competition rings. B) Cross with angular deviation (FIG, 2013).

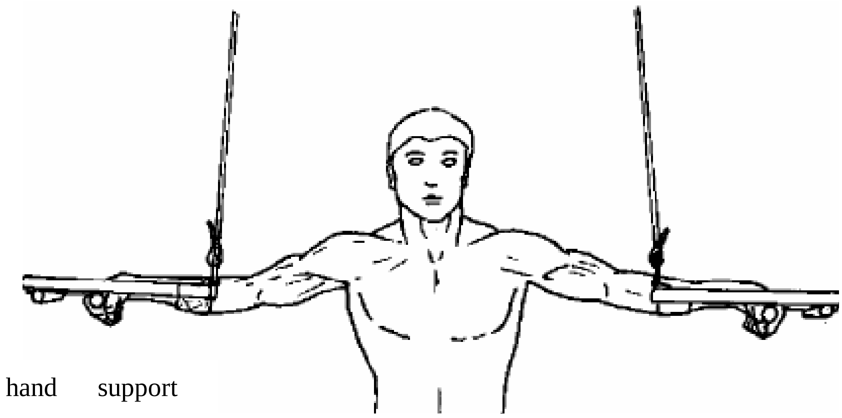

FIGURE 2 – Cross on training apparatus with forearm support (BERNASCONI et al., 2004).

Information about asymmetry at the rings is important for performance and coaching. Information about a participant's applied forces asymmetry on the rings may build the coaching–biomechanics interface (IRWIN; BEZODIS; KERWIN, 2013) to better understand the postural stability on rings. Asymmetry scores were used to analyse the performance in sprint running (EXELL et al., 2012c) and to allow the comparisons among athletes over time and between asymmetry and performance (EXELL et al., 2012a). Besides, in gymnastics, the asymmetrical performance leads to penalties during contests (FIG, 2013). Still needed to be investigated is whether the use of this training device is a specific drill to the static cross posture and whether it improves performance on competition rings.

Moreover, the support biomechanically implies reducing the length of resistance arm to shoulder, diminishing the lever arm and then reducing mechanical loads (ARKAEV; SUCHILIN, 2009; BORRMANN, 1980). In turn, changing the length of rings cables results in forces in shoulder that may be different from those found with competition rings, implying that loads of training will be different from expected (CARRARA; MOCHIZUKI, 2008; DUNLAVY et al., 2007). However, no specific research measured the existence of these differences, or its influence on shoulder asymmetry. Is the force asymmetry in training rings and competition rings the same?

Most of the studies about the rings in gymnastics have focused on the shoulder EMG parameters (BERNASCONI et al., 2004; BERNASCONI et al., 2006; BERNASCONI et al., 2009; CAMPOS; SOUSA; LEBRE, 2011) comparing competition and training devices, or, in other words, an approach about the influence of a drill upon a target skill (IRWIN; HANTON; KERWIN, 2004, 2005). Compared to the rings, the cross performed on the training apparatus had shown lowered latissimus dorsi muscular activity, increased teres major muscular activity. The muscles pattern were modified, probably due to the forearms support, which does not occur on competition rings (BERNASCONI et al., 2004; BERNASCONI et al., 2006). This change in biomechanics of the cross contradicts the principle of specificity of training (CARRARA; MOCHIZUKI, 2008). No further analysis enrolled about this issue, such as the pattern of muscle activity or muscles co-contraction (CIFREK et al., 2009), which could give more information about shoulder biomechanics during the cross. Are the patterns of upper limb muscles activation during the performance of the cross at the training and competition rings the same?

The forces needed to perform the cross were measured with force plates placed under gymnasts' arms and over boxes (DUNLAVY et al., 2007). Even under this condition, the asymmetric force curves were not presented (ZIFCHOCK et al., 2008). Therefore, does the gymnasts asymmetry on cross come from their intrinsic upper limbs/shoulder strength asymmetry? In case the internal forces and ring cables forces were correlated, would be athlete-centric asymmetry profiles influenced by his strength asymmetries? The kinetics asymmetry was observed for all gymnasts with the direction of the asymmetry being related to gymnasts' dominant limb in movement execution (EXELL et al., 2012b). Is there a relation between the maximal shoulder net torque during isokinetic exercise and the forces applied to the rings during cross? Could this relation be expressed by the shoulder maximal net torque asymmetry index?

There are models of forces distribution over shoulder joints, developed for health or ergonomic aims (BOLSTERLEE; VEEGER; CHADWICK, 2013; FAVRE; SNEDEKER; GERBER, 2009). However, there are few researches related to the forces over shoulder joint in MAG (ARAMPATZIS; BRUGGEMANN, 1999; COOLS et al., 2007; HILEY; YEADON, 2003; SHEETS; HUBBARD, 2009).

Most biomechanical analysis on rings relies on handstand (BREWIN; YEADON; KERWIN, 2000; NASSAR; SANDS, 2009; SPRIGINGS et al., 1998), evaluating the movement techniques and torque on shoulder and hips in dynamic situations. There is a lack of knowledge about the gymnasts' upper limb forces during the strength and resistance skills. The existing analysis of shoulder muscles activity at the cross on rings (BERNASCONI et al., 2004; BERNASCONI et al., 2006) do not consider the influence of body posture or forces over gymnasts' upper limbs, which could affect the muscles activity.

Based on these observations, the questions that guide this PhD research are:

1) How large is deviation from the ideal shoulder angle at the cross on the competition rings and on the training rings?

2) Is the force asymmetry on training rings and on competition rings the same?

3) Does the gymnasts asymmetry on cross come from their intrinsic upper limbs/shoulder strength asymmetry?

4) Is there a relation between the shoulder angles and the forces applied to the rings during cross?

5) Are the patterns of upper limb muscles activation during the performance of the cross on the training and on competition rings the same?

1.1 Main objective

To find answers to those questions, the main objective of this doctoral research is to investigate the biomechanics of the cross using training and competition rings devices.

1.2 Specific objectives

To respond each research question, we address the following specific objectives:

1) To describe and to analyze the left and right shoulder angle during the cross performance on training and competition rings.
2) To describe and to compare the left and right cable forces of the cross on training and competition rings.

3) To describe and to compare the left and right maximal isometric shoulder torques.
4) To compare shoulder angle asymmetry index with the cable force asymmetry index during the cross.
5) To describe and to compare the upper limb muscles activation pattern of the cross on training and competition rings.

1.3 Hypothesis

This research will look for the refutation of the following null hypothesis:

H_{0-1}: The shoulder angles of the cross are similar on training and competition rings.

H_{0-2}: The cable forces are similar on training and competition rings

H_{0-3}: The upper limb strength asymmetry is proportional to the cable force asymmetry during cross..

H_{0-4}: The shoulder angles asymmetry results from the position and force cables asymmetry.

H_{0-5}: The activation pattern of shoulder muscles in the cross is similar on training and competition rings.

1.4 Background

Body posture is determined by the muscular action and the forces over the upper limbs. Shoulder muscular action can be influenced by upper limbs position related to the torso (ESCAMILLA; ANDREWS, 2009). Thus, if there are shoulder angle differences between rings and training apparatus, it is possible to have differences on EMG values. Besides this, kinematics data is used as input parameters for quasi static calculations. So it is necessary to know in detail upper limbs position to calculation of forces over it.

Measuring forces over upper limbs is bifolded. Firstly, to verify if there is similar distribution of forces, comparable between the apparatuses, aiming to know if they provide training specific conditions. Secondly, to verify if the training apparatus induces joint forces that can be considered risk of injuries (BRADSHAW; HUME, 2012). If there are asymmetries on the skill related with limbs strength, it would be possible to balance limbs strength asymmetry to balance skill asymmetry. Also, if the training apparatus facilitate the skill, it would diminish the asymmetry values.

The measurement of shoulder angles would increase the understanding of the skill successful performance, and provide information about whether the training device contributes to reduce the deviation from the required 90° of shoulder abduction.

The analysis about this issue, such as the pattern of muscle activity or muscles co-contraction (ANDRADE et al., 2011; FRÈRE et al., 2012), could give more information about shoulder biomechanics during the cross. The training apparatus are constructed different from rings, which changes cables stability and body posture control. Changes on motor coordination are contrarily to training specificity. Besides, an individual approach is needed to differentiate apparatuses influence from gymnast' performance variations.

On rings or on other MAG apparatus, the need for joint stability stresses the gymnast's postural control. Meanwhile, the cross has some peculiarities: 1) the maintenance of abduction position, 2) the element repetition in large volume, often daily, in technical training or in physical preparation, 3) its importance on rings routines composition of all gymnasts, which characterize as a key element.

Most of elite gymnasts perform the cross on rings during their competition routines in order to satisfy specific judging requirements (FIG, 2013). However, there is no research measuring kinematics or kinetics on upper limbs performing the cross, aiming to know body posture adopted by gymnasts or the inherent forces over it. Neither if these combination of forces and posture can be associated with risk of injury to gymnasts' shoulders. Further biomechanical information is needed to know about injury mechanisms and risk factors in gymnastics (BRADSHAW; HUME, 2012).

Asymmetry measurements are one way of measuring the load differences between limbs (EXELL et al., 2012a). Asymmetry has been identified as increasing injury potential of one limb over the other (ZIFCHOCK; DAVIS; HAMILL, 2006). Recent research has developed methods of asymmetry quantification and applied these methods to the analysis of different sports (EXELL et al., 2012b; 2012c). Information about these could add knowledge about injury risks.

The cross requires from gymnast to hold the shoulder in an anatomical position that involves the extension of passive structures of the glenohumeral joint, causing shoulder instability (GRAICHEN et al., 2005; LEVANGIE; NORKIN, 2005). Thus, the use of auxiliary rings is common to the training of the cross, where its function is mechanical facilitation and increase of postural control. However, little information is available about muscle activity of cross on training rings. Gymnasts may undertake unbalanced strength training of joint stabilizers muscles, which can contribute to the instability and displacement of the glenohumeral joint (LABRIOLA et al., 2005). No information was provided about muscles cocontration in the cross (BERNASCONI et al., 2004). Nonetheless, more knowledge is required about the relation of muscles activity, kinematics and kinetics of cross performed on training or competitions rings, restraining a full understanding of the skill and the drill, and properly compare then biomechanically.

Shoulder is usually the most injured joint in MAG (CAINE; NASSAR, 2005; NASSAR; SANDS, 2009). SLAP lesion and rupture in acromioclavicular joint are the most common injuries in male gymnasts (CARAFFA et al., 1996; NASSAR; SANDS, 2009). From biomechanics point of view, shoulder injuries reveal joint instability, originated from static structures or from irregular muscular joint control, causing an inadequate force distribution (ESCAMILLA; ANDREWS, 2009; LABRIOLA et al., 2005).

The shoulder joint biomechanics on cross requires coaches attention on balanced physical preparation of shoulder muscles (CARRARA; MOCHIZUKI, 2008). To quantify loads allows proper adjustments to use training rings. The resolution of problems in shoulder should include, in addition to the treatment of the injury, the verification of the cause, where the unfit movement techniques should be corrected (ARONEN, 1985).

Regarding the implications in shoulder, more studies are needed to check the possible effects of training devices on the shoulder muscles, and what implications that might lead to instability or injuries in glenohumeral joint. Thus, this biomechanical study intends to assist with: to understand the existing performance (cross on competition and training devices), increase its safety (verifying the loads asymmetry on shoulder) and if necessary, to modify gymnast-apparatus interaction (PRASSAS; KWON; SANDS, 2007).

1.5 Definition of concepts and variables

In this section, the concepts and variables are defined. The definitions are detailed in accordance to biomechanical concepts.

DLT: Direct Linear Transformation (ABDEL-AZIZ; KARARA, 1971) is the linear algebra procedure for the reconstruction of three dimensional variables from two dimensional data.

Posture: is defined as a specific position and orientation of one's own body segments.

Movement pattern: time pattern of a kinematics variable (position, angle) or kinetics variable (force, torque) related to a movement or skill (MOCHIZUKI, 2008).

Cocontraction: Level of simultaneous EMG activity of two muscles (MOCHIZUKI, 2008).

Root Mean Square (RMS): indicates EMG amplitude or magnitude, produced mainly by increased number of active motor units and its activation frequency (WINTER, 2009).

2 REVIEW OF LITERATURE

2.1 Shoulder Biomechanics

The shoulder is a complex system consisting of three bones (scapula, humerus and clavicle), four joints (glenohumeral, scapulothoracic, acromioclavicular and sternoclavicular) and many surrounding tendons and ligaments (BEY et al., 2006); balancing, mobility and stability (VEEGER; VAN DER HELM, 2007; WHITE et al., 2012). In general, glenohumeral joint stability is provided by both static (ligaments restraints and labrum surfaces) and dynamic (muscular action) components. Therefore, to move the arms through the shoulder several structures are involved and they act simultaneously. Biceps brachii and teres major muscles are responsible for glenohumeral stability (WARNER; MCMAHON, 1995; WARNER et al., 1999) and the rotator cuff is responsible for shoulder (glenohumeral and scapulae) stability (LABRIOLA et al., 2005; TERRY; CHOPP, 2000). Many athletes have shoulder multidirectional instability and need to strengthen the dynamic stabilizers, mainly the rotator cuff (WRIGHT; MATAVA, 2002). Rotator cuff is the muscular group composed by sub scapular, supraspinatus, infraspinatus and teres minor muscles, which present a dynamic control of the humeral head on glenohumeral joint, while long head of biceps brachii has stabilization function on glenoid in shoulder abduction on scapular plane (WARNER; MCMAHON, 1995).

Shoulder abducted in scapular plane, such as during cross on rings, suffers modifications in its passive and dynamic structures (GRAICHEN et al., 2005; LABRIOLA et al., 2005; WARNER et al., 1992). For passive structures, there is an enlargement of the glenohumeral cavity (GRAICHEN et al., 2005; LABRIOLA et al., 2005; WARNER et al., 1999), and an anterior-posterior and inferior-posterior dislocation of humeral head (TERRY; CHOPP, 2000; WARNER et al., 1992). For the dynamic structures, biceps and teres major muscles are the most responsible for glenohumeral stability (WARNER; MCMAHON, 1995; WARNER et al., 1999), while shoulder stability is mostly provided by rotator cuff and biceps action, compressing humerus inside the glenoid cavity (LABRIOLA et al., 2005; TERRY; CHOPP, 2000). Injuries to the shoulder result from overuse, extremes range of motion, and excessive forces. Resistive isometric shoulder external rotation in a position of abduction should be used with caution when the goal is to maintain the stability (WHITE et al, 2012).

Gymnastics skills development should not be carried on with an unbalanced physical preparation, especially on shoulder abduction positions, as during cross. Muscular forces, important glenohumeral joint stabilizers, can also contribute with shoulder instability and dislocation (LABRIOLA et al., 2005). Besides appearing healthy, many athletes have multidirectional shoulder instability and need the dynamic stabilisers strengthening, mainly the rotator cuff (WRIGHT; MATAVA, 2002) .

Stabilisers muscles that suffered any traumatic event or repeated micro traumas became less precise or more instable to adjust the glenohumeral rotation centre (TERRY; CHOPP, 2000). After joint injury or fatigue (MYERS; LEPHART, 2000), there are proprioceptive deficits and modified motor control, which can cause reduced joint stability and changes on movement coordinated patterns. Shoulder motor control is highly challenged, mainly considering that the rings are instable in all directions.

One way of lowering humerus displacement in abduction position is limiting by spinal scapulae (LUDEWIG; COOK, 2000). Scapulae positioned anteiorrly tilted and humerus with medial rotation, soliciting muscles pectoralis action. Until now, researches about shoulder loads during cross on rings or on training apparatus were not found.

2.2 Gymnastics and Biomechanics of Training

Biomechanical studies on gymnastics comparing drills (ARAMPATZIS; BRUGGEMANN, 1998; IRWIN, G.; KERWIN, 2005) or equipments (FUJIHARA; GERVAIS, 2013) have been based on principles of training, as specificity, individualization, overload and progression (JEMNI, 2012). Coaches use a variety of modes of practice to teach skills in gymnastics (READHEAD, 1997). Preparatory activities known as skill progressions form the major focus of most gymnastic skill development, providing the basis of all gymnastic work, and allow the safe and effective learning of gymnastic skills (READHEAD, 1997). Progressions serve to guarantee further improvement in sports mastery (ARKAEV; SUCHILIN, 2004; SMOLEVSKIY; GAVERDOVSKIY, 1996).

The development of MAG skills is linked to intensive repetition of movements to reach consistence in execution (TRICOLI; SERRÃO, 2005). It is essential to create strategies to avoid injuries during this process (ARKAEV; SUCHILIN, 2004). Gymnastics issues underlying biomechanics are related to training, motor learning, skills techniques and injuries (BRADSHAW; HUME, 2012; PRASSAS; KWON; SANDS, 2007).

A conceptual understanding or "mind set" of one gymnastic skill is the key to its development (IRWIN; HANTON; KERWIN, 2004, 2005). These authors showed that gymnastics coaches replicate the spatial-temporal characteristics of the target skill in the preparatory activities, using training devices, which was validated in the subsequent biomechanics of skill development (IRWIN; KERWIN, 2007a).

It has also been reported (IRWIN; KERWIN, 2005a) that the fundamental principles of training need to be followed (BOMPA, 1999; SIFF; VERKHOSHANSKY, 2004). Coaches use the concept of specificity to encourage performance-related adaptations. Training practices attempt to impose physiological and neuromuscular demands on the performer, which are specific to the target activity (IRWIN; KERWIN, 2005).

There is a concern in biomechanics about shoulder mechanical loads in gymnastics (CARAFFA et al., 1996; IRWIN; KERWIN, 2007b; NASSAR; SANDS, 2009). Some studies approach the development of skills through drills (IRWIN; KERWIN, 2005b) mainly about swing on high bar (BUSQUETS et al., 2013); and others investigated the aspects of the long swing on the high bar, including the optimal kinematics and kinetics patterns to perform it (ARAMPATZIS; BRÜGGEMANN, 1999; HILEY; YEADON, 2003; YEADON; HILEY, 2000) and a multi joint coordination comparison of swing progression exercises to optimal skill performance (IRWIN; KERWIN, 2005b, 2007a, 2007b).

Other gymnastics studies concerned about measuring and diminish shoulder loads on rings (BREWIN; YEADON; KERWIN, 2000), or analysed the combined kinetics with inverse dynamics analysis on floor exercise movements (FARANA; JANDACKA; IRWIN, 2013; FARANA et al., 2014; FARANA et al., 2015).

On rings apparatus, the long swing forces were measured in one cable and peak forces calculated as high as about nine times the gymnast body weight (NISSINEN, 1983). Intending to diminish these high values on shoulder joint, skill models were developed, allowing to verify new values when changing the skill techniques and/or apparatuses' properties (BREWIN; YEADON; KERWIN, 2000), reducing injury risks.

The scheme by which the rings cables are attached to the frame allow the rings cables to move in a free direction pendulum. This inherent motion of the gymnast and rings cables increases the complexity of analysing and understanding their motions and interactions. However, the gymnast is not allowed to show holding elements with the cables moving, or himself being a pendulum, as that will be penalized (FIG, 2013). However, comparisons are not possible due to a lack of knowledge about muscle activation patterns, kinematics and kinetics of cross on training and competition rigs.

The principle of specificity facilitates skill development, making the training process more efficient and effective (ARKAEV; SUCHILIN, 2004; SMOLEVSKIY; GAVERDOVSKIY, 1996). Relating the principle of specificity of training and biomechanics, skill progressions should recruit appropriate muscle fibres and resemble the same movement patterns as the target skill (BOMPA, 1999; SIFF; VERKHOSHANSKY, 2004).

To quantify how effective is cross performance using training devices (forearm support, hip belt elastic band), it would be appropriate to compare its similarity using competition rings (BERNASCONI et al., 2006), using auxiliary equipment with similar shoulder loads found in competition rings (BERNASCONI et al., 2009). On other hand, a study (CAMPOS; SOUSA; LEBRE, 2011) about rear scale gymnastic skill verified that there are differences in shoulder coordination with use of training and competition rings. These differences need to be studied, because they imply the specificity of the training with different devices may be affected due to the incidence of loads or overloads around the shoulder joint. As gymnasts are already training close to their physiological maxima, coaches are continually seeking methods to develop elite performers in a safe and effective manner allowing the achievement of high standards of performance (IRWIN; KERWIN, 2005).

2.3 Kinetics of Gymnastics

A Brazilian gymnast spends 36 to 40 hours training in a week (NUNOMURA; PIRES; CARRARA, 2009), and use their upper limbs very often in closed kinetics chain activities, supporting their body weight, which requires muscle strength and stability of all contributing joints (COOLS et al., 2007; JEMNI, 2011). This way, overuse injuries are a large part of injury to the shoulder complex in the competitive artistic gymnast (NASSAR; SANDS, 2009). Shoulder injuries in gymnastics include SLAP injury and Acromioclavicular joint rupture (CARAFFA et al., 1996; CERULLI et al., 1998).

Several researches have suggested that peak internal loading of this magnitude in the shoulders increases the risk of ligament and muscular damage and is a cause of increased pain in this region (NISSINEM, 1995; CARAFFA et al., 1996). Such speculations have led to the governing body of gymnastics, FIG, providing guidelines to manufacturers of gymnastics apparatus stating that the rings apparatus must possess elastic properties, in an attempt to protect the gymnasts` joints and decrease the potential for injury (BREWIN; YEADON; KERWIN, 2000; FIG, 2013).

Gymnastics training aids aim to use drills that facilitate and reproduce the projected skill (ARKAEV; SUCHILIN, 2004, FUJIHARA; GERVAIS, 2013; READHEAD, 1997). Training rings allow more repetitions by reducing mechanical loads (ARKAEV; SUCHILIN, 2004; SMOLEVSKIY; GAVERDOVSKIY, 1996), but no studies were found about the reproducibility of cross in both conditions. Modified horizontal forces in training rings cause changes in the glenohumeral stability (CARRARA; MOCHIZUKI, 2008). It is not known if the training aid reproduces the shoulder angle or allows fewer deviations from the intended 90° shoulder abduction, nor about the shoulder asymmetry.

Belts supporting the upper arm affect in diminishing the resistance arm of shoulder joint. By mathematical modelling, the forearm support would diminish the loads on the shoulder, considering that the gymnast performs with the same shoulder angles on the rings and on the training apparatus (Carrara and Mochizuki, 2008), but there is no information of whether the shoulder angles are the same in both conditions.

The measurement of glenohumeral joint load is only provided in restricted situations, daily activities, (WESTERHOFF et al., 2009) or wheelchair users (MOON et al., 2013). Recent investigations on gymnastics have advanced on movement techniques and upper limbs loads reduction, in order to avoid potential injury mechanisms due to repeated forces (FARANA et al., 2015). Observations from a study (FARANA et al., 2014) reduced variability in the parallel hand position, with the combined increased ground reaction forces. The reduced variability increases the biological load due to repeated forces; and these factors have been previously identified as potential injury mechanisms (WHITING; ZERNICHE, 2001). Understanding the glenohumeral joint forces pattern during shoulder action has important implications for preventing shoulder joint injuries.

NISSINEN (1983) reported similar magnitudes of tension in both rings cables during performances of long swings. Thus, the measured tension in one cable was doubled to provide combined cable tension in long swings (BREWIN; YEADON; KERWIN, 2000). For strength exercises, force plates were used to measure the combined forces which were necessary to the gymnast to perform the cross (DUNLAVY et al., 2007) and the swallow (CAMPOS; SOUSA; LEBRE, 2011). Both stated that the summed forces should be equivalent or higher as the bodyweight to perform the skills. The time series data showed differences between limbs; but, none focused about the asymmetry differences.

Asymmetry differences are recently studied in athletics (EXELL et al., 2012a, 2012c) and gymnastics (EXELL et al., 2012b) as indicative of performance condition. An advance over the asymmetry of cross on rings would have a bi-folded contribution on performance analysis. First, to verify proficiency of gymnast technique. Second, considering MAG rules, the arms must be symmetric; otherwise the gymnast will suffer a penalty for the more angulated arm. Furthermore, considering that the cross is combined with other skills during the routine, asymmetry in the skill could cause the cables to swinging during the posture, another applicable penalty. Tension measures in both rings cables would be more specific and ecologically valid for strength skills than those realized on force plates.

In addition, implications for loading and injury may be revealed from kinetics asymmetry. There is some evidence that bilateral imbalances in strength, structure, or gait mechanics may contribute to increased injury risk on one side of a runner's body (ZIFCHOCK et al., 2008). Biomechanical asymmetry provides useful information regarding performance, injury and methods of data collection (EXELL et al., 2012a, 2012b, 2012c).

2.4 Kinematics of Gymnastics

The most renowned element which displays this rings characteristics is the Cross position, a classic display of the strength and control of the gymnast's shoulders (NASSAR; SANDS, 2009).

Currently, studies of gymnastics skills uses 2D kinematics approaches, due to the unique equipment and rules constraints imposed on the performer (FIG, 2013). To achieve this biological fidelity the approach must be one that is rich in ecological validly (WILLIAMS et al., 2011). Furthermore, some research designs impose logistical constraints, as to have an amount of expensive cameras available at the gymnast training places.

When re-digitising trials, from one to five, the average accuracy based on the known locations of six markers improved, from ±4.7 mm to ±4.3 mm in horizontal direction and ±2.3 mm to ±2.0 mm in vertical direction. These values correspond to 0.05% and 0.02%, respectively, of horizontal (10 m) and vertical (7.5 m) fields of view, for five digitisations. For just one digitization these values were found to be 0.05% and 0.03% of horizontal and vertical dimensions respectively (IRWIN; KERWIN, 2005b). Variation of 2D-DLT reconstruction were studied in gymnasts performing long swings on high bar, resulting RMSD (root mean square deviation) values on shoulder angles were around 2.29º (IRWIN et al., 2001).

A gymnastic study had examined injury risk and technique selection associated with the choice of hand placement in round off skills (FARANA et al., 2013). These authors showed increased elbow joint abduction torques and lower levels of biological variability (FARANA et al., 2015) in parallel technique round off skills.

Joint kinetics and bio-energetic contributions to skills techniques have been explained, as swing skills were kinematically similar but situate different biophysical demands on the performer, a finding that has direct implications for physical preparation of the gymnast (KERWIN; IRWIN, 2010)

Biomechanics were applied to examine the skills and the drills, comparing over its kinematics, kinetics and bio-energetic. PRASSAS, KWON and SANDS (2007) reviewed available literature on each apparatus in addition to the discussion on biomechanical performance variables and future research directions. The papers shared the idea that there was a gap between practical needs and available scientific data for rings.

2.5 Electromyography of Gymnastics

Coaches use the concept of specificity to encourage performance-related adaptations (IRWIN; HANTON; KERWIN, 2004). Training practices attempt to impose physiological and neuromuscular demands on the performer, which are specific to the target activity (IRWIN; KERWIN, 2007a). It is necessary to search for training rings effect on shoulder muscles and risk factors of instability and injuries. To apply isometric EMG measuring with forces variations is an efficient method to clinic evaluation a follow up of shoulder muscles functions (DE GROOT et al., 2004).

Analysis over swallow strength skill had shown that there were different shoulder muscular patterns between training and competition rings (CAMPOS; SOUSA; LEBRE, 2011). These differences implied in training apparatus efficiency. Different muscles activities were found between competition rings and belts (BERNASCONI et al., 2004). The muscle latissumus dorsi had lower activation and teres major larger activation. Number of trials performed (10) and equipment available (two EMG channels) allow questions about fatigue influence on muscles activity and the results obtained. Moreover, any detail about shoulder angles was provided to observe reliability of crosses performed. Two factors (variability and neuromuscular fatigue), can affect the interpretation of EMG. This information is crucial to properly interpret muscle coordination from EMG signals (HUG, 2011).

Adoption of such methods in those studies (BERNASCONI et al., 2004; BERNASCONI et al., 2006) and grouping results leaded to ask about individual differences on muscles control. Muscular control may show some failures as compromising strength and coordination on fatigue situation (WHITING; ZERNICHE, 2001), what could cause differences on movements pattern (MIZRAHI et al., 2000; PEREIRA et al., 2002; BRERETON et al., 1999; BONATO et al., 2002; KELLIS; KOUVELIOTI, 2009).

Gymnastics research seeks out findings that impact the understanding of coaching activity. A conceptual understanding of how a skill works biomechanically can provide a coach and clinician with knowledge of effective, efficient and safe technique development (IRWIN; HANTON; KERWIN, 2005).

Resuming, the cross on gymnastics rings was selected as the focus of this study, because the majority of strength movements on rings be combined with positions undergoing the cross position, or with abducted arms (FIG, 2013). The quality of this skill is defined by the FIG Code of Points (FIG, 2013), where 90° abduction of both shoulders with full extension of the arms during the whole movement is expected. Considering that cross is a static and score evaluated skill, some important postural characteristics of the cross have not been identified, as shoulder angle asymmetries. Shoulder angles importance on gymnastics is due the applicable penalties due to shoulder deviations from the required position. Penalties vary at each 15° of deviation, and will not be recognized with 45° of deviation or more.

Others investigated separately aspects of the cross, not allowing a comprehensive skill understanding or gymnasts evaluation. One study have characterized the cross, quantifying the forces needed by a gymnast to perform the skill outside the proper rings. One research used forces plates over stable supports, it means outside the proper ring apparatus, evaluated the kinetics of gymnasts who could perform the cross on rings (DUNLAVY et al., 2007).

Another study have compared a competition and training apparatuses employed EMG comparison of training apparatus with an ecological validity, performed in the real rings apparatus (BERNASCONI et al., 2004b; BERNASCONI et al., 2006b). This research suggested that the use of training device modified shoulder EMG patterns, and may be not suitable for training the cross on rings. Similarities between drills and the target skills need to be high, with a replication of the biomechanics of the target skill during the drill, including kinematics, kinetics and neuromuscular activity (IRWIN; KERWIN, 2005, 2007).

Nonetheless, none of them had researched the kinematics of this posture, examined performance gains of cross on training rings conditions, considered the posture of this skill, or analysed individual's performance basis, as the trend in recent sport biomechanics studies (BUSQUETS et al., 2013; FARANA et al., 2015; WILLIAMS et al., 2011).Thus, further research is necessary for individual analysis and to incorporate instruments, such as video analysis or force-instrumented rings, for a comprehensive understanding of the cross gymnastics skill (IRWIN; KERWIN, 2007, IRWIN; BEZODIS; KERWIN, 2013).

Our study aims to advance the knowledge about the cross on rings by a skill analysis, resulting in the following topics: 1) the understanding of the skill, 2) the training specificity, comparing competition and training apparatuses, 3) safety, looking at shoulder biomechanics that may mean risk of injury.

3 MATERIALS AND METHODS

3.1 Participants

The gymnasts were intentionally selected (PATTON, 2002) to meet the criteria of this study. Their coaches and physiotherapists were asked about the gymnasts possibilities to perform the cross on rings, and if they were not injured.

Twelve Brazilian elite gymnasts volunteered to joy in the study (TABLE 1). All gymnasts belong to the senior or junior national teams. All volunteers were informed about the study protocol and signed an informed consent, approved by University of São Paulo Ethics and Research Committee - CEP 717.171.

TABLE 1 – Participants' characteristics.

Gymnast	**Age (years)**	**Stature (m)**	**Mass (kg)**	**Time of practice (year)**	**Hand dominance**
1	24	1.56	61.90	17	right
2	23	1.68	57.40	17	right
3	24	1.74	74.30	16	right
4	23	1.66	64.20	16	right
5	24	1.71	63.20	17	right
6	17	1.62	63.80	11	right
7	20	1.68	69.40	9	left
8	20	1.63	60.80	12	right
9	15	1.62	57.80	10	right
10	18	1.65	63.10	10	right
11	16	1.64	53.10	9	right
12	23	1.73	78.60	16	right
Group	20.5±3.3	1.66±0.05	63.9±7.1	13.3±3.4	-

3.2 Instruments

For kinematics, trials were recorded by one high definition digital camera (model Logitech), sampling frequency 50 Hz, and placed 5 m away and in front of the participant to shut him in the frontal plane. The camera was two meters above the ground in order to centre the rings into the image. The camera was connected via USB to a computer and the video recording was controlled with the software MyoResearch (version 3.2, Noraxon, USA). The camera and electromyography (EMG) channels were connected to a data acquisition system controlled by the software Myoresearch (Noraxon) for acquisition, synchronizing, analogical/digital conversion of data and storage in an Intel Core i7 computer 2,20GHz.

For two-dimensional analysis of cross using a two dimensional linear transformation technique (2D DLT method, ABDEL-AZIZ; KARARA, 1971) a calibration frame was required. Calibration frame comprised of six markers and made of 20 mm wide reflexive tape, fixed directly onto the rings frame, forming rectangular solids of three meters high by three meters wide (BREWIN; YEADON; KERWIN, 2000). Reflexive markers were placed based in anatomical landmarks according to upper limbs model (RAB, PETUSKEY; BAGLEY, 2002) (FIGURE 3) following the International Society of Biomechanics recommendations

(WU et al., 2005). Only anterior view was evaluated for digitalization. Raw position data was processed and data were inputted into the software Visual 3D (Version 5, Germantown, C-Motion). Coordinates of body marks were restricted for the lateral-medial and vertical axes.

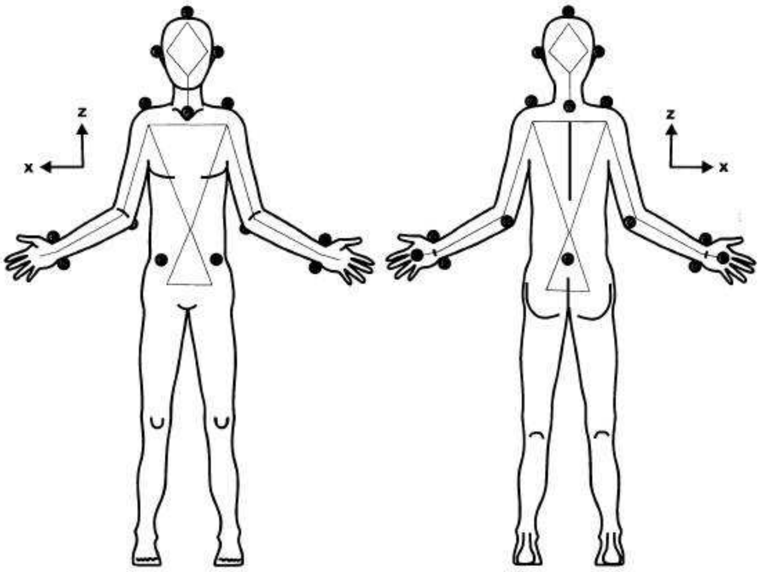

FIGURE 3 - Upper extremity landmarks.

For kinetics, one dimension strain gauge (EMG system Brazil model 2t) was attached to beginning of the cable ring to measure cable tension during the task (BREWIN, 1998). Longitudinal cable forces of two strain gauges were connected to an analogical/digital converter (EMG system Brazil model 1610) and force signal were recorded in HP Pentium 4 computer 1,6GHz. A trigger (EMG system Brazil) was used to synchronize the video and force signal. An isokinetic dynamometer (Biodex System 3, Biodex Medical Systems) was used to measure the maximal voluntary isometric contraction of the shoulder muscles.

A 12 channels EMG system (Myosystem 1400, Noraxon, Inc USA) was used to record the electrical activity of nine muscles of right upper arm, shoulder and trunk (mm. pectoralis major, PE; latissimus dorsi, LT; teres major, TM; infraspinatus, IE; trapezius - pars descendents, TZ; medial deltoid, MD; biceps brachii - caput longum, BI; triceps brachii - caput longum, TB; serratus, ST) at 1500 Hz sampling frequency. The EMG system built in characteristics were: 1^{st} order high-pass filters set to 10 Hz, Baseline noise < 1 uV RMS, Input impedance > 100 Mohm, CMR > 100 dB), Input range: +/- 6.3 mV, Electronic Gain: 200, Overall Gain: 500, Measurement Function Accuracy: +/- 2uV RMS (EMG).

EMG signal was measured with bipolar-surface-differential-active electrodes. The sites for electrode placement were prepared by abrading the skin with fine sandpaper and cleaning with alcohol. Shaving was performed if necessary. Distance between the centres of the disposable electrodes was two centimetres. Placing of electrodes followed the procedures indicated by SENIAM (HERMENS et al., 2000) and for muscles not indicated by SENIAM, electrodes were placed onto the medial line of muscle belly (DE LUCA, 1997), with shoulder angle abduction correspondent for task (HACKETT et al., 2014).

3.3 Procedures

Two procedures were performed for this study. One procedure was dedicated to evaluate the maximal voluntary isometric contraction of the shoulder muscles. The second procedure was done to evaluate the participant performing the cross.

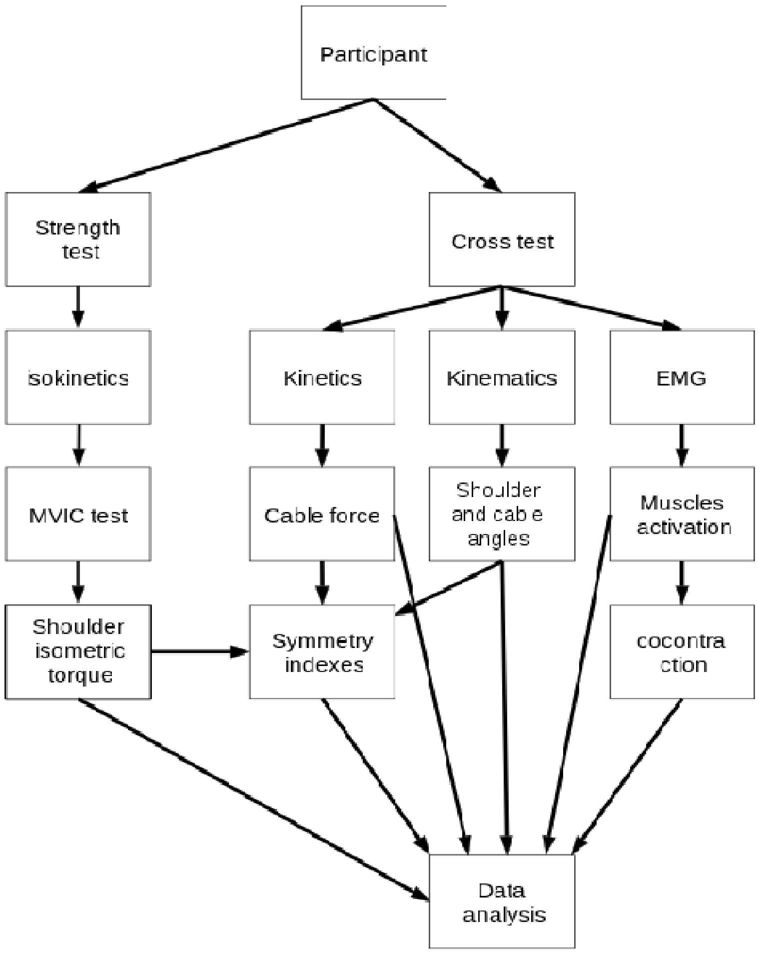

FIGURE 4 - Setup of procedures applied on this thesis.

3.3.1 Maximal voluntary isometric contraction test

Before isokinetic testing, athletes underwent 5-min with 60 rpm warm-up exercises at 25 W with upper body ergometer (Cybex Inc., Ronkonkoma, NY). Maximum voluntary isometric contraction (MVIC) of shoulder muscles was evaluated in isokinetic dynamometer (Biodex System 3, Biodex Medical Systems Inc., Shirley, NY, USA). Participants seated with hip and trunk attached with belts to dynamometer chair with the tested arm elevated, in frontal plane and elbow extended (DE GROOT et al., 2004). Range of motion was set from 30° to 90° of adduction/abduction. For equipment accommodation, participant performed two warm up series with five repetitions of shoulder abduction/ adduction in frontal plane, first series at an angular velocity of 120°/s and second series at 60°/s (LAND; GORDON, 2011). MVIC test was performed to generate the maximal adduction torque and be sustained for five seconds. Position test was set on 90° of shoulder adduction. MVIC test was repeated three times with one minute rest between trials (OLIVEIRA; GONÇALVES, 2008) and the effect of gravity correction were included in dynamometer (LAND; GORDON, 2011).

3.3.2 The cross task

Each gymnast has done his warm up exercises, similar to what he usually does before a training section on rings. His coach was close to manage the warm up. There was not training day of rings when biomechanical evaluation had been done to avoid muscle fatigue. Participants performed the cross with the training and competition rings (FIGURE 5A) (Gymnova, model 3770, France). The training rings were a handmade belt attached on the ring and beneath gymnast forearm. The support point on the forearm was 0.12 m from the gymnast handgrip (FIGURE 5B). For each type of rings, they performed three times the task. The order between training and competition rings was randomized, throwing a dice before the test. Data collection occurred in the gymnasts' training gym, with the apparatus that they used to practice. Only crosses considered technically correct were considered for analysis.

The initial position was when the participant has reached the maintenance position with upper limbs abducted with 90º to the trunk on the transverse plane. The participant has maintained the cross posture for two seconds; then, an oral warning asked him to stop the cross. Any unsuccessful cross was discarded and the task was repeated. The attempts were considered valid by one gymnastics judge with FIG brevet. Between each repetition, the participant had two minutes to rest (DE LUCA, 1997).

FIGURE 5 – A) Competition rings. B) Training rings.

3.4 Signal Processing

The videos were digitised and data were filtered with a low-pass Butterworth filter, with appropriate cut-off frequency (5.3 Hz) determined by residual analysis (WINTER, 2009). Digitised data of the calibration markers was combined with their known locations to calibrate the camera digitiser system, using the direct linear transformation (DLT) procedure (ABDEL-AZIZ; KARARA, 1971). The known locations of the digitised landmarks on the gymnast and rings apparatus were subsequently reconstructed using the calibrated camera digitiser system based on DLT procedure (ABDEL-AZIZ; KARARA, 1971) using Matlab 6.5 (Mathworks Inc) (HEDRICK, 2008). For those digitizing and reconstruction, a specific routine "DV5" was run in Matlab (HEDRICK, 2008). The image digitalization occurred in Matlab environment; then, the coordinates data was converted in file converter (C-Motion) and exported into Visual 3D software for the calculation of the shoulder angle.

Kinematics data were converted from files with ".csv" extension in File converter software (C-Motion) to ".txt" extension and imported into Visual 3D (C-Motion). An upper limb model (RAB, PETUSKEY; BAGLEY, 2002) was applied to data points and the frontal plane angle between trunk and arm segments were considered as shoulder angles. Data analysed comprised the two seconds from the moment that gymnasts reached a static posture.

The upper body model for Visual 3D (FIGURE 6) (RAB, PETUSKEY; BAGLEY, 2002) (Appendix 4) was applied to define the coordinate system, and it was embedded the right-hand coordinate system with the X axis directed laterally to the right, and Z axis directed upward (vertical). Base position is defined as the anatomic position. This is a standardized, internationally recognized position with the subject standing, arms extended at the side, with forearms fully supinated and palms forward (RAB; PETUSKEY; BAGLEY, 2002). The initial static position, with shoulder adducted, was measured with the gymnast on the rings, as adopted in other specific gymnastic tasks (FARANA et al., 2014; FARANA et al., 2015).

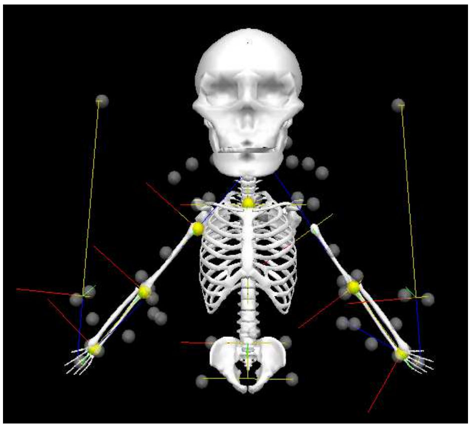

FIGURE 6 - Upper body model (Visual 3D).

By reconstructing six known marker locations distributed throughout the measurement plane, confidence in accuracy and reliability of the digitising was established. Difference between the known and digitised cable length measure was 0.02 m. For quantification of digitizing processes errors purpose, digitising of all trials on rings for the same gymnast was repeated by the author (reliability) and by a laboratory colleague (objectivity). For the right shoulder, the mean angle and standard deviation of three trials was 84.84±1.38°, Trials root mean square deviation (RMSD) 2.08°, Reliability RMSD 1.63° and Objectivity RMSD 1.75°. For the left shoulder, the mean angle and standard deviation of three trials was 82.89±1.15°, Trials RMSD 1.56°, Reliability RMSD 1.67° and Objectivity RMSD 1.82°. The resulting RMSD values of reliability and objectivity are lower or near to the inter trials RMSD. Repeating the digitizing up to five times did not improve the accuracy (IRWIN; KERWIN, 2007). These values corresponded to those reported for accuracy by Challis and colleagues (CHALLIS; BARTLETT; YEADON, 1997).

Rings cables were defined by a vector from the gymnast's hands to the pivot attachment of the cables, and they were considered undeformable. From these body segments, two angles in frontal plane were measured to describe gymnast performing the cross. Shoulder angles were defined as the angle between each arm and the torso. Static phase was determined as the shoulder angular velocity reached zero and lasted for two seconds. Shoulder angle was considered as the average angle along the two seconds time series.

Shoulder strength data was provided from the dynamometer software. Mean of three MVIC was considered for analysis. EMG data obtained from MVIC test and rings task had the same signal processing. EMG was normalized by the peak values obtained in isokinetic test. Raw EMG signals was demeaned, rectified and filtered with a low-pass Butterworth filter of 4th order of 200 Hz. Kinematics were interpolated while kinetics and EMG data were downsampled to 500 Hz. The EMG during the cross task was normalized by EMG activity during MVIC test (Figure 4). A 500 ms epoch in the middle of the static cross was used to calculate the intensity of muscle activation. At that epoch, it was calculated the RMS of the processed EMG for each muscle. A 500 ms epoch during the middle of the MVIC was used to calculate the RMS of the maximal EMG activation.

3.5 Data analysis

3.5.1 Symmetry analysis

Asymmetry left/right for angle, force and torque index were evaluated by asymmetry indexes. Percentage difference for shoulder peak torques T_{ASYM} and for cable F_{ASYM} values were calculated using the asymmetry index method (ZIFCHOCK et al., 2008) (Equation 1):

$$F_{ASYM} = \frac{F_{Rcable} - F_{Lcable}}{F_{Rcable}} . 100$$

Equation 1

The asymmetry torque index T_{ASYM} on cross was calculated by the equation 2:

$$T_{ASYM} = \frac{T_R - T_L}{T_R . 100}$$

Equation 2

Where T_R and T_L are the right and left isometric torque indexes, respectively.

The percentage differences between left and right angle values were calculated using the asymmetry angle index (θ_{ASYM}) method (ZIFCHOCK et al., 2008) (Equation 3):

$$\theta_{ASYM} = \frac{45° - \arctan\left(\frac{\theta_{left}}{\theta_{right}}\right)}{90°} . 100$$

Equation 3

Where θ_{ASYM} is the asymmetry angle; θ_{left} is gymnast's mean left shoulder angle and θ_{right} is gymnast's mean right shoulder angle. Asymmetry angles were rectified, allowing the magnitude of those values to be easily compared between conditions. Asymmetry index on cross is based on the assumption that the line between shoulder is tilted because of unbalanced cable rings. It means that horizontal and vertical force components of cable forces F_{Lcable} and F_{Rcable} are not equal. This tilt is represented by angle β and is defined by equation 4:

$$\tan\beta = \frac{\Delta F_h}{\Delta F_v}$$ Equation 4

The differences between left and right horizontal ΔF_h and vertical ΔF_v forces are

$$\Delta F_h = F_{h_{Rcable}} - F_{h_{Lcable}}$$ Equation 5

$$\Delta F_v = F_{v_{Rcable}} - F_{v_{Lcable}}$$ Equation 6

The left $F_{h_{Lcable}}$ and right $F_{h_{Rcable}}$ horizontal components of the force cables are

$$F_{h_{Rcable}} = F_{Rcable} \cdot \sin\theta_{Rcable}$$ Equation 7

$$F_{h_{Lcable}} = F_{Lcable} \cdot \sin\theta_{Lcable}$$ Equation 8

The left $F_{v_{Lcable}}$ and right $F_{v_{Rcable}}$ vertical components of the force cables are

$$F_{v_{Rcable}} = F_{Rcable} \cdot \cos\theta_{Rcable}$$ Equation 9

$$F_{v_{Lcable}} = F_{Lcable} \cdot \cos\theta_{Lcable}$$ Equation 10

Then, using equations 7, 8, 9 and 10 in equation 4, we have the asymmetry index (ASi) on cross, described by the equation 11:

$$ASi = \tan^{-1}\left(\frac{F_{Rcable} \cdot \cos\theta_{Rcable} - F_{Lcable} \cdot \cos\theta_{Lcable}}{F_{Rcable} \cdot \sin\theta_{Rcable} - F_{Lcable} \cdot \sin\theta_{Lcable}}\right)$$ Equation 11

Where θ_{Rcable} is right cable angle, θ_{Lcable} is left cable angle, F_{Rcable} is right cable force and F_{Lcable} is left cable force.

3.5.2 EMG analysis

EMG time series were compared by means of cross correlation in order to calculate the correlation index R. Cocontraction index is R^2 for lag zero. Cross correlation analysis was performed between all possible muscle pairs. Muscle pairs were grouped according to their function. Agonists (PE, LD, TE and TR), antagonist (DE) and postural (SE, BI, TZ and IF) muscles were grouped into functional groups: a) agonist/antagonist: PE/DE, TR/DE, DE/TM, DE/LT; b) agonist/agonist: PE/TR, PE/TM, PE/LT, TM/LT, TR/TM, TR/LT; c) agonist/ postural: PE/SE, PE/BI, PE/TZ, PE/IF, SE/TR, SE/TM, SE/LT, BI/TR , BI/TM , BI/LT, TR/TZ, TR/IF, IF/TM, IF/LT, TZ/TM , TZ/LT; d) antagonist/postural: SE/DE, BI/DE, DE/TZ, DE/IF; e) antagonist/antagonist: DE/DE; and e) postural/postural: SE/BI, SE/TZ, SE/IF, BI/TZ, BI/IF, TZ/IF.

3.6 Variables

Dependent variables were shoulder angle asymmetry index, shoulder torque asymmetry index, cable force asymmetry index, asymmetry index on cross, cocontraction index and kinematics, kinetics and EMG variables. Kinematics variables were shoulder angle at frontal plane. Kinetics variables were shoulder MVIC and cable force. EMG variable was intensity of muscle activation defined as the RMS (root mean square) of rectified, normalized, filtered EMG signal. Independent variables were RING (two levels: competition and training rings), SIDE (two levels: left and right sides), and MOTOR FUNCTION (five levels: agonist/ antagonist, agonist/agonist, agonist/postural, antagonist/postural and postural/postural).

3.7 Statistical analysis

All dependent variables were compared across SIDE and RINGS factors. The analysis of variance was applied to verify the effect of left and right sides, and the competition and training rings. The co-contraction index was also compared across MOTOR FUNCTION by means another analysis of variance. The post hoc Tukey HSD was utilized, to define differences between factor levels. Significance level was set at $p<0.05$.

An individual-orientated analysis strategy employed for each gymnast was quantified and evaluated. Individual gymnast means (M), standard deviations (SD) and coefficients of variation (CV %) were calculated (BRADSHAW; MAULDER; KEOGH, 2007) for muscle activation, shoulder angle and MVIC. Values below 5% were considered as low variability (FARANA et al., 2015).

After checking for data normality, the paired t test was run to verify the effect of SIDE, RINGS and MOTOR FUNCTION onto the individual dataset.

Linear and polynomial regression analysis were run to analyze the relation between strength asymmetry index and angle asymmetry index. According to data normality, the parametric and non parametric statistical tests were run in SigmaStat 3.5.

4 RESULTS

4.1 Isokinetic evaluation

The gymnasts' strength results measured at the dynamometer are depicted on TABLE 2. Right and left net shoulder peak torque were similar ($F_{1,23}$=0.007 p=0.93). The coefficient of variation of the right and left net shoulder peak torque were similar ($F_{1,23}$=0.005 p=0.94). The CV on isokinetic evaluation were greater than 5% in right shoulder for gymnasts #1, #3, #4, #9 and #10; and in left shoulder for gymnast #2, #3, #4, #6 and #9.

TABLE 2 – The mean right and left net shoulder peak torque (by participants and average results) their coefficient of variation and asymmetry ratio. The torque asymmetry index T_{ASYM} is shown for all participants.

Gymnast	Right		Left		T_{ASYM}
	Torque (N.m)	CV(%)	Torque (N.m)	CV(%)	
1	103.8	5.3	107.10	4.4	3.18
2	104.3	0.4	109.00	6.2	4.51
3	110.0	8.4	103.30	7.9	6.09
4	118.2	14.8	92.90	11.5	21.40
5	108.2	3.3	121.00	4.2	11.83
6	71.4	0.9	78.40	17.4	9.80
7	92.1	2.0	109.90	3.8	19.33
8	105.4	4.9	87.30	4.2	17.17
9	99.3	9.6	109.60	7.6	10.37
10	74.3	19.8	71.70	3.6	3.50
11	99.0	5.3	94.50	4.8	4.55
12	122.4	2.0	130.80	3.0	6.86
Group M±sd	100.7±15.4	6.4±5.9	101.3±17.1	6.5±4.2	9.9±6.4

4.2 Kinematics

An example of the shoulder kinematics during the cross task on the training and competition rings is depicted on FIGURE 8. The graphics show the time series for right and left shoulder angles in three phases: support, lowering and cross. Each one of these three phases was normalised by 100 points (%) of its extent. All following analysis just considered the cross phase.

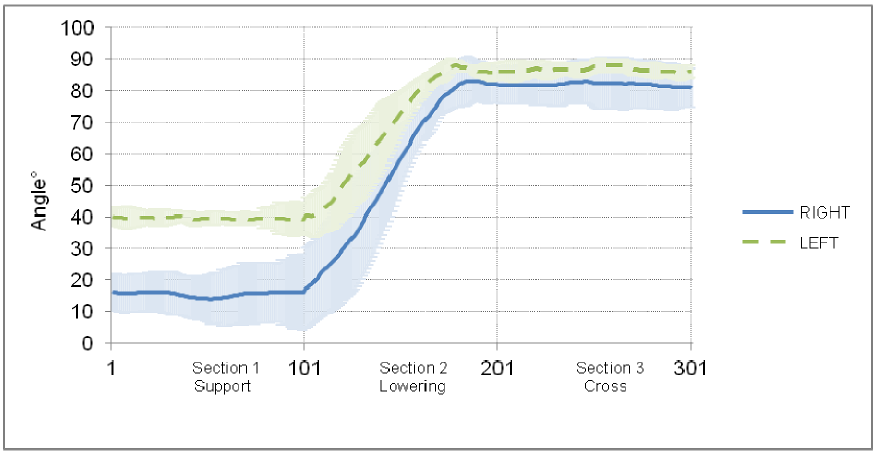

FIGURE 7 - Shoulder angle time series for competition condition – mean of three trials for gymnast #2.

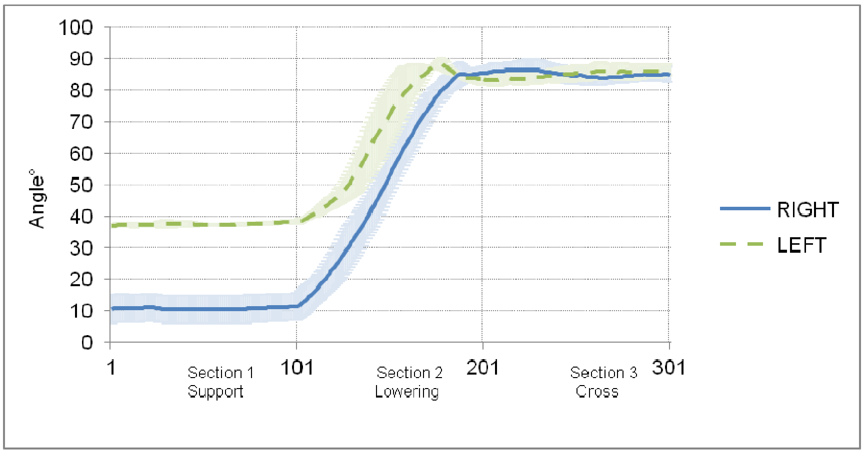

FIGURE 8 - Shoulder angle time series for training condition – mean of three trials for gymnast #2.

Mean shoulder angles during the cross with the competition and training rings are shown on TABLE 3. Right and left shoulder angles and asymmetry values in each condition (competition or training) are depicted. The two-way ANOVA was applied to check the effect of ring (competition and training) and side (left and right) on shoulder angles during the cross. The type of ring affected the shoulder angle ($F_{1,138}$=26.5 $p<0.001$) and the side did not affect the shoulder angle ($F_{1,138}$=0.5 p=0.45).

The post hoc Tukey HSD test showed that shoulder angle was the highest with the training rings. One way ANOVA was applied to check the effect of ring (competition and training) on shoulder angles during the cross. The type of ring affected the right shoulder angle ($F_{3,977}$=6,81 p=0,01) and left shoulder angle ($F_{3,977}$=23,40 $p<0.001$). The asymmetry angle was not affected by the type of ring ($F_{1,23}$=0.5 p=0.47).

The paired t-test was applied individually to check the differences of rings (competition or training) over shoulder angles. The shoulder angles were different between apparatuses for gymnast #4 on right shoulder (t =7.1 p=0.01) and on left shoulder (t=6.2 p=0.02); for gymnast #5 on left shoulder (t=8.4 p=0.01); for gymnast #6 on right shoulder (t=9.7 p=0.01); for gymnast #7 on right shoulder (t =27.1 p=0.001) and left shoulder (t=30.3 p=0.001); and for gymnast #11 on left shoulder (t=8.7 p=0.01).

The shoulder angle asymmetry index θ_{ASYM} were lower in training condition (more symmetric) for gymnast #4 (t=5.7 p=0.02), for gymnast #5 (t=8.6 p= 0.01) and for gymnast #10 (t=4.9 p=0.03). Coefficient of variation (CV %) was lower than 5% for most participants, except for gymnast #2, #8, #10, #11 and #12.

The second order polynomial ($y=A+Bx+Cx^2$) model was applied to fit to the relation shoulder MVIC and shoulder angles at the competition and training rings during the cross (FIGURE 7). For the competition rings, the second order polynomial model (A=3.8±0.6, B=0.8±0.1, C=-0.05±0.005) presented the adjusted R^2 of 0.92 and $p<0.05$. For the training rings, the same model (A=8.4±2.6, B=-0.8±0.3, C=0.03±0.01) presented the adjusted R^2 of 0.70 and $p<0.05$.

TABLE 3 – Gymnasts' shoulder angle, RMSD and asymmetry values (θ_{SYM}) on cross for competition and training conditions.

Gymnast	Type of rings	Right Shoulder		Left Shoulder		θ_{SYM}
		θ (°)	**CV**	**θ (°)**	**CV**	
	C	84.84±1.38	0.02	82.89±1.15	0.01	0.74
1	T	87.33±1.71	0.02	85.29±2.31	0.03	0.75
	RMSD	2.49		2.40		-
	C	86.82±2.27	0.03	82.08±6.97	0.08	1.79
2	T	85.15±2.16	0.03	85.33±2.46	0.03	0.07
	RMSD	1.68		3.26		-
	C	71.09±1.40	0.02	79.23±2.66	0.03	3.44
3	T	71.76±3.13	0.04	79.19±3.03	0.04	3.13
	RMSD	0.67		0.04		-
	C	77.25±2.19	0.03	71.94±2.13	0.03	2.26
4	T	85.26±0.75*	0.01	86.71±2.24*	0.03	0.53*
	RMSD	8.01		14.77		-
	C	70.76±2.48	0.02	66.34±2.88	0.04	7.29
5	T	79.47±3.47	0.01	72.97±2.32*	0.01	3.74*
	RMSD	8.71		6.63		-
	C	87.48±0.49	0.01	85.57±2.61	0.03	0.70
6	T	83.83±1.08*	0.01	88.05±1.44	0.02	1.56
	RMSD	3.65		2.48		-
	C	74.71±1.90	0.03	73.64±1.56	0.02	0.46
7	T	84.07±1.95*	0.04	82.66±1.58*	0.02	0.54
	RMSD	9.36		9.02		-
	C	77.35±3.91	0.05	76.94±7.36	0.10	0.17
8	T	79.69±3.98	0.05	85.94±7.97	0.09	2.41
	RMSD	2.31		9.00		-
	C	74.99±3.22	0.04	68.82±2.17	0.03	2.71
9	T	77.45±3.11	0.04	73.75±2.84	0.04	1.56
	RMSD	2.51		4.93		-

	C	65.05±5.64	0.09	63.61±3.55	0.06	0.71
10	T	77.57±1.98	0.03	74.49±2.33	0.03	1.29*
	RMSD	12.52		10.87		-
	C	61.25±2.96	0.05	62.65±4.95	0.08	0.72
11	T	79.38±5.06	0.06	80.82±7.25*	0.09	0.57
	RMSD	18.13		18.17		-
	C	72.27±3.34	0.05	77.94±1.02	0.01	2.40
12	T	80.43±1.96	0.02	84.28±1.18	0.01	1.49
	RMSD	8.16		6.34		-
Group Mean	C	76.82±8.49	0.03	74.52±7.64	0.04	0.89
	T	81.08±5.39*	0.03	81.87±5.43**	0.04	0.17
	RMSD	4.26	-	7.35	-	-

C= Competition, T = Training, AI = Asymmetry index. Rectified values of asymmetry. * $p<0.05$, ** $p<0.001$.

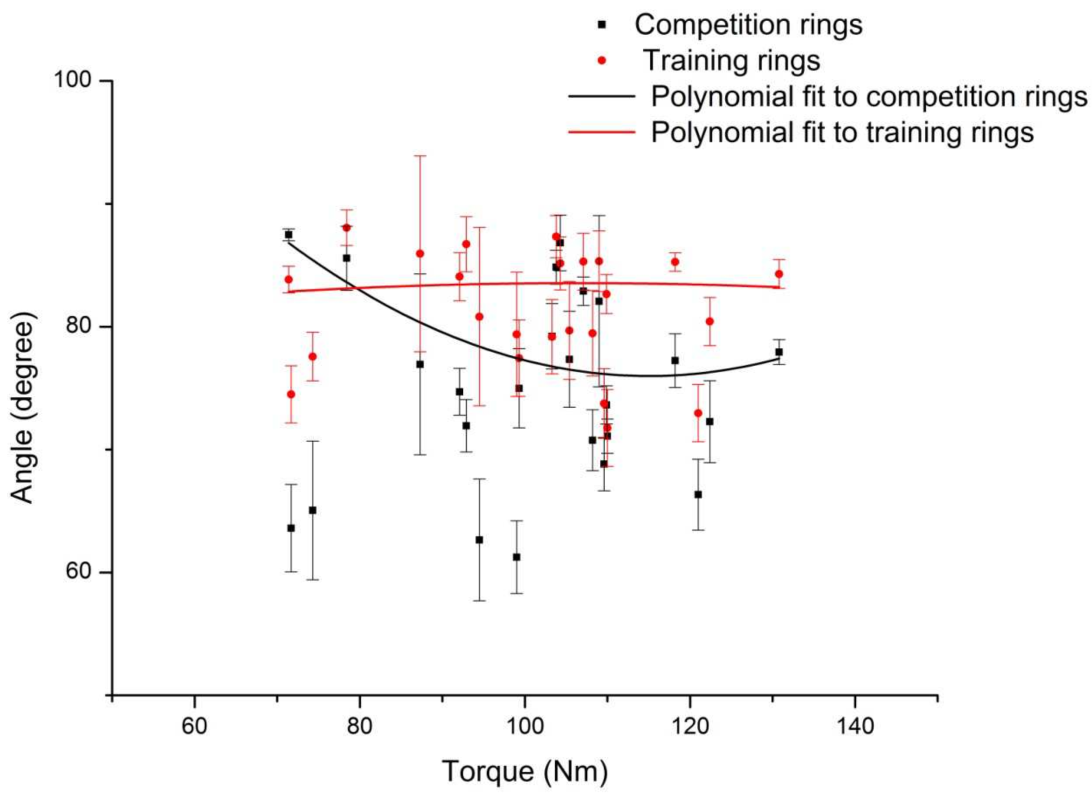

FIGURE 7 - The relation between shoulder angle at the competition and training rings with the MVIC..

4.3 Cable forces

Mean results of right and left cable forces, coefficient of variation and asymmetry index are depicted on TABLE 4. Two-way ANOVA was applied to check the effect of rings (competition and training) and side (left and right) on longitudinal cable force during the cross. Cable force was not affected by type of ring ($F_{1,49}$=0.5 p=0.50) or side ($F_{1,49}$=0.3 p=0.56). Asymmetry cable force index F_{ASYM} between type of rings were similar ($F_{4,301}$=0.8 p=0.37).

The paired t-test was applied individually to check the significantly differences of rings (competition or training) over cable forces. Gymnast #1 applied more force on the right competition ring (t=16.0 p=0.004) and more force on the left training ring (t=6.4 p=0.02). Gymnast #10 applied more force on the right training ring (t=15.2 p=0.004). Gymnast #11 applied more force on the right competition ring (t=6.0 p=0.02) and on the left training ring (t=9.6 p=0.01).

Asymmetry were larger for the competition rings for gymnast #1 (t=5.2 p=0.03) and gymnast #8 (t=8.0 p=0.01). The coefficient of variation was lower than 5% for all participants, except for gymnasts #7, #8 and #12.

Mean results of asymmetry index and coefficient of variation for the competition and training rings are depicted on TABLE 5. No difference for coefficient of variation was found between types of rings (T=0.9 p=0.35). Individual analysis found that coefficient of variation of the cable forces was similar between types of rings.

The linear regression (y=A+Bx) between the shoulder angle asymmetry index and the asymmetry index on cross was applied for the competition rings and training rings separately (FIGURE 8). For the competition rings, there is a linear relationship between shoulder angle asymmetry and asymmetry index on cross (A=-0.96±0.19, B=0.65±0.08 F=7.7 p=0.01 R=0.66 R^2=0.38). For training rings there is not a linear relationship between shoulder angle asymmetry and asymmetry index on cross (A=0.10±0.40, B=0.16±0.11 F=1.7 p=0.21 R=0.40 R^2=0.07).

TABLE 4 – Cable forces (N), difference and asymmetry (F_{ASYM}) values (%) on cross for competition and training conditions.

Gymnast	Type of rings	Right cable force (N)	CV (%)	Left cable force (N)	CV (%)	F_{ASYM} (%)
	C	356.0±1.6	0.01	326.0±1.8	0.01	8.43
1	T	350.6*±1.5	0.02	331.3*±0.5	0.03	5.51*
	D	1.52	-	1.61	-	-
	C	341.6±6.0	0.01	332.0±4.00	0.01	2.83
2	T	352.0±2.0	0.01	340.3±6.6	0.01	3.31
	D	2.94	-	2.45	-	-
	C	358.6±15.0	0.02	351.3±15.1	0.02	2.04
3	T	355.0±11.0	0.02	350.6±25.0	0.02	1.22
	D	1.03	-	0.19	-	-
	C	335.3±5.5	0.03	333.0±13.0	0.02	0.70
4	T	-		-		-
	D	-		-		-
	C	380.0±15.7	0.02	400.3±17.2	0.01	5.35
5	T	391.0±20.5	0.04	389.6±16.7	0.03	0.34
	D	2.81	-	2.74	-	-
	C	312.0±18.3	0.01	278.6±7.5	0.01	8.23
6	T	307.3±2.3	0.01	291.0±2.6	0.01	5.31
	D	1.19	-	4.24	-	-
	C	393.0±8.4	0.06	409.0±5.6	0.03	4.07
7	T	415.3±10.6	0.05	403.6±6.8	0.03	2.81
	D	5.38	-	1.32	-	-
	C	326.3±7.5	0.05	362.6±11.0	0.04	11.13
8	T	350.0±4.5	0.03	339.6±4.0	0.04	2.95*
	D	6.76	-	6.77	-	-
	C	330.5±0.7	0.03	329.5±3.5	0.02	0.30
9	T	337.0±6.0	0.02	335.3±8.3	0.02	0.49
	D	1.93	-	1.74	-	-
	C	317.6±3.7	0.03	313.6±4.04	0.01	1.26

10	T	338.0*±6.0	0.01	319.0±25.2	0.01	5.62
	D	6.02	-	1.67	-	-
	C	346.0±9.5	0.04	344.0±5.2	0.03	0.58
11	T	369.0*±14.1	0.02	385.6*±8.1	0.01	4.52
	D	6.23	-	10.8	-	-
	C	427.3±11.3	0.03	409.0±5.6	0.01	4.29
12	T	407.6±3.06	0.01	396.0±5.1	0.01	2.86
	D	4.82	-	3.28	-	-
	C	351.3±34.7	0.10	349.1±40.1	0.11	4.10±3.56
Group	T	361.1±32.2	0.09	352.9±35.9	0.10	3.18±1.93
	D	2.72	-	1.09		-

Right (RCF) and left (LCF) cable forces. C= Competition, T = Training, D = Difference of percentage in absolute values. Rectified values of difference and asymmetry. * p<0.05.

TABLE 5 – The average asymmetry index on cross for the competition and training rings and their coefficient of variation (CV).

Gymnast	**Asymmetry index competition**	**CV**	**Asymmetry index training**	**CV**
1	9.22±0.88	0.10	10.12±2.75	0.27
2	1.98±1.45	0.73	3.71±3.46	0.93
3	24.92±19.98	0.80	10.44±12.53	1.20
4	6.98±0.98	0.14	-	-
5	8.48±11.13	1.31	8.49±11.72	1.38
6	4.95±1.77	0.36	13.20±14.51	1.10
7	1.93±0.29	0.15	4.50±5.42	1.20
8	6.58±2.89	0.44	2.57±0.96	0.37
9	0.72±0.11	0.16	1.44±1.13	0.78
10	6.33±0.36	0.06	6.32±2.97	0.47
11	8.26±8.41	1.02	5.54±3.36	0.61
12	8.97±8.86	0.99	10.20±6.25	0.61
Group	7.44±6.23	0.84	6.96±3.78	0.54

Rectified values of asymmetry index.

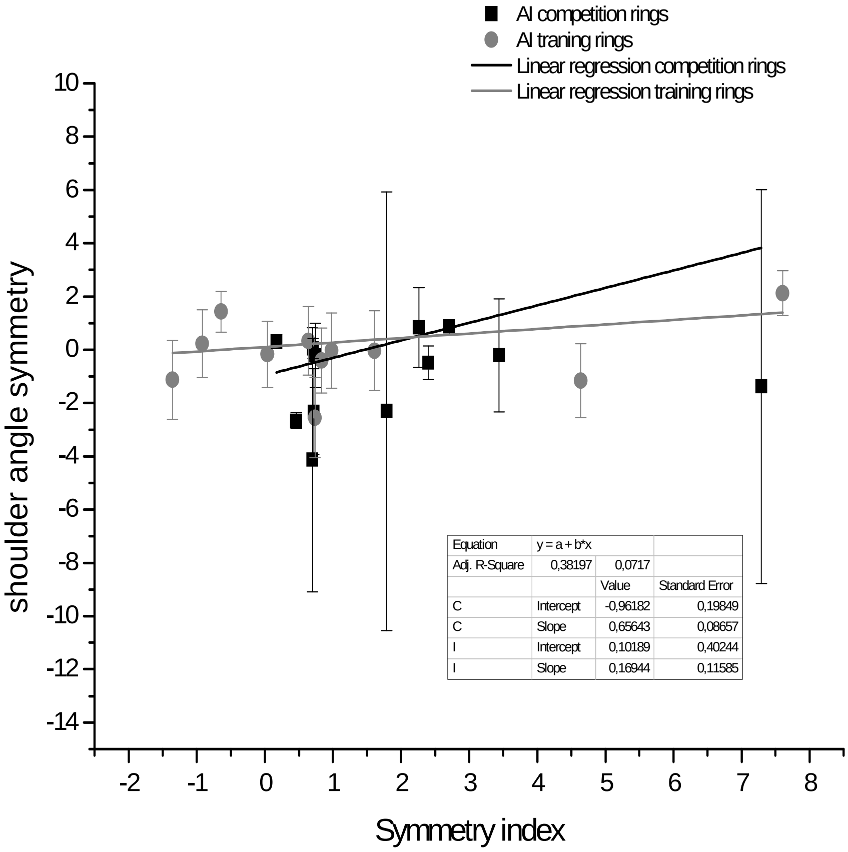

FIGURE 8 – Linear regression model between asymmetry index on cross and shoulder angle asymmetry for the competition rings and training rings.

4.4 Electromyography

The average electrical activity of the upper limbs muscles during the performance of the cross at the competition rings and training rings are presented on FIGURE 9. The parametric and non-parametric analyses of variance were applied to verify the effect of type of ring into the muscle activity. Muscles activation was similar in both apparatuses.

The muscles activity of pectoralis (H=0.003 p=0.95), serratus (H=0.96 p=0.32), biceps (F=1.6 p=0.21), triceps (F=0.25 p=0.61), deltoid (F=0.5 p=0.46), trapezius (H=0.8 p=0.35), infraspinal (F=1.3 p=0.25), teres major (H=0.003 p=0.95) and latissimus dorsi (H=1.2 p=0.27) were not influenced by the type of rings.

The comparison among gymnasts for each muscle also was perfomed. Pectoralis muscle activation was lower on training rings for gymnast #9 (t=8.9 p = 0.01) (FIGURE 10). Serratius muscle activation was lower on training rings for Gymnast #2 (t=5.6 p=0.03)

(FIGURE 11). Biceps brachii muscle activation was lower on training rings for Gymnast #1 ($t=23.8$ $p=0.002$), and for gymnast #6 ($t=5.2$ $p=0.03$) (FIGURE 12).

Triceps brachii muscle activation was lower on training rings for Gymnast #9 ($t=36.5$ $p<0.001$) (FIGURE 13). Deltoid medial muscle activation was lower on training rings for Gymnast #6 ($t=25.1$ $p=0.002$) and gymnast #7 ($t=40.8$ $p=0.01$) (FIGURE 14).

Trapezius muscle activation was lower on training rings for Gymnast #9 ($t=9.6$ $p=0.011$) and gymnast #12 ($t=5.1$ $p=0.035$) (FIGURE 15). Infraspinatus muscle activation was lower on training rings for Gymnast #2 ($t=6.2$ $p=0.02$), gymnast #4 ($t=4.3$ $p=0.04$), and for gymnast #8 ($t=5.6$ $p=0.03$) (FIGURE 16).

Teres major muscle activation was lower on training rings for Gymnast #9 ($t=7.8$ $p=0.01$). Teres major muscle activation was larger on training rings for Gymnast#1 ($t=11.8$ $p=0.007$), for gymnast #4 ($t=4.6$ $p=0.04$) and for gymnast #11 ($t=8.2$ $p=0.01$) (FIGURE 17).

Latissimus dorsi muscle activation was lower on training rings for Gymnast #1 ($t=4.4$ $p=0.04$), for Gymnast #2 ($t=15.6$ $p=0.004$) and for gymnast #9 ($t=4.8$ $p=0.04$) (FIGURE 18). No muscle activation difference was different for gymnast #3; #5 and #10.

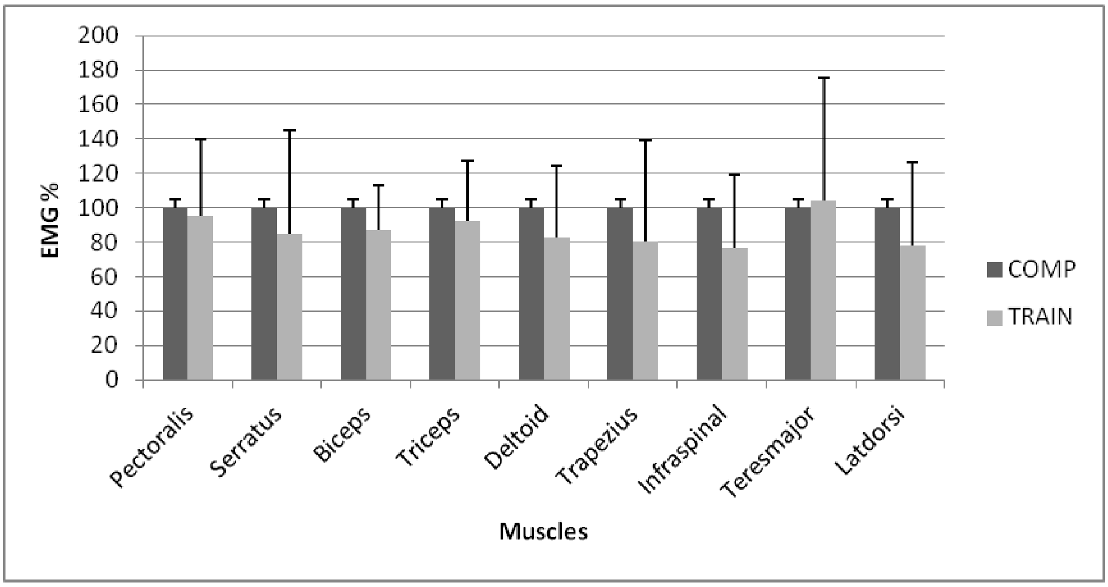

FIGURE 9 - Group mean EMG normalised by competition condition.

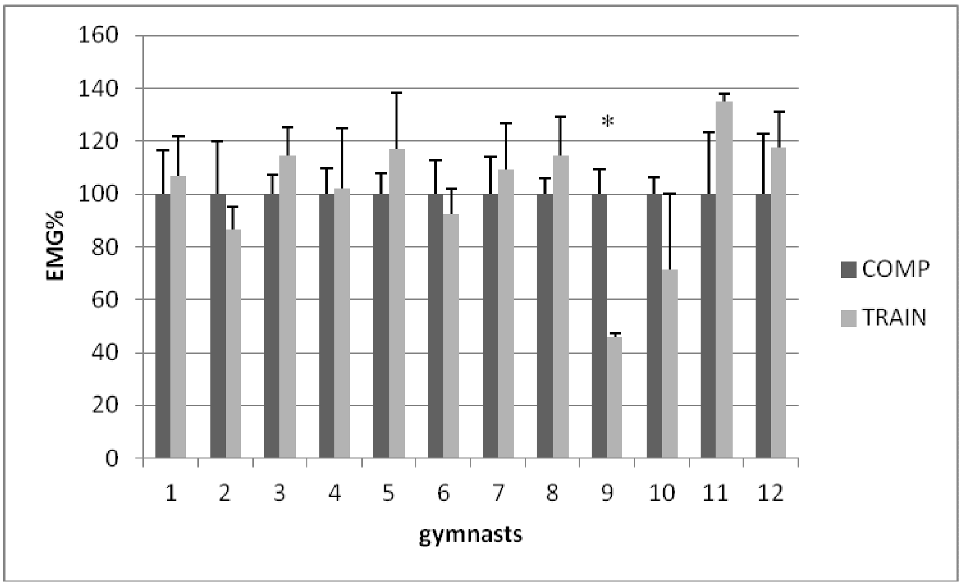

FIGURE 10 – Pectoralis activation on competition and training rings.

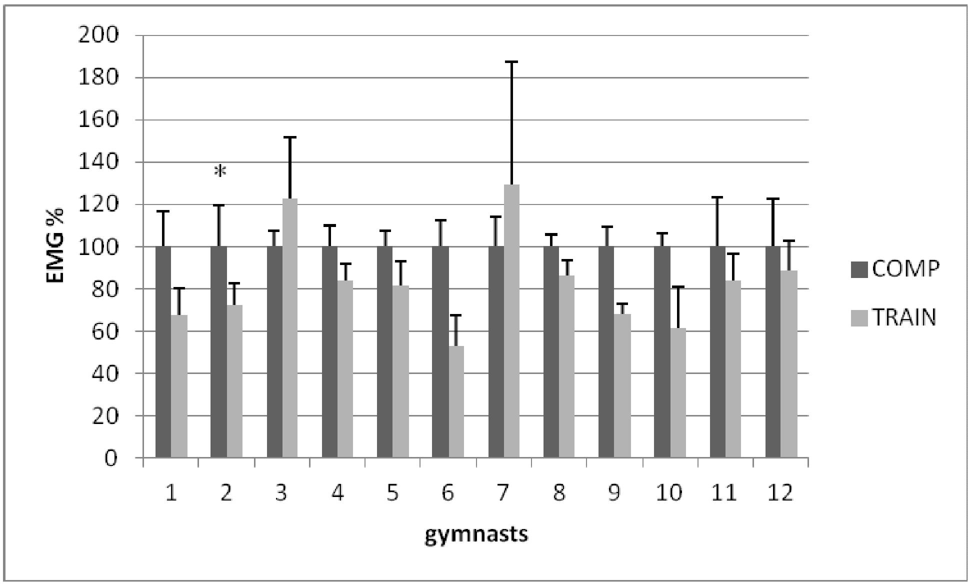

FIGURE 11 – Serratus activation on competition and training rings.

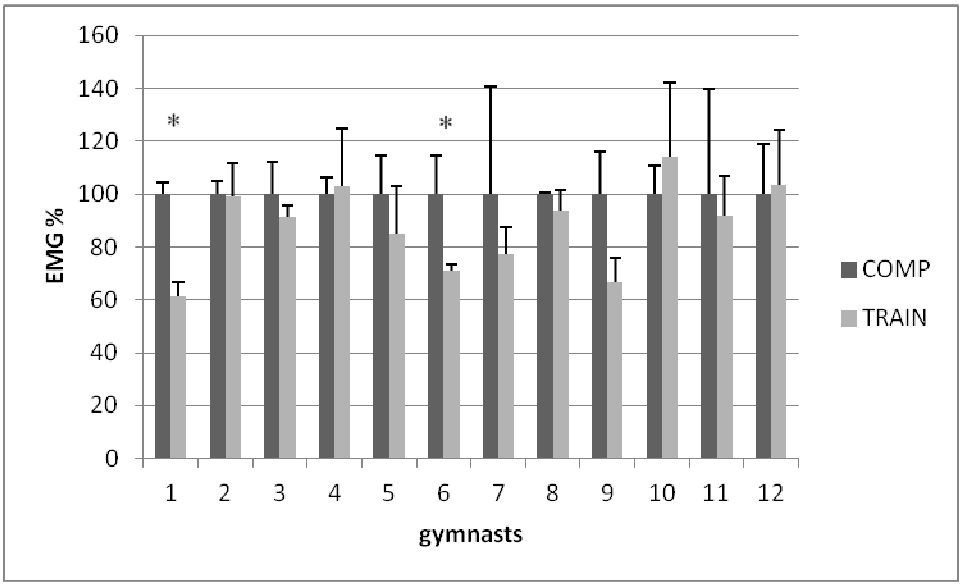

FIGURE 12 – Biceps brachii activation on competition and training rings.

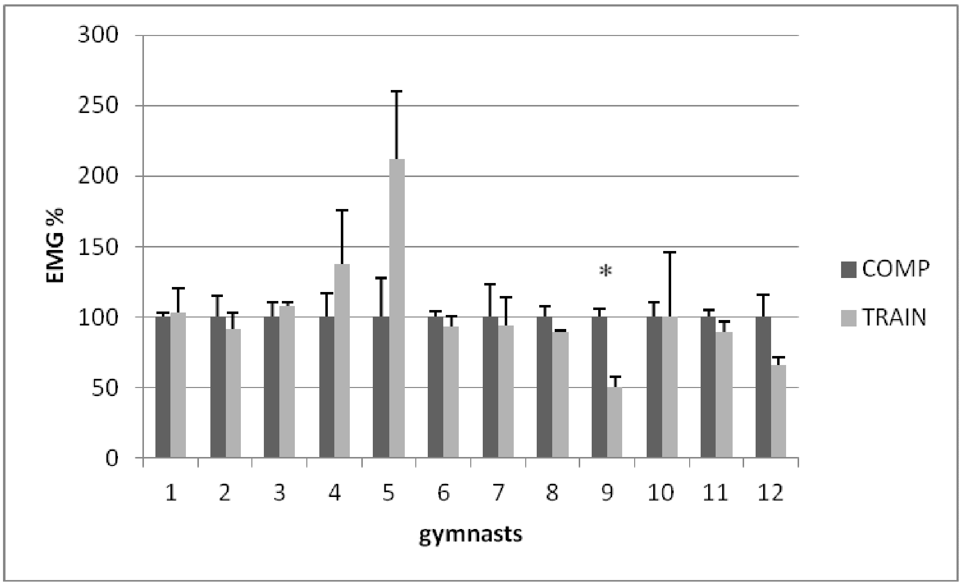

FIGURE 13 – Triceps brachii activation on competition and training rings.

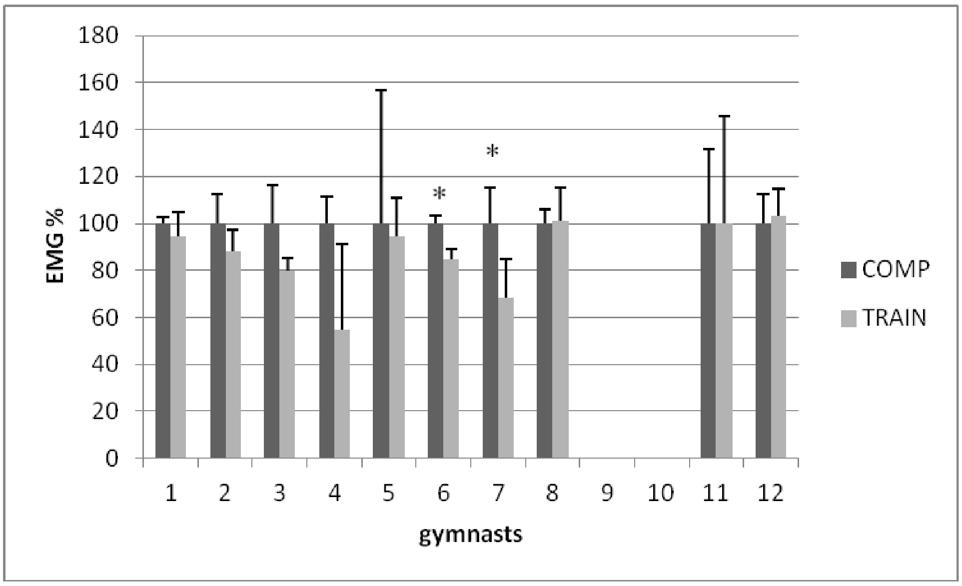

FIGURE 14 – Deltoid activation on competition and training rings.

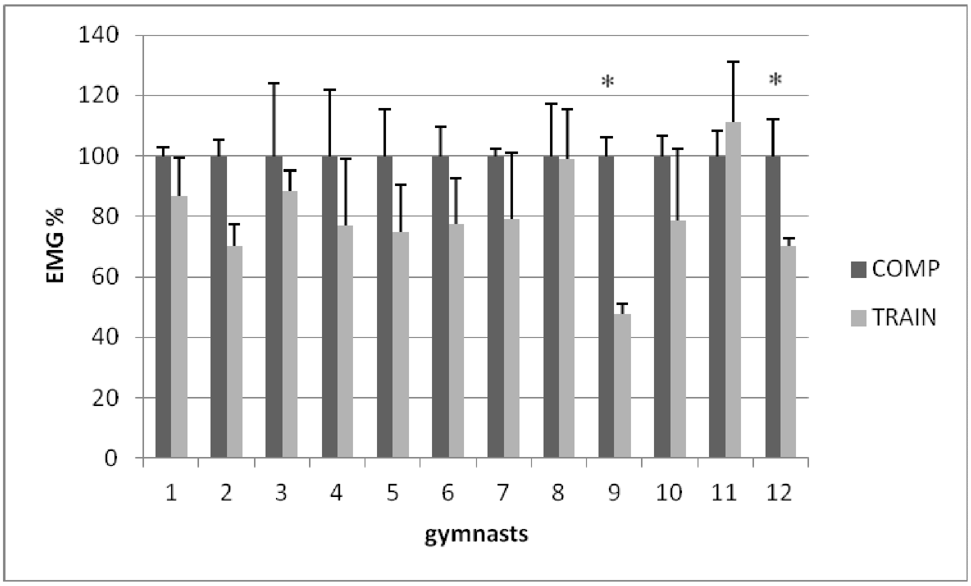

FIGURE 15 – Trapezius activation on competition and training rings.

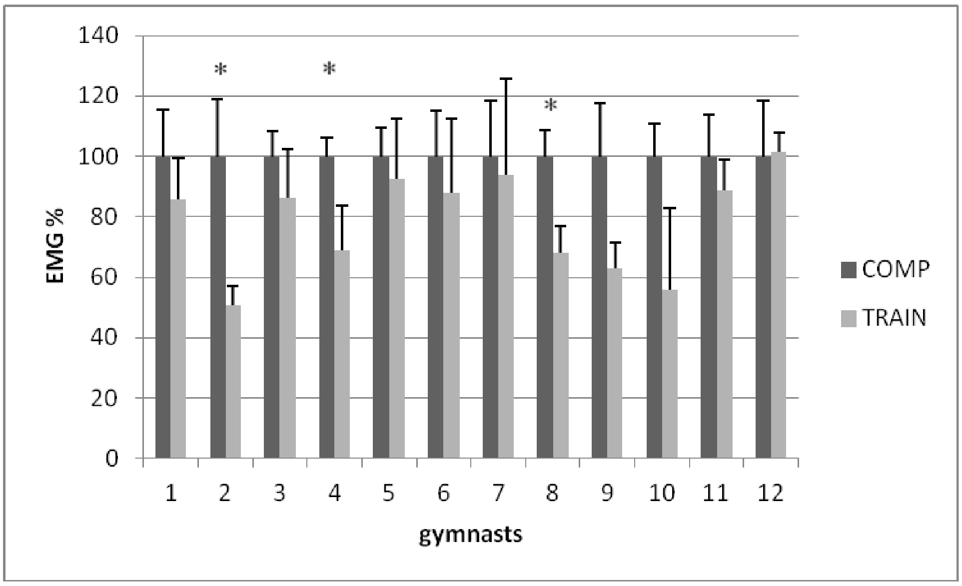

FIGURE 16 – Infraspinatus activation on competition and training rings.

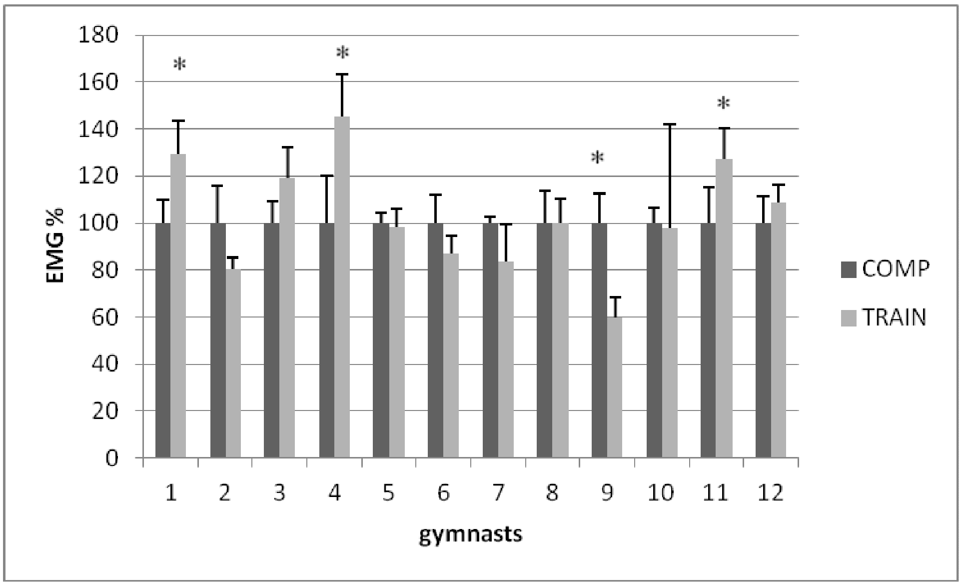

FIGURE 17 – Teres major activation on competition and training rings.

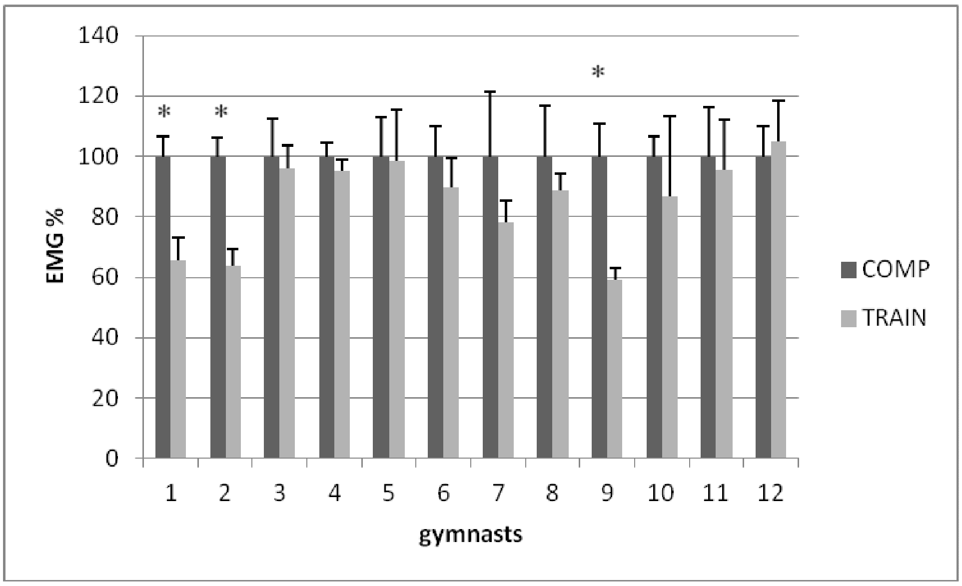

FIGURE 18 – Latissimus dorsi activation on competition and training rings.

4.4.1 Cocontraction

Cocontraction indexes were calculated for all muscle pairs. Pairs were separated by their functional status agonist, antagonist and postural. The co contraction indexes between muscles were not affected by the type of rings (PE/SE H=1.6 p=0.19; PE/BI F=1.7 p=0.18; PE/TR H=3.2 p=0.07; PE/DE F=0.1 p=0.66; PE/TZ H=0.08 p=0.77; PE/IF H=0.01 p=0.89; PE/TM H=0.1 p=0.67; PE/LT H=0.5 p=0.47; SE/BI F=0.01 p=0.97; SE/TR H=1.3 p=0.23; SE/DE H=0.01 p=0.97; SE/TZ H=0.6 p=0.42; SE/IF F=0.01 p=0.91; SE/TM H=0.1 p=0.67;

SE/LT H=0.9 p=0.31; BI/TR F=0.01 p=0.9; BI/DE H=2.7 p=0.09; BI/TZ H=0.1 p=0.68; BI/IF H=0.97 p=0.32; BI/TM F=0.1 p=0.73; BI/LT H=1.8 P=0.17; TR/DE F=0.38 p=0.53; TR/TZ H=1.1 p=0.28; TR/IF H=0.03 p=0.84; TR/TM H=1.7 p=0.18; TR/LT H=2.1 p=0.14; DE/TZ H=0.05 p=0.80; DE/IF F=3.2 p=0.07; DE/TM H=0.2 p=0.61; DE/LT F=0.08 p=0.77; TZ/IF H=0.9 p=0.32; TZ/TM H=0.3 p=0.53; TZ/LT H=0.2 p=0.62; IF/TM H=2.8 p=0.09; IF/LT F=2.7 p=0.1; and TM/LT H=0.07 p=0.78.

Those pairs were grouped according to their functional relation (agonists/agonists, agonists/antagonist, agonists/postural, antagonist/postural and postural/postural). Then, co contraction was compared along those relations and types of rings. The two-way ANOVA showed that functional relation affected the co contraction index ($F_{5,215}$=2.9 p=0.01) and the type of rings did not affect it, as well as, there was no effect of the interaction between type of rings and functional relation. The posthoc test showed that the pairs antagonists/antagonists presented less co contraction than agonists/agonists (p=0.02) and antagonists/antagonists showed less co contraction than agonist/antagonists (p=0.04).

The individual differences for muscle co contraction pairs were analyzed (TABLE 6). For gymnast #1, the functional relation affected the co contraction ($F_{5,215}$=2.3 p=0.04). For gymnast #4, the type of rings ($F_{1,215}$=5.2 p=0.02) and the functional relation ($F_{5,215}$=2.9 p=0.01). For #4, co contraction was the highest for the competition rings affected the co contraction. For gymnast #6, the functional relation affected the co contraction ($F_{5,215}$=3.5 p=0.004). For gymnast #12, the functional relation affected the co contraction ($F_{5,215}$=3.2 p=0.007). But the post hoc test was not able to find the difference among the levels of the functional relation for gymnasts #4, #6 and #12.

TABLE 6 - Mean of pairs co-contraction.

		Gymnast											
RINGS	**PAIRS**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
COMP	1	0.77±0.01	0.88±0.04	0.78±0.04	0.73±0.04	0.78±0.03	0.7±0.07	0.76±0.05	0.78±0.03	-	-	0.75±0.05	0.79±0.03
TRAIN	1	0.77±0.01	0.76±0.04	0.76±0.04	0.79±0.04	0.76±0.03	0.72±0.07	0.81±0.04	0.8±0.03	-	-	0.77±0.05	0.79±0.03
COMP	2	0.76±0.01	0.84±0.04	0.79±0.03	0.78±0.03	0.79±0.02	0.64±0.06	0.71±0.05	0.79±0.02	0.86±0.02	0.78±0.02	0.74±0.04	0.72±0.03
TRAIN	2	0.79±0.01	0.79±0.04	0.74±0.03	0.82±0.03	0.78±0.02	0.66±0.06	0.76±0.04	0.77±0.02	0.85±0.02	0.79±0.02	0.76±0.04	0.76±0.03
COMP	3	0.8±0.03	0.82±0.09	0.79±0.07	0.66±0.07	0.83±0.05	0.78±0.14	0.78±0.11	0.79±0.05	0.87±0.04	0.81±0.01	0.83±0.1	0.86±0.06
TRAIN	3	0.83±0.02	0.85±0.09	0.83±0.07	0.75±0.07	0.81±0.05	0.79±0.14	0.85±0.09	0.82±0.05	0.89±0.04	0.8±0.01	0.84±0.1	0.83±0.06
COMP	4	0.78±0.01	0.82±0.02	0.8±0.02	0.74±0.02	0.8±0.01	0.7±0.03	0.75±0.03	0.8±0.01	0.85±0.01	0.81±0.05	0.72±0.02	0.8±0.02
TRAIN	4	0.78±0.01	0.81±0.02	0.75±0.02	0.79±0.02	0.81±0.01	0.62±0.03	0.76±0.02	0.79±0.01	0.85±0.01	0.83±0.05	0.76±0.02	0.8±0.02
COMP	5	0.8±0.01	0.84±0.04	0.81±0.04	0.77±0.04	0.83±0.03	0.79±0.07	0.79±0.05	0.82±0.03	-	-	0.74±0.05	0.81±0.03
TRAIN	5	0.78±0.01	0.77±0.04	0.79±0.04	0.72±0.04	0.79±0.03	0.72±0.07	0.8±0.04	0.83±0.03	-	-	0.8±0.05	0.78±0.03
COMP	6	0.79±0.01	0.8±0.04	0.78±0.03	0.7±0.03	0.81±0.02	0.82±0.06	0.75±0.04	0.81±0.02	0.84±0.02	0.81±0.02	0.71±0.04	0.82±0.03
TRAIN	6	0.78±0.01	0.79±0.04	0.75±0.03	0.75±0.03	0.81±0.02	0.71±0.06	0.78±0.04	0.82±0.02	0.84±0.02	0.81±0.02	0.77±0.04	0.82±0.03

PAIR 1: agonist/antagonist; PAIR 2: agonist/agonist; PAIR 3: agonist/postural; PAIR 4: antagonist/postural; PAIR 5: antagonist/antagonist; PAIR 6: postural/postural.

5 DISCUSSION

5.1 Gymnasts exerting their maximal isometric contraction in isokinetic dynamometer

The main result of the isokinetic evaluation was the comparison of the right and left maximal isometric net torque of the shoulder. The gymnasts have generated equivalent right and left adduction shoulder peak torque. In fact, elite and young gymnastics have presented, for concentric shoulder protraction, to be stronger on their dominant and have equal strength for both sides for concentric shoulder retraction (COOLS et al., 2007).

For adduction, the maximal isometric strength in elite gymnasts is similar between left and right sides (6,5%). Torque production tends to be greater on the dominant side for non sportive populations (CAHALAN; JOHNSON; CHAO, 1991), or for unilateral sports (LAND; GORDON, 2011) but with different shoulder task. In our study, this characteristic may be individually restrained due their training.

Does the gymnasts asymmetry on cross come from their upper limbs/shoulder strength asymmetry? Our group's result suggests that asymmetry on cross is not related to the strength to sustain an isometric contraction of shoulder muscles during shoulder adduction at 90°. This result rejects the hypothesis $H_{0\text{-}3}$ which poses that the upper limb strength asymmetry is proportional to the cable force asymmetry during cross. However, individually, some athletes might have such different behaviour. For example, Gymnasts #4, #5, #7, #8 and #9 presented asymmetry torque index higher than 10%. These values should be observed with caution, as most gymnastics skills, as the cross, needs symmetric shoulder actions to maintain gymnast's stability on rings (FIG, 2013).

The variability in isometric shoulder adduction peak torque was similar for the right and left shoulder. Then, the group is not only shoulder adduction symmetric, but also their attempts to reach the maximal strength at the isometric test have similar behavior. In addition, five gymnasts presented low adduction strength variability (less than 5%). From those five gymnasts, three (#5, #7 and #8) presented more than 10% of shoulder torque asymmetry. Only gymnast #5 had suffered surgical intervention on right shoulder (for SLAP), eight months before the data collection. It is believed that modifications of training for theses gymnasts are needed to low shoulder torque asymmetry. Discrete measures of variability allows the quantification of movement variability in a way that does not rely on a large sample size, and provides information which is easy to interpret and understand by the athlete or coach (FARANA et al., 2015; PREATONI et al., 2013; WILLIAMS et al., 2011). On the other hand, three gymnasts (#2, #6 and #10) had very different variability between sides.

Thus, the results suggest that more variability in peak adduction might be related to the asymmetry in movement variability.

To describe and to compare the left and right maximal isometric shoulder torques led to observe that some individual behaviour of elite gymnasts is not alike. Results (FIGURE 7) have shown high correlation between torque values and shoulder angles on rings. Although group comparisons show that left and right shoulders are equally strong, some individuals have variability behaviour that calls our attention. Thus, from these values it can be expected that these gymnasts may perform the cross with small asymmetric values on cable forces.

5.2 The kinematics of the shoulder

The analysis of shoulder kinematics led to find that shoulder angle was larger when the gymnasts have performed the cross with training rings. Thus, in terms of gymnastics performance, their score should be higher during training condition compared to competition. A possible explanation for that is that the training device makes easier the cross performance (READHEAD, 1997; SMOLEVSKIY; GAVERDOVSKIY, 1996). Nevertheless, coaches should be, and probably are, aware that it is necessary to train with both types of rings (ARKAEV; SUCHILIN, 2004). Training device seems to allow elite gymnasts to reduce shoulder asymmetry and deviations from 90° whilst performing the cross, which can lower execution penalties in competition.

Elite gymnasts presented closer shoulder angles to 90° when performing the cross with training device. This result rejects hypothesis H_{0-1} which poses that shoulder angles would be similar between training and competition rings. High similarities between training and competition conditions are required to achieve a replication of biomechanics on the skill during training drills (IRWIN; BEZODIS; KERWIN, 2013; IRWIN; KERWIN, 2005, 2007).

How large is deviation from the ideal shoulder angle at the cross at the competition rings and the training rings? Most of the gymnasts performed the cross in the training condition with less shoulder angle deviations from the 90° objective that in the competition condition. Differences between conditions (RMSD) were higher for left shoulder angles, which served to reduce asymmetry in the training condition. Gymnasts shoulder angles were larger for right (RMSD 4.26°) and left (RMSD 7.35°) sides when performing the cross on training rings. Considering the gymnastics regulations, it is desirable to employ training devices approaching the drill execution to the accomplishment of the rules requirements (READHEAD, 1997), as to that facilitate training performance with less deviation from 90° of shoulder abduction.

The asymmetry shoulder angle index was similar for training and competition rings when the gymnasts performed the cross. The knowledge about the shoulder asymmetry in the different conditions facilitate the understanding and the development of the gymnastic skill (EXELL et al., 2012b), improving performance and developing more complex skill combinations safely and effectively (ARKAEV; SUCHILIN, 2004; READHEAD, 1997).

Specifically on the static position of cross, asymmetries have directly influence on performance, considering there are penalties for asymmetrical posture and the shoulder presenting angle deviation from 90º (FIG, 2013). This finding supports the use of the training device as allowing gymnasts to train closer to the desired target shoulder abduction angle, improving the posture stability as the position is balanced within rings cables. It is suggested that the use of the training device may be beneficial for improving performance of the cross on rings, allowing improvement of the key skills (IRWIN; KERWIN, 2007).

The results suggest that the use of training device should be beneficial for improving performance of the cross on rings. Moreover, it is necessary to consider other measurements besides video analysis, such as force-instrumented rings (BREWIN; YEADON; KERWIN, 2000), for a comprehensive understanding (IRWIN; BEZODIS; KERWIN, 2013) of the neuromuscular and kinetics demands (IRWIN; KERWIN, 2007b; WINTER, 2009).

Movement pattern alterations may lead to joint instability and biomechanics changes in task (BONATO et al., 2003), facilitating to increase injury risk or cause it directly (BRERETON et al., 1999). In this research, there was not a decrease of performance during the trials. Coefficient of variation values among trials was lower and comparable with competition condition.

Angle asymmetry profiles were influenced by strength profiles. For eight gymnasts the stronger shoulder was the less angled shoulder on rings. More studies would be necessary to determine if diminishing shoulder strength asymmetry would diminish the asymmetry on cross, independently of side dominance on cross. Similar results of shoulder asymmetry were found for gymnasts performing handspring, with touchdown values being larger for the opposite side to the lead leg and take off values being larger for the lead leg side (EXELL et al., 2012b). The asymmetry at the shoulders may represent a compensatory mechanics to allow the maintenance of the static balance with shoulder abducted position.

Research on gymnastic skills has suggested specific kinematics modifications to progressions in an attempt to make them more similar to the target skill and, therefore, more effective for skill learning (ELLIOTT; MITCHELL, 1991). In the present study, specific changes in the shoulder angle of cross diminished the deviations from the desirable performance, considered target skill by the CP. The most effective drills would be those that exhibit biomechanical characteristics that are similar to the target skill (IRWIN; KERWIN, 2005a; IRWIN; KERWIN, 2007b; KOLAR; KOLAR; STUHEC, 2002).

The description and analysis of the left and right shoulder angle during the cross performance on training and competition rings have provide useful information for coaching gymnastics skills, which may subjectively appear to be symmetrical (EXELL et al., 2012b). The understanding of these asymmetries can facilitate the development of understanding of the mechanisms of this gymnastic skill which in turn can inform strength and condition regimes (ARKAEV; SUCHILIN, 2004; SMOLEVSKIY; GAVERDOVSKIY, 1996)

5.3 Mechanics of the Cable forces

The main result of the cable forces measurements was the comparison of the right and left traction forces during cross on training and on competition rings. The gymnasts have performed the cross with equivalent cable forces and asymmetry on training and competition rings. This result accepts the hypothesis H_{0-2} which poses that cable forces would be similar on training and competition rings. Training rings sustaining the gymnast' forearms affect in diminishing the resistance arm of shoulder joint. By mathematical modelling, the forearm support would reduce the cable forces (CARRARA; MOCHIZUKI, 2008). However, considering that the gymnasts in the present study performed the cross on the training rings with increased shoulder angles, the cable forces results remained identical for group's results.

Although the energy on a drill may be similar on a skill, this does not always correspond to similarities in the movement pattern (IRWIN; KERWIN, 2007), effecting on physiological adaptations that occur through training may not be effective or desired. Based on the principle of specificity of training (BOMPA, 1999; SIFF; VERKHOSHANSKY, 2004) it may be suggested that the training device is effective in the training, as similar forces were found. Low variability on forces means that a controlled skill is performed (WILLIAMS et al., 2011). This is important when considering the rings instable characteristics.

The shoulder is the most commonly injured joint in men's gymnastics (CAINE; NASSAR, 2005; NASSAR; SANDS, 2009). Therefore, MAG coaches utilize apparatuses aiming to reduce the mechanical load to allow gymnasts to execute and repeat the cross during training (SMOLEVSKIY; GAVERDOVSKIY, 1996; READHEAD, 1997). Meanwhile, individual results showed that gymnast #1 had inverted the side forces using training rings. Gymnast #10 (rings RMSD 12,52°) and gymnast #11 (rings RMSD 18,13°) presented higher values of cable force on training rings, due to increased shoulder and cable angles. In that case, when a gymnast performs the cross with such amount of shoulder angle difference, the physical demands may not be lowered as expected by the coaches.

The variability on cable forces was similar for sides and rings, around 10% for group. Individually, variability was lower than 5% for most of the gymnasts (except for gymnasts #7 and #8). Asymmetry values were lower for gymnasts #1 and #8, what improve performance (EXELL et al., 2012b). Because the cross is a closed skill, well learned and performed by experts, it is reasonable to assume a stable movement pattern would exist (GABRIEL, 2002; WILLIAMS et al., 2011). Furthermore, each gymnast is constrained by the environment (rings) and the performance regulations of artistic gymnastics (BUSQUETS et al., 2013; FIG, 2013).

It is documented in coaching literature that “good” progressions safely and effectively serve to guarantee further improvement in gymnastic skill development (ARKAEV; SUCHILIN, 2004; READHEAD, 1997). Appropriateness of skill progression based on their biomechanical similarities to the final skill has been outlined (ELLIOTT; MITCHELL, 1991).

This section has highlighted that, compared to competition rings, the cross on training rings showed high similarity in its cables forces (physical demand) but not equal in its kinematics (skill pattern). Based on the principle of training specificity, this provides a dichotomy in terms of what constitutes an effective drill (IRWIN; KERWIN, 2007). Conversely, the kinematics changes in the cross were in benefit of reaching the target skill. Irwin and Kerwin (2005) suggested that the most effective progressions would be those that exhibit biomechanical characteristics that are similar to the target skill.

If there are angular asymmetries on the skill related with limbs strength, it would be possible to balance limbs strength asymmetry to balance skill asymmetry. Also, if the training apparatus facilitate the skill, it would diminish the asymmetry values.

5.4 Asymmetry index on rings

The Asymmetry index is related to the differences on horizontal and vertical cable forces. The assumption was that this index would be related to the differences between the right and left shoulder angles. The linear regression model has just showed a linear relationship between the asymmetry index and the shoulder angle asymmetry when the cross was performed on the competition rings (FIGURE 8). This result suggests that the importance of the cable forces increases when the cross is performed with the competition rings.

The importance of the cable forces for the shoulder angle changes with the type of the rings. Considering a static condition, we expected that the equilibrium among vertical and horizontal forces of the cables and the gravitation would be enough to sustain the cross posture. Therefore, if the right and left cable forces were different, we would expect a tilt in the shoulder horizontal alignment. This is the rings Asymmetry index that was calculated with the vertical and horizontal cable forces and right and left cables angles. For the competition rings, about 1/3 of the asymmetry shoulder angle is related to the unbalanced cable forces. For the training rings, there were no linear relation between shoulder angle asymmetry and the cable forces. These results accepts partially the hypothesis H_{0-4} which poses that shoulder angles asymmetry results from the position and force cables asymmetry.

Other side-to-side comparisons were done. Mostly, they have show that right and left angles and forces measured in our study were similar between the training and competition rings. Asymmetry scores are used to analyse sport performance (EXELL et al., 2012c) or to allow for asymmetry comparisons between athletes over time and between asymmetry and performance or injury occurrence (EXELL et al., 2012a). Individually, all gymnasts experienced equivalent forces when adopting the training or competition rings. Measuring forces over upper limbs is bi folded. Firstly to verify if there is similar distribution of forces, comparable between the apparatuses, aiming to know if they provide training specific conditions. Secondly, to verify if the training apparatus induces joint forces that can be considered risk of injuries (BRADSHAW; HUME, 2012). To know the pattern over joint forces implies on injuries risk prevention.

Considering training purposes, it might be highlighted whether or not the shoulder muscles reduces their activation when performing the cross on training rings. This issue will be discussed in the next section. At this moment, kinematics and kinetics data support the idea that belts under upper arms on the rings improve the shoulder angles performance.

Should the training rings also a choice for injury prevention? Our results show that the use of the training device leads the gymnasts to execute the cross closer to the desired 90° shoulder abduction angle, without negatively influencing the cable forces, i.e, inducing cable forces higher than those present on the competition rings. Loading frequency and total loading time appear in combination with the loading amplitude as key determinants of the mechanical stimulus in gymnastics (BRADSHAW; HUME, 2012).

Next studies should approach on how balancing the strength asymmetry would influence asymmetry of cross on rings.

5.5 Electromyography

The main results of the EMG measurements were to describe and to compare the shoulder muscles activation pattern of the cross on training and on competition rings. The gymnasts performed the cross with similar shoulder muscles activation pattern over both rings. This result accepts the hypothesis H_{0-5} which poses that activation pattern of shoulder muscles in the cross would be similar on training and competition rings.

The group analysis results show that shoulder muscle activation during cross does not changes when it is compared the training and competition rings. These results are divergent from other study, where the muscle activation on training rings was lower, except for muscle teres major (BERNASCONI et al., 2004). The equipment configuration, as the support distance on forearm from the handgrip, in that study was 0.18 m while on present study it was 0.12 m, what could explain the difference on muscle activation.

Three elite gymnasts (#3, #5 and #10) did not change the level of activation with the competition and training rings. Four gymnasts only changed the activation of one muscle between competition and training rings, whose only one changed the activation of the deltoid muscle, decreasing its activity for the training rings. The other gymnast that has reduced the deltoid activation with training rings also has decreased the activation of the biceps brachii. Moreover, five gymnasts changed the activation of two or more muscles when training and competition rings conditions are compared. Most of changes in activation, individually, were lower activation of postural and antagonist muscles for the training rings. Considering group analysis, the absence of group differences between competition and training rings suggest that differences could be more likely to individual-centred patterns of the gymnast performing the skill than apparatus condition.

Three gymnasts increased teres major activation with the training rings while for another gymnast it has decreased. For other study the teres major activation was not similar in training and competition rings (BERNASCONI et al., 2004). The larger activation of teres major could be related to the voluntary shoulder medial rotation due to using the training rings (BERNASCONI et al., 2004). Also, these gymnasts could be doing an over grip, a practice that changes the mechanics of the cross. This medial rotation is done principally by the muscle teres major, one of the prime movers for this action (LEVANGIE; NORKIN, 2005). By the present study, it is more likely that these three gymnasts are changing substantially the motor pattern on training rings, than being influenced by equipment inherent characteristics, as results for the other nine gymnasts were similar activation of teres major in training and competition rings. Moreover, differences on teres major muscle appear to be caused by gymnast not using the scapulae to limit humerus displacement on training rings. Scapulae not tilted anteriorly leads to different humerus stablilization by teres major in abducted position (LEVANGIE; NORKIN, 2005). For the cross, changing the shoulder abduction position on anterior-posterior position should change the balance of the gymnast on the rings. Scapular kinematics alterations have been identified in subjects with a tight soft-tissue structures in the posterior shoulder region, excessive thoracic kyphosis or with flexed thoracic postures (LUDEWIG; REYNOLDS, 2009), characteristics that can be present on gymnasts. Finally, humerus positioned in medial rotation leads to labrum compression, what is a risk of injury (LUDEWIG; REYNOLDS, 2009).

Three gymnasts reduced the activation of latissimus dorsi muscle for training rings. These results are also found before; but, for the whole group of participants (BERNASCONI et al., 2004). Their recording method (two muscles studied per trial) may have influenced the muscle activity and coordination in that study (BERNASCONI et al., 2004).

The individual activation patterns for performing the cross could presented low variability. Differences in the kinematic variability associated with each gymnast and skill technique support that the functionality of variability may not be generalized (BARTLETT; WHEAT; ROBINS, 2007) and that different motor strategies can be used to achieve the same motor task (CLARK, 1995; IRWIN, GARETH; KERWIN, 2007a; PREATONI et al., 2013). The individual differences probably were covered by the mean results of the EMG activation. The cocontraction analysis will provide more information about how muscles were activated.

5.5.1 Cocontraction between agonist, antagonist and postural muscles

The muscles pairs were separated by their functional status agonist, antagonist and postural and they had similar activation. The cocontraction indexes between muscles were not affected by the type of rings. The modulation of the muscle pair's activation was similar for the training and competition rings.

Our results show different comparisons for the cocontraction. Instead of only look at the muscle pairs, we have grouped the muscle pairs according their anatomical motor function. The cocontraction divided by functional groups permits to evaluate possible strategies coordinated by the nervous system to achieve the joint stability and maintain the shoulder position during the cross. In fact, no other study has done such a kind of cocontraction analysis when several muscles were evaluated.

Individual analysis has provided information suggesting that the gymnasts have used different strategies to stabilize the joints during the cross. The cocontraction is one of most simple neuromuscular strategy to increase joint stability. For example, four gymnasts have shown different strategies for cocontraction between competition and training rings. One serious problem for the EMG evaluation during cross is the fact that muscles activation is higher than the conventional isokinetic evaluation. This finding highlights that certain drills may be similar to the target skill in terms of movement pattern but different in terms of the musculoskeletal loading (IRWIN; KERWIN, 2007).

When all the muscles pairs were compared, it was observed effect of motor function. Pairs antagonists/antagonists presented less cocontraction than agonist/antagonists. It seems that coactivation reflex is an important issue for the joint stability and to build the muscle synergy. Such behaviour may have relation with muscular synergy, once agonist muscles group may have more contribution to shoulder action (BOIAS et al., 2009; PEREIRA et al., 2009). This information is crucial to properly interpret muscle coordination from EMG signals (HUG, 2011). The cross lasted four seconds, from support until the end of static maintenance, and no indices of skill failures (PREATONI et al., 2013) task repetition were observed, as shoulder angles CV were below 0.05.

Moreover, there are evidences for altered muscle activation associated with shoulder impingement, rotator cuff tendinopathy, rotator cuff tears, glenohumeral instability, adhesive capsulitis, and stiff shoulders (LUDEWIG; REYNOLDS, 2009). Besides gymnasts had been questioned about their shoulder conditions and the ability to perform the cross, any of these shoulder clinical conditions could be presented in the participants, and had influenced on results obtained. Gymnasts performing without clinical evaluation can be a common practice, as they still able to perform even feeling discomfort (CARAFFA et al., 1996).

It has been suggested that progressions that are biomechanically similar to the target skill may be more effective in the development of that skill (ARKAEV; SUCHILIN, 2004; ELLIOTT; MITCHELL, 1991; SMOLEVSKIY; GAVERDOVSKIY, 1996), a concept which concurs with the principle of training specificity (BOMPA, 1999). From a coaching perspective, the importance of identifying the most effective progressions is primary to coaching process and maximizes the probability of performers achieve full potential (IRWIN; HANTON; KERWIN, 2004; IRWIN; HANTON; KERWIN, 2005a; READHEAD, 1997).

Studies about gymnastic skills have suggested specific kinematics modifications to progressions in an attempt to make them more similar to the target skill and, therefore, more effective for skill training (BROWN; ZIFCHOCK; HILLSTROM, 2014; ELLIOTT; MITCHELL, 1991; IRWIN; KERWIN, 2005; READHEAD, 1997). The present thesis have approached over the biomechanical similarities of the training device, which may can be considered as a skill progression for those gymnasts unable to perform the cross within proper requirements of shoulder angle on the competition rings.

5.6 Study Limitations

It was not possible to use a 3D motion system for kinematics because the cross evaluation were executed outside the Laboratory. Then, the kinematics was limited to one motion plane. The strain gauge sensor was one dimensional. The one dimension data simplifies the analysis model, but it matches with kinematics data available. The number of repetitions was limited by the task, time of rest and gymnast time availability, what may decrease statistics power. The normalization EMG procedure might affect the condition's difference. Nevertheless, the training facilities and apparatuses used advances the ecological validity over rings studies, enhanced by the elite gymnasts who had volunteered.

6 CONCLUSION

The main objective of this doctoral research was to investigate the biomechanics of the cross on training and competition rings device. Underlined by the principles of training specificity, individualization, overload and progression, and using biomechanical analysis techniques, the findings of this study provided methods to quantify the biomechanics of shoulder between these two devices for performing the cross on rings. Gymnasts' performances of cross on rings were characterized by on an individual basis. The study investigated about the following on the cross:

1) Isokinetic

The upper limb strength asymmetry was proportional to the cable force asymmetry during cross. Shoulder angles asymmetries of cross on rings were right correlated with strength dominance and asymmetry on isometric tests. Based on the findings, it should be emphasized that coaches need to consider the gymnast asymmetry strength and its asymmetries on cross to improve their performance.

2) Kinematics

The shoulder angles of the cross were different on training and competition rings. Lower deviation from target skill and lower shoulder asymmetry was presented on training rings. Differences observed for limbs and asymmetry within each gymnast should be considered as important information source of individual variation in this skill. Most gymnasts performed the cross in the training condition with less deviation from 90° than on competition rings. Based on the findings, it should be emphasized that coaches need to consider individual variations when applying results from group data. The training device with forearm support allowed gymnasts to perform the drill of cross with the shoulders more abducted (closer to 90°), improving specificity between training and the target skill. Moreover, lowered limb asymmetry was presented with the training device.

Training device seems to allow elite gymnasts to reduce shoulder asymmetry and deviations from 90° whilst performing cross, which can lead to execution penalties in competition.

3) Kinetics

The cable forces on cross were identical on training and competition rings. There was a trend to lower force asymmetry on training rings. Asymmetry index on cross were equivalent on training and competition rings, presenting the specificity of training apparatus.

4) Electromyography

The activation pattern of shoulder muscles in the cross was similar on training and competition rings. Individual variations occurred for nine gymnasts, and for two gymnasts the muscular cocontraction was altered with training device.

The training rings characteristics examined in training environment added new theoretical knowledge about the cross, with ecological validity, having used biomechanics to identify similar characteristics on rings and training apparatus.

The training rings with forearms support allowed gymnasts to perform the drill of cross with less shoulder deviations, a practice that aims to attend the gymnastics sportive requirements. Moreover, lowered limbs asymmetry was presented with the training device, with similar cable forces and muscle activation. Information about similarities in motor pattern, kinetics and muscles activation between the training drill and target skills from this study embrace a comprehensive understanding of the cross on rings, allowing to recommend using the belts training apparatus. Gymnasts' orientation is needed to reproduce the task the same way as performed on rings, in order to maintaining the proper similar characteristics of the training rings.

Based on the findings, it should be emphasized that individual variations need to be considered besides the results from group data. For the next studies it could be done: a follow up with participant gymnasts; a research about the specificity of other devices; or how the cross is developed in a long term. It would be useful to consider the applicability of the findings of this study to other gymnastic groups, such as novice gymnasts learning the skill.

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APPENDIX 1 - TERM OF FREE AND INFORMED CONSENT (TFIC)

I - Participants identification data or legal representative

1. Participant data

Full name ______________________________

Gender ☐ Male

Document ______________________________

Date of birth ______________________________

Address ______________________________

ZIP code ______________________________

Phone ______________________________

e-mail ______________________________

2. Legal representative data

Full name ______________________________

Relationship (parent, tutor, etc.) ______________________________

Gender ☐ Male
☐ Female

Document ______________________________

Date of birth ______________________________

Address ______________________________

ZIP code ______________________________

Phone ______________________________

e-mail ______________________________

II - Data about scientific research

1. Title of Research Project: Biomechanical Analysis of Cross on training and competition rings.

2. Research supervisor: Prof. Dr. Luis Mochizuki

3. Position/Function: Associate Professor of University of São Paulo - EACH

4. Research risk evaluation:

X	MINIMUM RISK		LOW RISK		MEDIUM RISK		HIGH RISK

(Probability that participant suffer any hazard as immediate or late consequence from the study)

5. Research duration: Approximately 60 minutes to complete the experimental protocol.

III - Explanations from researcher to the participant or his legal representative about the research, in clear and simple form, provides:

Justification and research objectives:

In gymnastics different rings are utilized to training the cross, what causes unknown muscular demands for each situation. The aim of this experiment is to measure differences in shoulder muscles coordination with different rings - training and competition.

Procedures utilized and purposes:

a) The data collecting will occur in your gym and apparatuses were you train, with the presence of the researches and coaches. The collecting time will be 60 minutes approximately, being the time you have to be available. It is optional to use your training equipments (bandages and grips).

Research participant signature or Legal representative	Researcher signature (stamp or legible name)

b) The procedures that you will do:

- warm up

- Initially will be realized skin peeling and washing of nine points of your right shoulder, to fix disposable superficial electrodes (non invasive), to evaluate muscular activities of your right shoulder.

- Three crosses you be performed in each experimental conditions: on competition and on training rings, with two minutes of rest between each cross.

1. Discomforts and expected risks:

The inherent risk in the data collecting is minimal, because the skills asked to you are typical of a gymnastics training session. The tests executed are non invasive; therefore you will not feel any pain sensation or discomfort. You will be protected by anonymity, having any possibility of personal identification results.

2. Benefits that can be achieved:
Moreover than contribute with biomechanics of shoulder muscles, the results of this research can help elucidating training specificity, prescription of muscular strengthening and shoulder injury prevention.

IV - CLARIFYING GIVEN BY RESEARCHER ABOUT RESEARCH PARTICIPANT`S GUARANTEES:

1. You will have access, anytime, to information about procedures, risks and benefits related to the research, including elucidating eventual doubts;
2. You will be free to remove your consent anytime and leave the research, without any loss;
3. Your collect data will be confidential, being used only to research purposes; and
4. You will be available to be assisted at HU or HCFMUSP for any occurrences resulted from research.

V - INFORMATION ABOUT NAMES, ADDRESSES AND TELEPHONES OF THE RESEARCH RESPONSIBLE, TO CONTACT ON CASE OF CLINICAL OCCURRENCES AND ADVERSE EFFECTS.

Prof. Dr. Luis Mochizuki, Professor Orientador. Email: mochi@usp.br
Paulo Carrara, Doutorando em Educação Física. Email: paulocarrara@usp.br
ADDRESS: Laboratório de Biomecânica da Escola de Educação Física e Esporte da Universidade de São Paulo. Rua Professor Mello Moraes, 65 - Cidade Universitária - CEP: 05508-900. Tel: (11) 3091-3184

VI - POS CLARIFYING CONSENT

I declare that, after conveniently informed by the researcher and have understood what was explained, I consent to participate in the present research project.
São Paulo, _____/_____/_____

Research participant signature or Legal representative	Researcher signature (stamp or legible name)

INSTRUCTIONS TO fulfilment (Resolution of National Council of Health 196, October 10, 1996)

1. This term will contains registered information that the researcher will provide to the participant, in clear and accessible communication, avoiding technical terms not compatibles with the interlocutor`s level of knowledge.

2. The risk evaluation must be detailed, considering any possibility of intervention and harm to participant physical integrity.

3. This term can be fulfilled legibly in manuscript or by electronic means.

4. This term must be elaborated in two copies, being one kept by the participant or his legal representing and one filed by the researcher.

5. The Term of Free and Informed Consent submitted to the analysis of the Committee on Ethics in Research must be identical to that provided to the participant.

APPENDIX 2 - TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO

(Instruções para preenchimento ao final)

I - DADOS DE IDENTIFICAÇÃO DO SUJEITO DA PESQUISA OU RESPONSÁVEL LEGAL

1. DADOS DO INDIVÍDUO

Nome completo ____________________

Sexo ☐ Masculino ☐ Feminino

RG ____________________

Data de nascimento ____________________

Endereço completo ____________________

CEP ____________________

Fone ____________________

E-mail ____________________

2. RESPONSÁVEL LEGAL

Nome completo ____________________

Natureza (grau de parentesco, tutor, curador, etc.) ____________________

Sexo ☐ Masculino ☐ Feminino

RG ____________________

Data de nascimento ____________________

Endereço completo ____________________

CEP ____________________

Fone ____________________

E-mail ______________________________

II - DADOS SOBRE A PESQUISA CIENTÍFICA

1. Título do Projeto de Pesquisa: Análise biomecânica do crucifixo em argolas de treino e de competição.
2. Pesquisador Responsável: Prof. Dr. Luis Mochizuki
3. Cargo/Função: Professor Associado da Universidade de São Paulo - EACH
4. Avaliação do risco da pesquisa:

X	RISCO MÍNIMO		RISCO BAIXO		RISCO MÉDIO		RISCO MAIOR

(probabilidade de que o indivíduo sofra algum dano como consequência imediata ou tardia do estudo)

5. Duração da Pesquisa: Aproximadamente 60 minutos para realização do protocolo experimental.

III - EXPLICAÇÕES DO PESQUISADOR AO INDIVÍDUO OU SEU REPRESENTANTE LEGAL SOBRE A PESQUISA, DE FORMA CLARA E SIMPLES, CONSIGNANDO:

1. Justificativa e os objetivos da pesquisa:

Na Ginástica Artística diferentes tipos de argolas são utilizados para o treino do crucifixo, o que ocasiona solicitações musculares desconhecidas para cada situação. O objetivo deste experimento é mensurar diferenças na coordenação muscular do ombro com a utilização de diferentes argolas – de treino e de competição.

2. Procedimentos que serão utilizados e propósitos

a) A coleta de dados ocorrerá no seu ginásio e aparelhos onde treina, com a presença dos pesquisadores e dos treinadores responsáveis. O tempo de coleta será de aproximadamente 60 minutos, sendo o tempo que terá que ficar disponível. O uso dos equipamentos de treino (bandagens e protetor palmar) é opcional.

Assinatura do sujeito da pesquisa ou responsável legal	Assinatura do pesquisador (carimbo ou nome legível)

b) Os procedimentos executados por você serão:

- aquecimento
- inicialmente será realizada a raspagem e limpeza de oito pontos da pele da região do seu ombro direto, para a colocação de eletrodos descartáveis de superfície (não invasivos), para avaliar a atividade muscular dos músculos do seu ombro direito.
- três crucifixos serão realizados em cada uma das duas condições experimentais: uma em argolas de competição e três em argolas de treino, com descanso de dois minutos entre cada crucifixo.

3. Desconfortos e riscos esperados:

O risco envolvido na coleta de dados é mínimo, pois os movimentos a você solicitados são típicos a uma sessão de treino da Ginástica Artística. Os testes serão realizados de forma não invasiva, portanto você não sentirá nenhuma sensação de dor ou desconforto. Você estará protegido pelo anonimato, não havendo qualquer possibilidade de identificação pessoal dos resultados.

4. Benefícios que poderão ser obtidos:

Além de contribuir com avanços na biomecânica dos músculos do ombro, os resultados deste estudo podem auxiliar no planejamento do treino e na prescrição de atividades de fortalecimento muscular para a prevenção de lesões no ombro.

IV - ESCLARECIMENTOS DADOS PELO PESQUISADOR SOBRE GARANTIAS DO SUJEITO DA PESQUISA:

1. Você terá acesso, a qualquer tempo, às informações sobre procedimentos, riscos e benefícios relacionados à pesquisa, inclusive para dirimir eventuais dúvidas;

2. Você terá liberdade de retirar seu consentimento a qualquer momento e de deixar de participar do estudo, sem que isto lhe traga qualquer prejuízo;

3. Os dados de sua coleta serão confidenciais e sigilosos, sendo usados apenas para fins de pesquisa;

4. Você terá disponibilidade de assistência no HU ou HCFMUSP por qualquer ocorrência resultante da pesquisa.

V - INFORMAÇÕES DE NOMES, ENDEREÇOS E TELEFONES DOS RESPONSÁVEIS PELO ACOMPANHAMENTO DA PESQUISA, PARA CONTATO EM CASO DE INTERCORRÊNCIAS CLÍNICAS E REAÇÕES ADVERSAS.

Prof. Dr. Luis Mochizuki, EACH. Email: mochi@usp.br Tel: 3091-8805 CEP EACH: Email: cep-each@usp.br Tel: (11) 3091-1046. Responsável: Luís Fernando S. Moraes

VI - CONSENTIMENTO PÓS-ESCLARECIDO

Declaro que, após convenientemente esclarecido pelo pesquisador e ter entendido o que me foi explicado, consinto em participar do presente Projeto de Pesquisa. Autorizo que os resultados da pesquisa sejam divulgados em eventos e artigos científicos.

São Paulo, _____/_____/_____

______________________________	______________________________
Assinatura do sujeito da pesquisa ou responsável legal	Assinatura do pesquisador (carimbo ou nome legível)

APPENDIX 3 - UPPER EXTREMITY LANDMARKS (RAB, PETUSKEY; BAGLEY, 2002).

Point	name	Anatomical point
Thorax:	C7:	Processus Spinosus (spinous process) of the 7th cervical vertebra
	T8:	Processus Spinosus (spinal process) of the 8th thoracic vertebra
	IJ:	Deepest point of Incisura Jugularis (suprasternal notch)
	PX:	Processus Xiphoideus (xiphoid process), most caudal point on the sternum
Clavicle:	SC:	Most ventral point on the sternoclavicular joint
	AC:	Most dorsal point on the acromioclavicular joint (shared with the scapula)
Scapula:	TS:	Trigonum Spinae Scapulae (root of the spine), the midpoint of the triangular surface on the medial border of the scapula in line with the scapular spine
	AI:	Angulus Inferior (inferior angle), most caudal point of the scapula
	AA:	Angulus Acromialis (acromial angle), most laterodorsal point of the scapula
	PC:	Most ventral point of processus coracoideus
Humerus:	GH:	Glenohumeral rotation center, estimated by regression or motion recordings
	EL:	Most caudal point on lateral epicondyle
	EM:	Most caudal point on medial epicondyle
Forearm:	RS:	Most caudal–lateral point on the radial styloid
	US:	Most caudal–medial point on the ulnar styloid

APPENDIX 4 - SEGMENT DEFINITIONS USED FOR BIOMECHANICAL MODEL (RAB, PETUSKEY; BAGLEY, 2002).

Moving segment	**Reference segment**	**Designated joint movement**
Head	Neck	Head
Neck	Shoulder girdle	Neck
Shoulder girdle	Pelvis	Trunk
Left upper arm	Trunk	L shoulder
Right upper arm	Trunk	R shoulder
Left lower arm (elbow center to distal ulna)	Left upper arm	L elbow
Right lower arm (elbow center to distal ulna)	Right upper Arm	R elbow
Left hand	Left lower arm (elbow L wrist center to wrist center)	L wrist
Right hand	Right lower arm (elbow R center to wrist center)	R wrist
Pelvis	Global (Laboratory)	Pelvic obliquity

APPENDIX 5 - ANATOMICAL POINTS TO INPUT KINEMATICS MODEL.

# point	Anatomical point	# point	Anatomical point
1	Head		
2	suprasternal notch		
3	xiphoid process		
4	Right side	20	Left side
5	iliac crest	21	iliac crest
6	Angulus Acromialis	22	Angulus Acromialis
7	Proximal cluster (humerus)	23	Proximal cluster (humerus)
8	Upper cluster (humerus)	24	Upper cluster (humerus)
9	Lower cluster (humerus)	25	Lower cluster (humerus)
10	medial epicondyle	27	medial epicondyle
11	cluster (forearm)Upper	28	cluster (forearm)Upper
12	Lower (forearm)Upper	29	Lower (forearm)Upper
13	Distal (forearm)Upper	30	Distal (forearm)Upper
14	radial styloid	31	radial styloid
15	ulnar styloid	32	ulnar styloid
16	Forearm support on training ring	33	Forearm support on training ring
17	Rings cable Inferior	34	Rings cable Inferior
18	Rings cable superior	35	Rings cable superior
19	Internal malleolus.	36	Internal malleolus.

APPENDIX 6 - VISUAL 3D PIPELINE

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! /SIGNAL_NAMES=
! /RESULT_FOLDER=PROCESSED
! /RESULT_SUFFIX=
! /FILTER_CLASS=BUTTERWORTH
/FREQUENCY_CUTOFF=5.3
! /NUM_REFLECTED=6
! /TOTAL_BUFFER_SIZE=6
! /NUM_BIDIRECTIONAL_PASSES=1
;
------------------------------------------------------------------------
Interpolate
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! /MAXIMUM_GAP=10
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! /POLYNOMIAL_ORDER=3
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        NUM_FIT    =    3
        POLY_ORDER    =    3

------------------------------------------------------------------------

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! /NORMALIZATION_METRIC=
! /NEGATEX=FALSE
/NEGATEY=TRUE
! /NEGATEZ=FALSE
! /AXIS1=X
! /AXIS2=Y
! /AXIS3=Z
```

```
;
          Type :   JOINT_ANGLE
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Compute_Model_Based_Data
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/REFERENCE_SEGMENT=RTA
/RESOLUTION_COORDINATE_SYSTEM=
! /USE_CARDAN_SEQUENCE=FALSE
! /NORMALIZATION=FALSE
! /NORMALIZATION_METHOD=
! /NORMALIZATION_METRIC=
! /NEGATEX=FALSE
! /NEGATEY=FALSE
! /NEGATEZ=FALSE
! /AXIS1=X
! /AXIS2=Y
! /AXIS3=Z
;
          Type :   JOINT_ANGLE
----------------------------------------------------------------------

Metric_Mean
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/RESULT_METRIC_NAME=_MEAN
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/EVENT_SEQUENCE=CROSS+END
/EXCLUDE_EVENTS=
! /SEQUENCE_PERCENT_START=0
! /SEQUENCE_PERCENT_END=100
/GENERATE_MEAN_AND_STDDEV=FALSE
! /APPEND_TO_EXISTING_VALUES=FALSE
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          Compute Mean :
----------------------------------------------------------------------

Metric_StdDev
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! /SIGNAL_FOLDER=PROCESSED
/SIGNAL_NAMES=LSHOANGLE+LSHOANGVEL+RSHOANGLE+RSHOANGVEL
```

```
/SIGNAL_COMPONENTS=
/COMPONENT_SEQUENCE=ALL
/EVENT_SEQUENCE=CROSS+END
/EXCLUDE_EVENTS=
! /SEQUENCE_PERCENT_START=0
! /SEQUENCE_PERCENT_END=100
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! /APPEND_TO_EXISTING_VALUES=FALSE
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        Compute Standard Deviation :
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Export_Data_To_Ascii_File
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