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# Swallow Element and Training Perspectives in Men's Artistic Gymnastics: an electromyographic study case.

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**KEYWORDS:** MEN'S ARTISTIC GYMNASTICS, RINGS, SWALLOW, ELECTROMYOGRAPHY, SURFACE ELECTROMYOGRAPHY.

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# Abstract

The present study aimed to identify the muscular contribution during swallow execution on rings. In fact the main intent of the study is to study the muscular activation to understand the muscular coordination during swallow executed on rings, to compare it with training exercises. The sample was composed by a senior male gymnast from Portuguese national team. The evaluation was made through surface electromyography, measuring simultaneously eight muscles in twelve exercises at the same evaluation session. Two attempts were performed for each exercise, being analyze the last to seconds of each exercise. We resorted to the Correlation of Spearman and to the calculation of means and maximal percentages for data analysis. As key results, we found that: the triceps brachii muscle acts in the elbow extension and in moving the humerus head forward; the biceps brachii, pectoralis major and deltoid anterior muscles act in shoulders flexion; the serratus anterior muscle acts in the scapula stabilization promoting the scapula co-option to thorax; the trapezius inferior muscle acts in scapula stabilization and depression; the latissimus dorsi muscle acts in scapula depression; the infraspinatus muscle prevents the anterior dislocation of humerus head promoting the shoulders stabilization; the recommended exercises to develop swallow element are: “upon small balls”, “rings feet on floor”, “forearm support”, “fitness balls”, “trampolines support”, “help on pelvis”; “pelvis supported by fitness ball” e “rubber band support”; the exercises that could work as complementary help to develop swallow element are: “barbell” and “dumbbells”.

Finally we conclude that: swallow is performed by the coordinate action between biceps brachii, triceps brachii, serratus anterior, trapezius, pectoralis major, latissimus dorsi, deltoid anterior and infraspinatus muscles. The swallow’s correct position is achieve with shoulder’s protraction, scapula depression and with upper limbs extended elbow joint in external rotation and with a slight abduction.



**KEYWORDS:** MEN’S ARTISTIC GYMNASTICS, RINGS, SWALLOW, ELECTROMYOGRAPHY, SURFACE ELECTROMYOGRAPHY.

# Resumo

O presente estudo visou identificar os músculos responsáveis pela execução do "swallow" enquanto elemento realizado nas argolas. Em concreto pretendeu-se estudar a activação muscular, de modo a compreender a coordenação muscular durante a execução do "swallow" nas argolas, para posterior comparação com exercícios de treino. A amostra foi composta por um ginasta sénior da selecção nacional Portuguesa. A avaliação foi efectuada através da electromiografia de superfície medida simultaneamente em oito músculos e ao longo de doze exercícios durante a mesma sessão de avaliação. Foram realizadas duas tentativas para cada exercício, sendo analisados os últimos dois segundos de cada. Para a análise dos dados recorremos à Correlação de Spearman e ao cálculo de médias e percentagens máximas. Como resultados principais, verificamos que: o músculo tricípite braquial actua na extensão do cotovelo e no movimento anterior da cabeça do úmero; o músculo bicípite braquial, grande peitoral e deltóide anterior actuam na flexão do ombro; o músculo grande dentado actua na estabilização da omoplata fazendo a cooptação da mesma ao tórax; o músculo trapézio actua na estabilização e depressão da omoplata; o músculo grande dorsal actua na depressão da omoplata; o músculo infraespinhoso previne a luxação anterior do úmero sendo estabilizador do ombro; os exercícios recomendados para desenvolver o "hirondelle" são: "upon small balls", "rings feet on floor", "forearm support", "fitness balls", "trampolines support", "help on pelvis"; "pelvis supported by fitness ball" e "rubber band support"; os exercícios de ajuda complementar no desenvolvimento do "swallow" são: "barbell" and "dumbbells".

Concluímos que: o "swallow" resulta de uma acção coordenada entre os músculos: bicípite, tricípite, grande dentado, trapézio, grande peitoral, grande dorsal, deltóide anterior e infraespinhoso. A posição mais correcta para a execução do "swallow" é com a articulação do ombro em protracção, a omoplata em depressão e o membro superior com o cotovelo em extensão e em rotação externa realizando um ligeira abdução.



**PALAVRAS-CHAVE:** GINÁSTICA ARTÍSTICA MASCULINA, ARGOLAS, SWALLOW, ELECTROMIOGRAFIA, ELECTROMIOGRAFIA DE SUPERFÍCIE.

# Abbreviation list

**AG** - Artistic Gymnastics

**CG** – Centre of Gravity

**CMRR** - Common Mode Rejection Ratio

**CP** – Code of Points

**EMG** – Electromyography

**FIG** - *Federation Internationale de Gymnastique*

**MAG** – Men's Artistic Gymnastics

**MM** - Mechanical Movement

**MVC** – Maximal voluntary contraction

**RMS** – Root mean square

**SEMG** – Surface Electromyography

**UL** – Upper limb

# 1. Introduction

Men's Artistic Gymnastics (MAG) is one of the most popular and demanding sports of Olympic programme (Smolevsky & Gaverdovsky, 1996).

Over the past decades MAG has suffered a huge development expressed by the introduction of new equipments, new methods, means and training techniques that created a enormous progress in exercises complexity and difficulty (Arkaev & Suchilin, 2004). Also the changes on code of points (CP), with the elimination of start note limit (10 points), allowed gymnasts to increase their routines difficulty beyond all measures (F.I.G., 2009).

Maintaining the same competitive objective expressed by exercise composition and quality of execution on competitive field, MAG is today a complicated coordination sport with high technical demands attached to the art of movement expressed by elements difficulties (Arkaev & Suchilin, 2004).

This means that MAG stills the same sport, the same human motion between apparatus, the same beauty, the same sport expression, but with much more risk, more unpredicted movements and with much more complexity in skills performed at every apparatus.

Now a days, coaches and gymnasts strategy lays on the “hunt” of bonus to increase routines difficulty and be more competitive at sports field.

Therefore coaches and gymnasts strategies, turn into a pursuit of elements with high difficulty to increase as much as possible their routines value.

According to Arkaev and Suchilin (2004) Artistic Gymnastics (AG) is a sport growing founded in further complexity of competition programmes and by the developing of technical proficiency.

Following these ideas our work arises in a way to understand one of those difficult elements - swallow element performed in rings routines. Swallow is a strength hold element performed on rings (F.I.G., 2009). The perfect swallow is achieved with the body and arms straight in horizontal position at rings level maintained during 2 seconds by hands support (Bernasconi & Tordi, 2005; Bernasconi et al., 2009; F.I.G., 2009; Sands et al., 2006). Considered as one of the most difficult strength elements to do in rings routines according to Cuk and Karácsony (2002), it is an element performed by all top-level gymnast during international competitions (Campos et al., 2009).

In this perspective we will use surface electromyography (SEMG) to evaluate the muscular behaviour during swallow execution on rings. Evaluating a set of training exercises in different situations of execution, we will try to identify the differences between swallow element and the training exercises. In particular we intent to identify the best strategies to develop swallow element by discovering their contribution to swallow learning process.

For this approach we will evaluate eight muscles (biceps brachii, triceps brachii, serratus anterior, trapezius inferior, pectoralis major, latissimus dorsi, deltoid anterior and infraspinatus) during the execution of twelve different exercises.

Initiating our study with the literature review, where we will present an overview of the sport, explaining the rules and rings exercises composition, passing through a description of swallow as an element, then to mechanical aspects of gymnastics movements, followed by join movements and muscular functions and ending with use of electromyography (EMG).

Then we will illustrate the study sample and the methodology used for data collection and process, followed by the results presentation.

Proceeding with discussion of results, where we relate the data results with author's perspectives and our experiences, beginning with the relations between muscles and muscular co-activations, then the muscular analysis of swallow element, and ending with a comparative analysis between swallow and training exercises.

At the end, will be revealed all the conclusions achieve on our study.

# 2. Literature Review

## 2.1 Artistic Gymnastics

Artistic Gymnastic is one of the most wonderful sports. Is played for both genders, each one on their own category, Masculine and Feminine.

Men's Artistic Gymnastics is strict for male gymnasts and composed by 6 apparatus - Floor, Pommel Horse, Rings, Vault, Parallel Bars and High Bar. Women's Artistic Gymnastics is only for female gymnasts and is practice on 4 apparatus - Vault, Uneven Bars, Beam and Floor.

Pastor (2003) defines AG as being a complex and difficult sport that impose a constant strangle between the gravitational force and body control. As a sport, AG has a strong technical competitive component (Arkaev & Suchilin, 2004; Gluck, 1982; Smolevsky & Gaverdovsky, 1996). Therefore, the *Federation Internationale de Gymnastique* (FIG) created a document that sustains all technical regulations needed on this sport. The CP rises to establish a fare and equal competitive environment. It integrates a set of rules that allow an objective and uniform evaluation of AG routines in all competitive levels (F.I.G., 2009). Aware of this idea, CP is not only a regulation document, is much more than that. In it, are included all information about routines composition, such as elements and techniques movements; technical requirements and deductions applied for execution errs committed during the performance (F.I.G., 2009).

Since the first Olympic Games edition, many things changed. The introduction of new training equipments, allowed new training methods, more safety during the learning process, and the appearance of new training techniques to take advantage of the apparatus change (Arkaev & Suchilin, 2004; Smolevsky & Gaverdovsky, 1996). As consequence of that evolution, the training loads increased, and in a relative short time, the difficulty level of the exercises performed by gymnasts got beyond all measures. Arkaev and Suchilin (2004) use the expression "what fantastic progress" to expresses that evolution in AG, from the first Olympic Games to our times.

The definition of new rules and policies by FIG aimed to keep the intrinsic characteristics of the sport, without losing the evolution made on the technical field (Grandi, 2008). So we can easily say that CP as a tool escorts the evolution and the changes made during or after each Olympic cycle.

All this factors contributed to build the actual reality of AG. Today, AG is a Sport that brings beauty, risk, difficulty, expression, character and movement to our eyes. Even with all modifications done and all elements complexity achieved, behind his structure, AG maintains the original characteristics, where the domination of body movements prevailed (Arkaev & Suchilin, 2004; Grandi, 2008; Smolevsky & Gaverdovsky, 1996).

In our work we will centralise the attention on the MAG, specifically in rings routines. Before any sustain approach, we must understand that MAG is a sport with many demands. On following chapters, we will discuss some important concepts that could be helpful on the general understanding of our work.

## 2.2 Code of Points

Every sport has its own rules. The CP is a document that integrates a set of rules that establishes fare and equal opportunity on AG competitive context. Responsible for an objective and uniform evaluation of all routines presented at any competitive level (national or international), CP became more than a regulation document, and it is also a technical guide for judges, coaches and gymnasts. In it, are included all the information about routines composition, elements and techniques movements; technical requirements for the routines, and deductions applied for execution errs committed during the performance. Admitting that it works simultaneously as regulator document, evaluation tool and as guide on structuring and composing competition routines, we can consider it, almost, as "Bible" of AG, (Campos, 2008). In Arkaev and Suchilin (2004) opinion, CP is the main tool for AG development. Understanding the modifications applied since it existence, means to be aware of the technical evolution of AG (Grandi, 2008). Indeed, the new rules, the new elements performed and all the new requirements apply on CP at each Olympic cycle, were, are, and will be determinant to defy and codify the new trend for AG as sport.

## 2.3 Rings

From all 6 apparatus that make up MAG, rings stands as unique due to its intrinsic characteristics. Looking to this apparatus we see two steel cables fixed in a steel structure with a ring in the bottom. All the dynamic of this apparatus is based on these two cables. The gymnasts can move them in any direction, while performing a routine. Taking that in consideration, Smolevsky and Gaverdovsky (1996) categorize rings as an apparatus with a mobile support. On the other hand Arkaev and Suchilin (2004), complete this affirmation classifying rings as an apparatus with two kinds of actions, the pendulum-type movement of the rings, the stage where the movement is transferred, and the relative movement, the stage where the gymnast plays a relative movement about the rings. The evolution on this apparatus is supported by those characteristics that allowed the use of “swings” and “giant swings”, which largely contributed to increase the movements’ amplitude on rings routines (Smolevsky & Gaverdovsky, 1996).

Apparently the intrinsic characteristic of this apparatus demands the use of strength to stabilise the support and, coordination to control the constant modifications of the body on the swings. Aware of this idea, Smolevsky and Gaverdovsky (1996) refers that all the work done on rings, change depending on the strength direction applied during the support.

In today’s routines, we see gymnasts exploring all the dynamic possibilities of this apparatus. The combinations of strength and swing elements with difficult dismount at the end of the routines, well demonstrates the movement’s evolution on rings.

Currently Cuk and Karácsony (2002) distinguish tree groups of movements performed on rings routines: static elements, strength elements and swing elements. The CP describes rings routines as exercises composed by equivalent parts of swing, strength and hold elements (F.I.G., 2009).

The **static elements** can be executed in hanging or in support, where biomechanically, the body weight is supported under or upper the support (Cuk & Karácsony, 2002). The **strength and swing elements** can be performed from hanging to hanging, from hanging to support, from support to support and from support to hanging, and at last from hanging to dismount (Cuk & Karácsony, 2002).

In other words F.I.G. (2009), say that those elements can be executed or combined "in hang positions, to or through support position, or to or through the handstand position". CP also suggests that every element should be performed as much as possible with the straight arms (F.I.G., 2009).

As we have seen before, the particular characteristics of rings become from the presence of two supports: mobile (rings) and fixed (rings cable), (Arkaev & Suchilin, 2004).

In a few words, we can conclude that every element executed on rings is done "with a fixed support through an auxiliary mobile link" (Arkaev & Suchilin, 2004).

## 2.4 Rings Routines Composition

Before any routine composition, we must be aware of all requirements, all penalties and all technical elements that could be done to increase the routines difficulty and consequently obtain the highest start note as possible.

Pastor (2003) clarify this idea saying that the routines composition should include elements and combinations that respect the specific demands of CP for each apparatus. Same is to say that before any routine composition, coaches and gymnasts must study the CP, to choose wisely which technical elements should be included on gymnast routine's, using the written rules on their benefit.

The CP recommend that all performed elements on a routine must be done safely and with a technical mastery (F.I.G., 2009). Once more we observe the intrinsic characteristics of AG. Perform difficult and risky elements are not enough to win, they must be performed with high technical mastery, otherwise the routine won't be a good catch.

That balance is clarified on CP by two ways, **deductions applied** when an element present small deviations from the correct position and **non recognition and deduction applied** when there are high deviations on the element performed (F.I.G., 2009). Both rules, accentuated the real meaning of AG since ever - performance versus perfection.

For rings routines, it is necessary to include 5 different groups of elements, minimum 1 per each of the following groups according to CP (F.I.G., 2009):

I – Kip and swing elements;

II – Swing to handstand;

III – Swings to strength hold elements;

IV - Strength and hold elements;

V – Dismounts.

On the others apparatus with the exception of Vault, the same rule is applied but with different elements on each group of elements, ones that are specifically done on that apparatus (F.I.G., 2009).

So, knowing the requirements and technical elements expressed on CP, is to be aware of all possibilities to create a complete, adaptable and competitive routine to any gymnast.

In other words, knowing the CP rules and having the knowledge of elements technique is the same as having tactical advantage on the field.

Looking to Campos et al. (2009) research, we found that Portuguese gymnasts as team, took the 22nd place being on the best 24th teams of the last world championship. This team only had one gymnast performing one of the most valuable strength hold elements done on rings – a strength hold element with Swallow position; while the other 24 teams had more than one gymnast performing it, and the majority of them, did perform two positions of swallow in their routines. According to Campos (2008), the number of strength elements present on CP for rings routines, is highly superior to the swing elements. Counting with the strength elements from group III and IV, they found that more than 50% of realizable elements on this apparatus are strength elements, and some of those are also the most valuable, between “D” and “F” difficulty. Assuming the importance of this statement and looking to the intrinsic characteristics of this apparatus, we are able to see how necessary the strength elements are on rings routines.

Knowing the actual reality of gymnastics, where performing the most difficult elements with high level of execution is the same as improving the start value note and commit the minimum faults to get the highest final note as possible. This relation between difficulty and perfection is the new role of Gymnastics reality. Considering this point of view, coaches should understand more about train technique of those difficult elements to improve the learning processes and reach the skill perfection.

## 2.5 Swallow Element

Swallow is a strength hold element performed on rings routines. The swallow's external static position resembles to support scale at rings level (Bernasconi & Tordi, 2005; F.I.G., 2009). The difficulty of swallow lays in the maximal contraction demanded at shoulder joint level to support the body weigh in a complete horizontal extended position during the two seconds as CP requirement, (Bernasconi & Tordi, 2005; Bernasconi, et al., 2009; Sands, et al., 2006).

On Campos et al. (2009) research, the rings finalists of 2007 World Championships, performed two strength elements with swallow position to increase their routines start value. In fact, the gymnasts are allowed to perform two times the same strength hold position on rings routines if it is done from a different start movement (F.I.G., 2009). The CP contemplates two groups with strength elements, the "swings to strength hold elements" – Group III, and the "Strength and hold elements" - Group IV. Swallow as strength hold element is included on Group IV, however it can be part of other elements as strength static position. Therefore we can find fourteen(14) different elements with Swallow position, tree(3) elements on Group III and eleven(11) elements on Group IV (F.I.G., 2009). So, swallow position could be combined with swing movements (Group III) and strength movements (Group IV) forming a unique element with particular value. Sands et al. (2006) consider the swallow an essential element to potentiate the difficulty on rings routines. This idea underlies on the competitive advantage provide from its value, "D" difficulty value as "basic" element – Swallow as a strength hold element (F.I.G., 2009).

This means that Swallow can be performed twice in rings routine, with the advantage of fulfil the groups requirements with the most value elements and increase the start value of rings routines (Campos, et al., 2009).

Being Swallow such an important strength hold element on rings routines, becomes essential to study it from the practical point of view. On training contest, where gymnasts and coach daily workout to improve their routines with new and difficult rang of elements, the focus remains in increasing the routines difficulty to achieve higher start note. In this process where the goal is the competitive context, becomes crucial to identify and understand which methods are the best to improve the learning process.

In our study we will use electromyography to evaluate and understand the learning process of swallow's position performed on rings.

## 2.6 Mechanical Aspects of Gymnastics Movements

All movements respect mechanical laws and animation principles. In AG where the elements performed by gymnasts are extremely complex and technical demanding, the biomechanical and kinematical aspects become a very important rule.

Arkaev and Suchilin (2004) sustain that a change in body position and its links (parts of body) in space and time, is a biomechanical process that is expressed by the gymnast's skills. So every element, part or exercise performed by gymnasts represents a change on body position that is externally expressed on mechanical movement (MM).

"The mechanical movement could be translational (linear) and angular (circle or turn), constant, accelerated, slow down, one or multi-dimensional, varying, reverse, as well as simple and complex" (Arkaev & Suchilin, 2004). All MM can be combined and applied to body as a whole or to the joints as parts, respecting the anatomical limitations of the body.

According to (Peixoto, 1988) when we intent to understand the technical aspects of AG skills, we must face it as a sport done by opening and closing body segments. To complement this idea Kerwin and Trewartha (2001), demonstrate on their research that wrist, shoulder and hip joints are determinant for maintaining the balance on an handstand skill. The authors confirm that the action and position of these joints could affect the balance of the handstand skill.

Many variables must be known to describe a MM. To organize our point of view, first, we must understand that the MM is no more than the expression of a technical skill. Arkaev and Suchilin (2004) describes technique as being one of the most important aspects to learn and perform AG skills. The author applies the term technique to describe the way which each movement, each gymnastic exercise is made of. Assuming that an exercise is made by a group of elements that are well engage and perfectly synchronized (Pastor, 2003); a technical skill is a series of body movements perfectly synchronized on space and time, which is call technique (Arkaev & Suchilin, 2004).

### 2.6.1 BALANCE AND POINT OF GRAVITY

According to gravitational law every mass or corpse is composed by infinity of small particles that are attracted to the centre of the earth. This attraction produces a parallel system of forces that act vertically. The measure of this vertical system of forces results on one simple force, corps weight (Smolevsky & Gaverdovsky, 1996).

Applying an identical corps weight force in an opposite direction of corps mass (upper force), it is possible to determine a point witch the corps is able to maintain the balance in any position. This is known in literature as centre of gravity (CG), and is where all corps weight is applied (Gluck, 1982; Kendall et al., 1993)

In Gluck (1982) opinion, the CG of an object is given by the point where the object can be balanced due to a certain posture. The centre of mass is presented as a single point that can be use as if all the mass of the body were concentred at that point.

At this point is essential to understand the meaning of the word equilibrium. According to Gluck (1982), equilibrium is a condition where the sum of all external forces and torques acting is zero. Same is to say, a body with no tendency to alter its own rotational or translational status, is a body in equilibrium.

In gymnastics, the word balance is use to express the gymnast ability to maintain the equilibrium, whether moving or still upon the apparatus (Gluck, 1982).

The Newton's third law says that every applied force has an equal reaction with the same magnitude and on the opposite direction of the applied force, (Gluck, 1982; Smolevsky & Gaverdovsky, 1996). Whenever a first body exerts a force on a second body, the second body exerts the same force in magnitude but in opposite direction on the first body - **Action-reaction law**, (Arkaev & Suchilin, 2004).

On Piard (1992) opinion, the static elements are the ones where the CG is maintain on the vertical of the support – **unstable balance** or on hanging point – **stable balance**.

In other words, Gluck (1982) distinguish stable balance from unstable balance assuming:

- **Stable balance** - when the CG is below the support axis – example: long hang or the motionless hang at the vertical.
- **Unstable balance** – when the CG lies above the support axis or the support with minor angular displacement – example: handstand.

Following the same reason Smolevsky and Gaverdovsky (1996) went further and consider four approaches of equilibrium:

- **Stable balance** – when the CG is under the gymnast support, like a hang position on high bar (doesn't need learning process).
- **Unstable balance** – when the CG is upon the gymnast support, in a support position, like a handstand.
- **Indifferent balance** – when a gymnast perform a rotational movement where virtually is no need to maintain the balance,

something between stable and unstable balance. The snooker ball upon the table could be an example.

- **Limited stable balance** – is the combination of all tree described balance. Is the most important for gymnastic movements because combines the references of stable, unstable and indifferent balance. The “standing scale” position (floor element – nº67 on CP) is a good example for a limited stable balance (F.I.G., 2009).

Gluck (1982) supports that there are two possibilities when an object is fixed at some point: if the force acts through the fixed point, the object will not move because of the upward balance reaction (action-reaction law); if the force acts upon the object but not through the fixed point, the object will start to rotate trough the axis of the fixed point.

Therefore, to maintain the body balance in an unbalance static position, the gymnast must produce an equal force on the direction of his weight through the support member. In this case, the CG is maintain in balance whenever, the vertical line of CG pass through the base of support.

### 2.6.2 TECHNICAL ASPECTS

According to Arkaev and Suchilin (2004), speaking about element technique is the same as finding the biomechanical characteristics and parameters of movement. The technical aspects of gymnastics elements are not more than the biomechanical movements expressed for the gymnasts body in motion. In theory, the body can assume many different positions on a direct relation to the apparatus. Those movements depend from the combination of basic skills that are produced according the kinematic of the body position, body orientation and posture, (Smolevsky & Gaverdovsky, 1996).

Clarifying the patent idea, Pastor (2003) distinguish 3 fundamental divisions on the basic factors of gymnastics actions, which are:

- **Body position -** refers to the general aspect that body acquire in temp and space in relation to the apparatus. In other words, is the place that it occupies over the apparatus during performance.
- **Griping -** consist in the way of grabbing the apparatus using the hands. Could be in support or hanging with gripe variations: supination or pornation;
- **Postures -** are all the different forms adopted by gymnast during a performance. The postures are related to the body internal aspects, which are produced by joints movements and classified on tree categories: tuck, pike and straight. So, posture is the anatomical form that body acquires in every done motion.

With a similar point of view, Piard (1992), divide the mechanical actions in two types of successive operations: creation of enough power to control the body weight; and use the impulse produced by the body action to improve the extern reaction. Furthermore, the author focus that taking energy to modify the principal joints working, such as **opening**, **closing** and **locking movements** of the major joints, will work for or against the motion. This means that all the internal work done by a gymnast while performing a skill, changes the mass-inertia parameters of his body, providing him the ability to control the speed of his own movement, (Arkaev & Suchilin, 2004).

In fact when we analyse the gymnast's external movements, we are able to see many body adaptation during the skills executions upon the apparatus. So, at this point we may assume that a dynamic body posture is an indispensable characteristic of gymnastics' biomechanics (Arkaev & Suchilin, 2004). Following this idea, Gluck (1982) suggest that a single adjustment on a segment position or single action with a body part could be sufficient to maintain or lose the balance. Knowing that posture, body position and gripe are the main aspects that should be identified before any approach, Arkaev and Suchilin (2004) suggest an objective and clear form to analyse the gymnastics elements, "From end to beginning". The authors suggest two criterions to analyse gymnastics elements into parts: support criterion and force of gravity criterion. The first one leads us to the condition of action, support and unsupported elements. The second lies on naturals downwards action of force of gravity. The combination of both criterions, points to two different situations: elements performed on support position and elements performed on unsupported position. Depending on it, Arkaev and Suchilin (2004) illustrated how the force of gravity acts in a support period during elements performance, dividing it in two stages. The Accumulation stage which there is accumulation of kinetic energy, using the external force to increase the speed of movement, and the working stage, where the internal work is use to reduce the loss of motion or to raise the body's CG on bellow's to upwards motion (Arkaev & Suchilin, 2004).

These means that gymnasts are able to accumulate kinetic energy in the support position (accumulation stage), and to spent kinetic energy on lifting the body CG against force of gravity in unsupported or support position.

Also maintaining the body with a strong tension between all segments/joints during multiple somersaults execution, allow gymnasts to turn faster comparing to a relaxed body (Arkaev & Suchilin, 2004). Following this logic, one of the main keys to preserve a good posture, such keeping trunk and legs as a single part, body alignment, is to work the abdominal muscles with the pelvic zone in retroversion (Piard, 1992).

Combining those technical factors of gymnastics actions, we can classify swallow's element as static position held in supination grip with the body in a straight posture supported at rings level position.

Observing the gymnastics movements in single parts, we can understand that a proper acknowledge related with human segments and mechanical laws, could lead us to a better way of implementing training programmes.

## 2.7 Joints Movements and Positions

The human body can adopt many different positions. The anatomical position is known as erect posture, where all body segments are aligned in a gravitational vertical line (Kendall, et al., 1993). This position is use as reference to define and describe the pure joint movements in space. Laying on anatomical position, the segments motion can adopt tree referential axis of motion: **Longitudinal axis** – horizontal motion (rotation); **Sagittal axis** – vertical motion or anterior/posterior motion (flexion or extension); and **Transverse axis** – lateral motion, where segments move away/back from medial body plane - abduction or adduction (Kapandji, 2007; Kendall, et al., 1993).

As general definition, axis of action are referential lines that represent the possible motion of corporal segments (Kendall, et al., 1993).

Longitudinal axis is represented for rotational movements with internal or external direction in relation to vertical point. The sagittal axis is represent for back and front line movements, and transverse axis, all side to side line movements.

So, words as flexion (segments approximation), extension (segments hold off), abduction (segment hold off of the body medial plane), adduction (segment approximation of the body medial plane), medial rotation, external rotation and circumduction, are used to describe the direction of motion (Kapandji, 2007).

On our study, where we pretend to understand how muscles work with joints to hold the swallow position on rings, we must describe the upper limb (UL) movements and joints participations.

Considering the shoulder joint the most mobile joint of the human body, (Kapandji, 2007), the anatomical structure of this joint allows the UL to move in the tree axis of motion – Transversal axis, Sagittal axis and Longitudinal axis.

In Transverse axis of motion, the UL **abduction** is held by shoulder joint (glenohumeral) from 0º to 60º, then from 60º to 120º which demands the scapula joint participation and from 120º to 180º beyond glenohumeral and scapula joints participation, a trunk tilt on the opposite side is needed (Kapandji, 2007). So in this case the UL describes a lateral movement from the anatomical position to a side position where the UL is vertically up the trunk.

The extension-flexion movements of shoulder joint are done on sagittal plane and horizontal plane. On the Sagittal plane the UL describes a anterior-posterior movement where **flexion** movement (anterior direction) achieves 180º of amplitude and the **extension** movement (posterior direction) achieves 50º of amplitude (Kapandji, 2007). With the UL elevated at 90º of abduction, it is possible to determine the horizontal flexion-extension. The **horizontal flexion** is provided by the combination of flexion and abduction where the UL sifts between lateral and anterior position in 140º of amplitude (Kapandji, 2007). This movement is provided by the following muscles: deltoid anterior (clavicular part), subscapularis, pectoralis major, pectoralis minor and serratus anterior (Kapandji, 2007). The **horizontal extension** is a movement that combines extension and abduction, where the UL sifts between lateral and posterior position in only 30º-40º of amplitude (Kapandji, 2007). The muscles responsible for that movement are: deltoid (medial and posterior part), supraspinatus, infraspinatus, rhomboid, teres major and minor, trapezius e latissimus dorsi (Kapandji, 2007).

Those anterior-posterior movements result from glenohumeral and scapular joints movements. In particular the anteversion or retroversion movements (protraction and retraction) on shoulder joint are caused by the forward or backward movements of scapular joint in horizontal plane (Kapandji, 2007). The author distinguish the pectoralis major, minor and serratus anterior as the main responsible muscles for **anteversion movement**, and the rhomboid, trapezius (transverse parte) and latissimus dorsi for **retroversion movement**.

Another important movement is the UL rotation. According to Kapandji (2007) the **lateral rotation** with external direction achieves 80º of amplitude from anatomical position and the **medial rotation** with internal direction achieves 100º or 110º of amplitude when the forearm is placed behind the trunk. The author measure these amplitudes with the elbow flexed at 90º and the forearm in sagittal plane, otherwise, to those amplitudes would be added the pronation/supination of the forearm.

Relating the body possible movements to swallow element we can picture the following external position:

- UL in lateral rotation with hands grabbing the rings following the body line with elbows extended;
- The body lined up in a lay down position with pelvic zone in retroversion;
- Shoulders rotated to anteversion position.

If we analyse the swallow from this point of view we are able to identify the muscles that actually could be responsible for the execution of this element. At same time and according to Brukner and Khan (1994), a normal function of shoulder joint requires a smooth integration movement of glenohumeral, scapulothoracic, acromioclavicular and sternoclavicular joints. This means that the execution of swallow demands also the participation of different joints, essentially the glenohumeral and scapular joints as we will be able to observe on the next chapter.

## 2.8 The Muscular Function

Muscles work as agents of body movement and body posture. The movements result from cooperative actions of muscles and joints, where the muscles are the main players on the possible joint movement. Is important to know that the change on body position, translated as movement, drifts essentially from the combination of muscular work of a group of muscles that between origin and insertion (support points) possess a mobile structure - joint, (Massada, 2000). Depending on that, the muscles are able to flex or extend joints, there for are responsible for approaching or moving away the body segments, using bones as support points.

According to Latash (1998), this could be a reductive picture of human movement, because to flex or extend a joint is needed not only a “muscle” but the whole complex structure that includes muscle fibres, tendons and ligaments.

The author also states that the force generated from the muscle fibres shortening, is transferred to tendons creating torques in joints that will support the body segment movements.

As discussed before, swallow element has a particular combination of segments placement. The UL are use to hold up the body mass in a support scale upon a mobile support. The shoulder’s joint is not fully designed to support the body mass on this position (Bernasconi, et al., 2009). Being shoulders joint the most mobile joint of the humans body, the muscles enclose the task of working as a dynamic component to provide the joint stability (Kapandji, 2007). Brukner and Khan (1994) consider that rotator cuff muscles act as a dynamic structure to stabilize the glenohumeral joint controlling the position of humeral head in glenoid cavity. According to Kapandji (2007) shoulder’s joint stability is achieved by the interaction of two groups of muscles: the **transversal cooptatores** that compress the humerus head to the glenoid cavity and **longitudinal cooptatores** that prevent the downward dislocation of shoulders joint when carrying heavy objects with the UL. The **transversal cooptatores** are composed by supraspinatus, infraspinatus, teres minor, subscapularis and biceps brachii; and the **longitudinal coaptatores** by deltoid, triceps brachii, biceps brachii, coracobrachialis and pectoralis major (Kapandji, 2007). So, shoulders cooptation is done by a “synergic-antagonistic” relation of transversal and longitudinal cooptatores muscles, preventing the frontal, upward and downward dislocation of humerus head (Kapandji, 2007). Following this logic, the author considers supraspinatus and biceps long head, the principal muscles that form the upper shield of shoulders joint. In addition, pectoralis major act as a flexor and adductor of shoulders joint, and the long head of triceps brachii takes humerus head forward during the elbow extension (Kapandji, 2007). On the other hand, supraspinatus, infraspinatus and teres minor work on the opposite direction keeping the humerus head on glenoid cavity and helping on shoulder's extension (Kapandji, 2007). In Brukner and Khan (1994) opinion, the rotator cuff, such supraspinatus, infrasapinatus, teres minor and subscapularis are required to balance the deltoid muscular force, acting against deltoid action and preventing the upward movement of humerus head during the arm lifting. At last, Kapandji (2007) refers that serratus anterior is use to pull the scapula forward and outward helping on shoulder protraction; when the abduction is superior a 30º it also helps on flexion and abduction movements.

In a clear explanation, Brukner and Khan (1994) refers that trapezius (tree portions), serratus anterior (upper and lower portion) and rhomboids muscles are the principal muscles controlling the scapular rotation. The retraction, elevation and upward rotation of scapula are promoted by trapezius; the upward rotation and protraction (co-option) of scapula are hold by serratus anterior; the downward rotation, retraction and elevation of scapula are supported by rhomboid muscle; and the depression of scapula by latissimus dorsi (Brukner & Khan, 1994).

To a deeply understanding of our work becomes necessary to describe the muscular actions of the principal muscles involved on Swallows holding position. Therefore we based our choice in shoulder's anatomy, segments positions and some completed studies in this area (Bernasconi & Tordi, 2005; Bernasconi et al., 2002, 2004; Bernasconi, et al., 2009; Bernasconi et al., 2006; Sands, et al., 2006).

Following Kendall et al. (1993) perspective, the principal actions of the muscles that will be evaluated on our study are:

- Biceps brachii – **Flex the elbow joint** moving the forearm on the direction of humerus bone when the muscle origin is looked; and **flex the shoulder joint** moving the humerus on the direction of forearm when muscle insertion is locked – arm lifting on anterior direction.
- Triceps brachii - **Extends elbow joint** moving the forearm on the opposite direction of humerus bone (triceps short portion); the triceps

long portion **adduct and extends the shoulder joint -** arm lifting on posterior direction with adduction action.

- Deltoid – **Abduct shoulder joint** with medium portion fibres and while the anterior and posterior fibres work to stabilize the movement. The anterior fibres are responsible for the **flexion and internal rotation** of shoulder's joint; and the posterior fibres are responsible for the **extension and external rotation**.
- Pectoralis major – Is responsible for the **internal rotation and adduction of humerus bone** and with the arm in adduction helps to elevate the chest.
- Infraspinatus – **Stabilize the humerus head on the glenoid cavity** and is an **external rotator of shoulder joint**.
- Trapezius – Looked on the origin, works as **scapula adductor** due to the medium fibres while superior and inferior fibres work as stabilizers. In opposite relation, is a **scapula abductor -** superior and inferior fibres responsible for scapula motion and medium fibres responsible for stabilize the action. Also, the superior fibres can act as scapula lifters and the inferior fibres as scapula depressors. When the muscle is looked on the insertion and acting unilaterally, the superior fibres generate lateral flexion, extension and rotation on the head (face to the opposite side) and the cervical joints.
- Serratus – Is responsible for **scapula abduction**, moving the glenoid cavity on the direction of the head and simultaneously keep the scapula against the chest – **scapula co-option**. The superior fibres are able to move the scapula upward and the inferior fibres downward.
- Latissimus dorsi – Is able to perform the **internal rotation, adduction and extension of shoulder's joint** when the muscle origin is fixed. It is also used to **lower the scapular waist** and contributes for the **lateral flexion of the trunk**. Acting on both sides, the Latissimus dorsi helps on the **spine extension**, providing **body lifting** when the body is upon the arm support. When the muscle insertion is fixed it

helps on anterior and side pelvis movements. Can even act as accessory muscle of breathing.

### 2.8.1 THE MUSCULAR CONTRACTION PROCESS

The muscular contraction is a neuromuscular process that depends on two main mechanisms: neural stimulation and mechanical contraction process. First, the brain emits a signal through nervous system that activates the chemical process, wish will activate the mechanical process inside the muscle and produce the muscle contraction that could result on segment/joint movement (Powers & Howley, 2000b).

For a better understanding we have to identify the anatomical structure involved. The muscles are constituted by motor units. Each motor unit is composed by one motor neuron that innervates a group of muscular fibres of that unit (Powers & Howley, 2000a). The motor neurons act as switchers on muscle contraction, promoting or inhibiting the muscular contraction process. The motor neuron is responsible for realising the electrochemical impulse on the neuromuscular junction, where the nerve contacts the muscle, to initiate the contraction process (Powers & Howley, 2000b). So, the mechanical process starts when the brain impulse arrives to motor unit. The motor unit fires and the impulse is carried down to the motor neuron which liberates a chemical compound (accetilcolina) on neuromuscular junction, causing an impulse called an **action potential** (Hunter, 1994; Latash, 1998; Powers & Howley, 2000a). After the impulse is transmitted across the neuromuscular junction, an action potential is elicited in all muscle fibres of that particular motor unit. The innervations of muscle fibres is done through the fibre membrane or **sarcoplasmatic reticulum** (a tubular system that surrounds each myofibril) terminating on **terminal cisterns** - place where the calcium is stored (Hunter, 1994; Latash, 1998; Powers & Howley, 2000a). Between and perpendicular to **terminal cisterns** there is a tubular structure called **T-tubules**, running from outlying myofibrils and the fibre membrane - sarcolemma. The **T-tubules** are in contact with the fibre membrane, and together with **sarcoplasmatic reticulum** and **terminal cisterns**, are responsible for carrying the electrical impulse (action potential) from the surface to all depths of the muscle fibre nearly simultaneous (Hunter, 1994; Latash, 1998; Powers & Howley, 2000a). This chemical process release the calcium saved on terminal cisterns, which in turn activates the bridge connections (cross-bridges) between actin and myosin filaments causing the muscular contraction (Hunter, 1994; Latash, 1998; Powers & Howley, 2000a). The contraction occurs when the calcium ions realised from terminal cisterns, bind with troponin, a protein situated at regular intervals along actin filament, causing the shifting of tropomyosin, another protein molecule that runs along the actin filament, providing the attachment of myosin cross-bridges head (Hunter, 1994; Latash, 1998; Powers & Howley, 2000a). This mechanical process is called “sliding-filament theory”, actin filaments slide over myosin filaments due to the flexion of myosin cross-bridges, shortening the muscle fibre and developing muscular tension (Powers & Howley, 2000a).

An isometric action happens when the muscular tension remains relatively constant. Same is to say that the tension developed by cross-bridges must shortening the muscle to a point that equals the extern resistance, maintaining the muscular length relatively constant (Hunter, 1994).

Force production is directly related to the number of cross-bridges created between filaments (Hunter, 1994). Therefore the greater is the amount of calcium in myofibril as much cross-bridges are created and more tension is generated in that muscle. So, “increasing the frequency of stimulation of a motor unit results in a increased force production of that motor unit” (Hunter, 1994). Also, the greater is the number of motor units recruited, the greater is the force produced (Hunter, 1994).

This means that the force production depend on the frequency of stimulation of motor units and the number of motor units recruited (Hunter, 1994; Latash, 1998). The synchronization of motor units on firing process is also a way of achieving higher amount of force or maintaining a certain level of force during a significant period of time (Latash, 1998). The author states that this phenomenon “will sum up to higher total muscle force”, but may induce a quicker fatigue.

Another important concept is that the central nervous system doesn’t control the level of activity of every neural and muscular fibre separately, it simplifies the task using the motor units to synchronize the contraction on muscle fibres (Latash, 1998). The fire process in each motor unit will activate all muscular fibres of that unit. This behave is classified according the law of **all-or-none** muscular fibres recruitment (Latash, 1998). The innervations’ rate of muscular fibres it is not constant and varies from muscle to muscle (Powers & Howley, 2000b). The author refers that the innervations rate is lower on small muscles (extraocular muscles), the ones with motor control characteristics, than large muscles such legs muscles.

## 2.9 The Electromyography

Electromyography is a method of study the neuromuscular activity, (Correia & Mil-Homens, 2004). Konrad (2005) describes it as an investigational “technique concerned with development, recording and analysis of myoelectric signals”. Based on word meaning, EMG is a graphic representation of the muscular electrical activity (Correia & Mil-Homens, 2004). In the last 40 years, it has been used in different areas of research, such medical research, rehabilitation, ergonomics and sports science, providing valuable information about the muscle (Konrad, 2005). In a easy explanation De Luca (1997) defines EMG as a technique that provides easy access to the physiological processes that causes the muscular contraction.

Therefore with EMG we are able to evaluate and record data from the electrical activity produced by the skeletal muscle, looking directly to what it is happing in the muscle.

There are two ways of colleting EMG data, from surface method or intramuscular method. The intramuscular EMG is frequently used on clinical tests, and is made with a needle electrode that is inserted through the skin into the muscle tissue (Latash, 1998). The use of this technique can be painful for the patient and collects data only from a specific part of the muscle, giving a local picture of the whole muscle activity.

On the other hand, surface electromyography (SEMG) is a non invasive method and provides a general picture of muscle activation. This is frequently used to study voluntary movements of healthy persons (Latash, 1998).

According to the physiological mechanism of muscular contraction, the action potential that is generated during the muscular contraction causes an electrical chain that diffuses through biological tissues activating the muscular fibres. So, when we use SEMG, the electrical sign collected by the electrodes, is not the action potential in it, but the electrical chain released on its path (Correia & Mil-Homens, 2004).

After a quick explanation of the main differences between the intramuscular and surface EMG data collection, we will now centralise our attention on the use of SEMG, method that we will use on our study.

According to De Luca (1997), SEMG signal is usually used to study the following indicators:

- muscles activation;
- force contribution of individual or groups of muscles;
- muscles fatigue.

Considering that SEMG can provide many important and useful applications, the author aware that it also has many limitations that should be considered, to prevent any scientific depreciation of the collected data.

For that reason, we will need to understand as much as possible about SEMG signal and its variations. Starting from the complexity of the muscle structure and the placement of the electrode, De Luca (1997) characterize the main factors that could influence the SEMG signal in the following groups:

Causative extrinsic factors:

- **Area, shape and distance between the electrodes** – influences the number of motor units that are detected;
- **Location and orientation of the electrode** – influences the amplitude and frequency of detected signal and the amount of crosstalk detected on the signal.

Causative Intrinsic factors:

- **Number of active motor units during the signal collection** – in a particular contraction the amplitude of the detected signal depends from the motor units that were activated;
- **Muscle fibre type and diameter** – the changes in the pH of the muscle interstitial fluid depend from the muscle fibre type and the amplitude and conduction velocity of the action potentials depend from the fibre diameter;
- **Blood stream in the muscle** – determines the capacity rate of removing metabolites during a contraction;
- **"Depth and location of the active fibres"** – the amplitude and frequency of the detected signal depend from the relationship between muscle and electrode detection surface, so that, the amount of tissue between electrode and muscle surface affects also the "spatial filtering" of the signal;

Intermediate factors:

- **"Band-pass filtering aspects and detection volume of the electrode"** – depend from intrinsic characteristics of the electrode, which determine the signal heaviness of motor unit's action potential;

- **“Superposition of action potential in detected EMG signal”** – transform the amplitude and frequency of the signal;
- **“Crosstalk collected from nearby muscle”** – contaminates the signal misleading the interpretation data information;
- **“Conduction velocity of the action potentials in muscle fibre”** – affects the amplitude and frequency characteristics of the signal;
- **“The spatial filtering effect”** – changes on the distances between the electrode detection surface and the active fibres.

<u>Deterministic factors:</u>

- **“The number of active motor units”;**
- **“Motor unit force-twitch”;**
- **“Mechanical interaction between muscle fibres”;**
- **“Motor unit firing rate”;**
- **“The number of detected motor units”;**
- **“Amplitude, duration and shape of the motor units action potential”;**
- **“Recruitment stability of motor units”.**

Analysing the causative, intermediate and deterministic factors together, we are able to understand the possible limitations of each particular study. This perspective allows us to consider and eventually adjust the practical application of the research.

According to the causative extrinsic factors described, locating the electrodes on the belly of the muscle will prevent crosstalk from other active structures. As much as close to the middle portion of muscle belly are positioned the electrodes, less signal interference will be collected. It is also recommended to attach the electrodes on the skin in a parallel position and on the orientation length of the muscle fibre to minimize the signal shifting. This will prevent the crosstalk and the alterations in amplitude and frequencies of detected signal, increasing the signal stability (De Luca, 1997).

On the other hand, the causative intrinsic factors which are related to the particular characteristics of each individual can't be manipulated or controlled. Those also influences the signal detected, therefore should be taken in consideration. In a case study like ours, where the evaluation is done with same subject, these limitations are minimized. Nevertheless we have to consider the anatomical differences in the skeletal muscle fibres in a comparative analysis. The differences between the largest muscles and small muscles are well known. Large muscles have motor units that innervate a larger number of fibres comparing to small muscles (Powers & Howley, 2000b). Therefore the number of active motor units and the duration of action potential could change the amplitude and frequency of the detected signal (De Luca, 1997).

To understand how complex and sensitive is SEMG system, is necessary to understand that a simple skin slide during a muscular contraction or a takeoff of single part of electrode, are sufficient to change the detection signal. Knowing that the signal is detected from the electrodes that are attached to the skin, if the skin slide during the contraction, the electrodes will reap signal from a new set of motor units, altering the signal stability (De Luca, 1997). This alteration in the EMG reading usually occurs in a dynamic movement (Konrad, 2005). Such alteration does not occur in isometric contraction, because the detected signal is collected from the same muscle area, maintaining the signal stability (De Luca, 1997).

The fidelity of EMG signal depend from how judicious is the applications of the described facts, providing a reduction in the crosstalk and improving the stationarity in the signal (De Luca, 1997).

All taken procedures for SEMG evaluation follow the described recommendations and will be written in more detail in procedures on methods chapter

# 3. Objectives

## 3.1 General objective

Identify the muscular contribution of each muscle during the performance of swallow element on rings.

## 3.2 Specific objectives

Verify and identify the training exercises that contribute for performing swallow on rings;

Verify the relation between muscles, identifying the muscular coordination during swallow execution on rings;

Determine the relation between agonist/antagonist muscles, understanding how shoulder stabilization is maintained during swallow execution on rings.

## 3.3 Hypotheses

H1: The best exercises to learn and perform swallow elements on rings are those executed upon rings.

H2: The higher values of muscular activation belong to anterior muscles during swallow performance on rings.

# 4. Methods

## 4.1 Subject

Our work is a study case of a top level gymnast from the Portuguese national team. This gymnast was silver medal in rings final at Juniors European Championship 2008 and at the same apparatus was six times finalist at World Cups wining the bronze medal at Stuttgart World Cup 2009. Is a senior athlete with 20 years old and 15 years of practice, completes approximately 25 hours of training per week, measures 171 cm and weighs 66,5 kg. Note that this sample expresses the Portuguese universe of performing Swallow element at rings.

## 4.2 Procedures

Before any practical evaluation an authorization request was sent to the Portuguese Gymnastics Federation with all information about the experimental tests. The tests were completed 1 month before European Artistic Gymnastics Championships 2009.

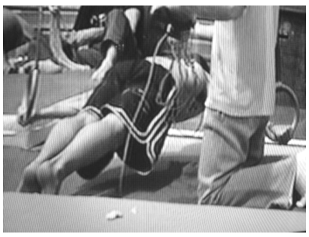
To measure height and weight, was used respectively the stadiometer *Seca Mod 220* and the weight machine *Tanita body composition analyzer BC-418*.

The gymnast started with the habitual warm-up of a normal training section, with approximately 15 minutes of general activation. For muscular activation was used a rubber band to move the UL in all different directions, preparing the joints and muscles for the test.

The evaluation protocol combined the swallow position through 12 different exercises. During the same section were performed two trials per exercise with 5 minutes of rest between them, to prevent muscular fatigue between attempts (Bazett-Jones et al., 2005). Each exercise was performed during 4 seconds of isometric contraction, being used only the last 2 seconds of each exercise for evaluation, following CP demands for static elements (F.I.G., 2009). The SEMG signal was collected from the right shoulder and recorded simultaneously from 8 different muscles: biceps brachii (long head), triceps brachii (long head), Serratus anterior, trapezius inferior (fibres with upper orientation), pectoralis major, latissimus dorsi, deltoid anterior (clavicular head) and Infraspinatus.

The SEMG evaluation was completed through one isometric position performed as competition context and through eleven different training exercises. The exercises were performed by the following order and under the described conditions in table 1.

Table 1 – Description of the evaluated exercises.

| Exercise | Exercise Description |
|---|---|
| <br>**“Swallow on rings”** | Swallow performed on rings just like competition context |
| <br>**“Upon small balls”** | With feet on the floor and coach providing a small support at shoulder’s joint, swallow is performed upon two balls, each with 17 cm of diameter; |
| <br>**“Rings feet on floor”** | Swallow performed on rings with feet on the floor; |

**“Rings lying on floor”**

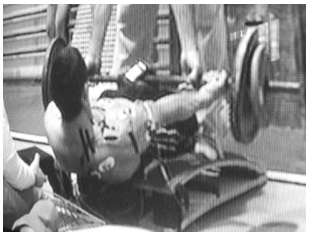
Swallow performed on rings with the body lying on floor;

**“Forearm support”**

Swallow performed on rings with the forearm support (putting the UL between rings cable and using the ring to support the forearm);

**“Fitness balls”**

With feet on the floor and coach providing a small support at shoulder’s joint, swallow is performed upon two fitness balls with 81 cm of diameter;



**“Barbell”**

Lying in a dorsal position, holding a bar with approximately 70% of the gymnast weight (46 Kg) maintaining the hands in supination;

**“Trampolines support”**

Swallow performed upon two vault trampolines;

**“Dumbbells”**

Lying in a dorsal position, holding a dumbbell in each hand with approximately 25% of the gymnast weight (16 Kg) maintaining the hands in supination;

**“Help on pelvis”**

Swallow performed on rings with coach support at pelvis zone;

**“Pelvis supported by fitness ball”**

Swallow performed on rings with pelvis supported by a fitness ball with 81 cm of diameter;

**“Rubber band support”**

Swallow performed on rings with a rubber band support at pelvis zone.

The evaluation started with the skin preparation, shaving the muscle belly surface and cleaning it with alcohol solution. After that, surface electrodes Ag/AgCl (Unilect) with circular shape of 5mm of diameter and bipolar configuration were placed on muscle belly following the muscular fibers orientation with a distance of approximately 2cm between their centre points.

The reference electrode was placed on olecranon as earth point. This local was chosen because didn't interfere with the gymnast performance and was nearby the muscular points being evaluated. This procedures were taken based in SENIAM (1999) recommendations, to obtain a correct electrodes placement and better signal collection.

To collect the EMG signal from the electrode was use a pre-amplifier AD621 BN, with a gain of 100 and a common mode rejection ratio (CMRR) equal to 110 dB (Carvalho et al., 1999; Correia & Mil-Homens, 2004).

The EMG signal passed by an analogical/digital (A/D) converter of 16bits – *BIOPAC System, Inc*; with an input range of ±10 volts at acquisition index of 1000 samples per second for 8 channels of SEMG. To synchronise the EMG signal was use a digital video camera *Sony® - GR-SX1* recording 50 frames per second. The video camera and a led just positioned in front of the camera were connected to a channel on *BIOPAC system, Inc*, synchronising the EMG signal with the start/end of each trial. The software *Ariel Performance Analysis System* was used to analyse the video image and collect the frame data of the led lightning up and the start/ending moment of each exercise. The SEMG collected signal was processed by *Acqknowledge® 3.2.5*, *BIOPAC System, Inc*, data acquisition programme.

According to Correia and Mil-Homens (2004), before any data interpretation is necessary to prepare the SEMG signal for a quantitative and qualitative evaluation. Using MATLAB 7.0 software, the following procedures were taken (Correia & Mil-Homens, 2004; SENIAM, 1999):

1. Remove DC offset;
2. Signal filtering to a bandwidth of 10 to 350 Hz;
3. Signal rectification – transforming the signal in absolute values;
4. Convert SEMG signal in root mean square (RMS) with an epoch of 250 milliseconds;
5. RMS normalization – to a maximal voluntary contraction (MVC);
6. Calculate the muscular co-activation index – agonist / antagonist relation.

After step 4, the average of RMS activity for each muscle analysed and the co-activation index were recorded in a “txt” file for every attempt of the 12 performed exercises.

At the end of the test, was performed a swallow on rings until gymnast exhaustion. The maximal value of isometric contraction of each muscle was taken from that exhaustion exercise, and then, used as indicator to normalize the muscular activity between exercises before determine the co-activation index. According to Kellis et al. (2003), the muscular co-activation index was establish with the following formula:

$$\text{Co-activation index} = \frac{\text{RMS antagonist}}{\text{RMS agonist} + \text{RMS antagonist}} \times 100$$

The muscular co-activation index was calculated for each exercise and between the following muscles in table 2.

Table 2 – Muscles distribution for muscular co-activation.

| | Agonist | Antagonist |
|---|---|---|
| 1 | Biceps brachii(long head) | Triceps brachii (long head) |
| 2 | Serratus anterior | Trapezius inferior |
| 3 | Pectoralis major | Latissimus dorsi |
| 4 | Deltoid anterior | Infraspinatus |

## 4.3 Statistical Analyses

At first, the recorded data from repeated measures of each muscle among 12 exercises were collected from txt file with *OxiMetrics 5 - OxEdit software*. The mean between those examinations per exercise were calculated using the recorded RMS average of each muscle and the co-activation index among the 12 exercises with *Microsoft Office Excel 2007 software*. Subsequently, the percentages of RMS activity of each muscle among the 12 exercises were calculated using the MVC recorded from each muscle during exhaustion exercise, as 100% indicator.

To observe the relation between the muscular activities among the different exercises, was used the Spearman's Correlation with statistical significance of $p<0,01$ and $p<0,05$ to found relations between the muscular RMS values and muscular co-activation index, using the statistical data software - *SPSS 18.0 software for Windows*.

# 5. Results

## 5.1 Muscular Correlations

Table 3 is presented below with the correlations between 8 muscles during the execution of 12 exercises, which are “swallow on rings”, “upon small balls”, rings feet on floor”, “rings lying on floor”, “forearm support”, “fitness balls”, “barbell”, “trampolines support”, “dumbbells”, “help on pelvis”, “pelvis supported by fitness ball” and “rubber band support”.

Table 3 – Correlations values among the muscular activations along the performed exercises.

**BB** – Biceps brachii; **TB** – Triceps brachii; **SA** – Serratus anterior; **TI** – Trapezius inferior; **PM** – Pectoralis major; **LD** – Latissimus Dorsi; **DA** – Deltoid anterior; **I** – Infraspinatus; **r** – Correlation value; **p** – Significance value. Correlation is significant at the 0,01 level (**), Spearman’s Correlation.

| Muscles | | BB | TB | SA | TI | PM | LD | DA | I |
|---|---|---|---|---|---|---|---|---|---|
| **Biceps Brachii** | r | 1,000 | 0,364 | 0,336 | 0,203 | 0,238 | 0,154 | -0,049 | 0,189 |
| | p | | 0,245 | 0,286 | 0,527 | 0,457 | 0,632 | 0,880 | 0,557 |
| **Triceps Brachii** | r | | 1,000 | 0,371 | 0,084 | 0,399 | 0,298 | 0,531 | **0,748****  |
| | p | | | 0,236 | 0,795 | 0,199 | 0,347 | 0,075 | **0,005** |
| **Serratus Anterior** | r | | | 1,000 | -0,483 | 0,245 | -0,350 | 0,476 | 0,098 |
| | p | | | | 0,112 | 0,443 | 0,264 | 0,118 | 0,762 |
| **Trapezius Inferior** | r | | | | 1,000 | 0,119 | 0,214 | -0,042 | 0,434 |
| | p | | | | | 0,713 | 0,505 | 0,897 | 0,159 |
| **Pectoralis Major** | r | | | | | 1,000 | 0,151 | -0,014 | 0,364 |
| | p | | | | | | 0,640 | 0,966 | 0,245 |
| **Latissimus Dorsi** | r | | | | | | 1,000 | 0,025 | 0,028 |
| | p | | | | | | | 0,940 | 0,931 |
| **Deltoid Anterior** | r | | | | | | | 1,000 | 0,531 |
| | p | | | | | | | | 0,075 |
| **Infraspinatus** | r | | | | | | | | 1,000 |
| | p | | | | | | | | |
| **Exercises** | | | 12 | 12 | 12 | 12 | 12 | 12 | 12 |

Table 3 shows a positive high correlation (r=0,748) between triceps brachii and infraspinatus muscles with statistical significance of p=0,005. This correlation is statistically significant for p=0,005 at p<0,01 level of significance.

In the Table 4 are presented the correlation between the muscular co-activation of biceps/triceps, serratus/trapezius, pectoralis/latissimus dorsi and deltoid/infraspinatus during the execution of 12 exercises, which are “swallow on rings”, “upon small balls”, rings feet on floor”, “rings lying on floor”, “forearm support”, “fitness balls”, “barbell”, “trampolines support”, “dumbbells”, “help on pelvis”, “pelvis supported by fitness ball” and “rubber band support”.

Table 4 - Correlations values among the muscular co-activation along the performed exercises.

**BB** – Biceps brachii; **TB** – Triceps brachii; **SA** – Serratus anterior; **TI** – Trapezius inferior; **PM** – Pectoralis major; **LD** – Latissimus Dorsi; **DA** – Deltoid anterior; **I** – Infraspinatus; **r** – Correlation value; **p** – Significance value. Correlation is significant at the 0,05 level(*). Spearman’s Correlation.

| Muscular co-activation | | BB / TB | SA / TI | PM / LD | DA / I |
|---|---|---|---|---|---|
| **Biceps/Triceps** | r | 1,000 | -0,126 | -0,238 | 0,063 |
| | p | | 0,697 | 0,457 | 0,846 |
| **Serratus/Trapezius** | r | | 1,000 | **0,594*** | 0,252 |
| | p | | | **0,042** | 0,430 |
| **Pectoralis/Latissimus Dorsi** | r | | | 1,000 | -0,294 |
| | p | | | | 0,354 |
| **Deltoid/infraspinatus** | r | | | | 1,000 |
| | p | | | | |
| **Exercises** | | 12 | 12 | 12 | 12 |

The Table 4 shows a substantial correlation between the muscular co-activation of serratus/trapezius and pectoralis/latissimus dorsi (r= 0,594) that is statistically significant (p=0,042) at p<0,05 level of significance. The correlation index of muscular co-activation between biceps/triceps and serratus/trapezius (p=0,697); biceps/triceps and pectoralis/latissimus dorsi (p=0,457); biceps/triceps and deltoid/infraspinatus (p=0,846); serratus/trapezius and deltoid/Infraspinatus (p=0,430); pectoralis/latissimus dorsi and deltoid/Infraspinatus (0,354) are not statistically significant at p<0,05 level of significance.

The following table (according to table 5) expresses the correlation between the muscular co-activations of biceps/triceps, serratus/trapezius, pectoralis/latissimus dorsi, deltoid/infraspinatus and the 8 muscles analysed, which are biceps brachii, triceps brachii, serratus anterior, trapezius inferior, pectoralis major, latissimus dorsi, deltoid anterior and infraspinatus.

Table 5 - Correlations values among the muscular activations and muscular co-activations along the performed exercises.

**BB** – Biceps brachii; **TB** – Triceps brachii; **SA** – Serratus anterior; **TI** – Trapezius inferior; **PM** – Pectoralis major; **LD** – Latissimus Dorsi; **DA** – Deltoid anterior; **I** – Infraspinatus; **r** – Correlation value; **p** – Significance value. Correlation is significant at the 0,05 level (*) and 0,01 level (**), Spearman's Correlation.

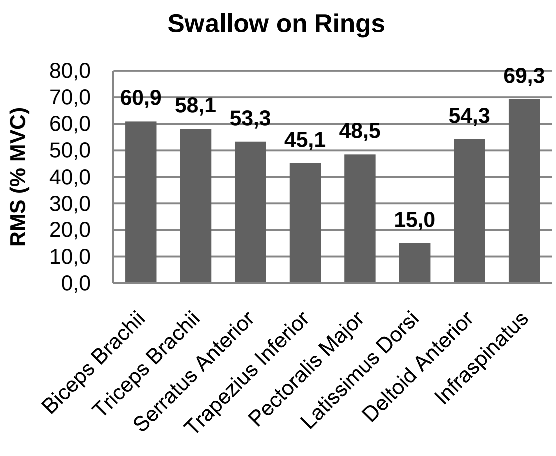
| **Muscular Co-activation** | | **Muscular activation** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **BB** | **TB** | **SA** | **TI** | **PM** | **LD** | **DA** | **I** |
| **BB / TB** | r | -0,287 | **0,608*** | 0,175 | -0,294 | 0,196 | -0,116 | 0,294 | 0,392 |
| | p | ,366 | **0,036** | 0,587 | 0,354 | 0,542 | 0,721 | 0,354 | 0,208 |
| **SA / TI** | r | -0,084 | -0,084 | **-0,853**** | **0,825**** | -0,091 | 0,343 | -0,266 | 0,224 |
| | p | 0,795 | 0,795 | **0,000** | **0,001** | 0,779 | 0,275 | 0,404 | 0,484 |
| **PM / LD** | r | -0,231 | -0,070 | **-0,622*** | 0,378 | -0,434 | **0,697*** | 0,140 | -0,056 |
| | p | 0,471 | 0,829 | **0,031** | 0,226 | 0,159 | **0,012** | 0,665 | 0,863 |
| **DA / I** | r | 0,378 | 0,434 | -0,070 | 0,441 | 0,510 | -0,004 | -0,070 | **0,741**** |
| | p | 0,226 | 0,159 | 0,829 | 0,152 | 0,090 | 0,991 | 0,829 | **0,006** |
| **Exercises** | | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |

In a general perspective, table 5 illustrate tree high correlations at p<0,01 level of significance and tree substantial correlations at p<0,05 level of significance. The muscular co-activation of serratus/trapezius muscles presents a negative high correlation (r=-0,853) with the serratus muscle presenting a statistical significance of p=0,000. The co-activation of serratus/trapezius muscles and co-activation of deltoid/infraspinatus presented respectively a positive high correlation with trapezius (r=0,825) and Infraspinatus (r=0,741) muscles, with the corresponding statistical significance of p=0,001 and p=0,006 at p<0,01 level of significance.

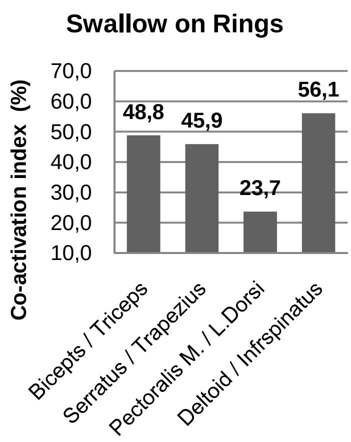
At p<0,05 level of significance there are two positive substantial correlations between muscular co-activation of biceps/triceps and triceps muscle (r=0,608); and between muscular co-activation of pectoralis/latissimus dorsi and latissimus dorsi muscle (r=0,697), with the respective statistical significance of p=0,036 and p=0,012. On the other hand the serratus muscle presents a negative substantial correlation with muscular co-activation of pectoralis/latissimus dorsi (r=-0,622), with a statistical significance of p=0,031.

## 5.2 Muscular Activation During “Swallow on Rings” Exercise

The graphics 1 and 2 respectively demonstrate the muscular activation of each muscle analysed and the muscular co-activations of agonist/antagonist muscles during “swallow on rings” exercise.




Graphic 1 – Percentage distribution of muscular RMS activity during “swallow on rings” exercise.




Graphic 2 – Co-activation index of agonist/antagonist muscles during “swallow on rings” exercise.

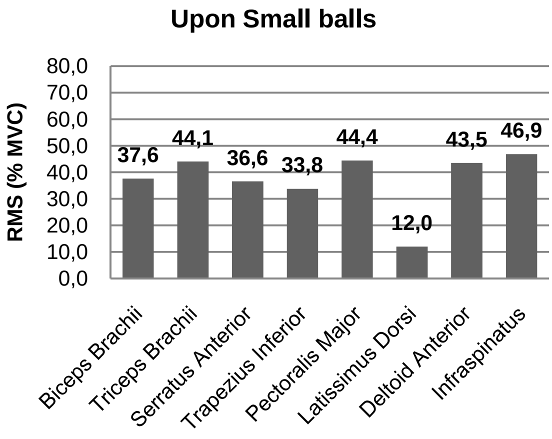
In a general observation of Graphic 1, infraspinatus and biceps brachii presented the highest activation values with respectively 69,3% and 60,9% during the swallow performance on rings. Just a step below were found the triceps brachii with 58,1%; deltoid anterior with 54,3% and serratus anterior with 53,3%. The lowest ones, were pectoralis major with 48,5%; trapezius inferior with 45,1% and latissimus dorsi which with only 15% of maximal activation, becoming the lowest muscle used on this exercise.

Observing graphic 2, the co-activation index between biceps/triceps and serratus/trapezius muscles were proximally to 50% of co-contraction with the corresponding values of 48,8% and 45,9%, where agonist muscular contraction was slight superior comparing to the antagonist muscle. Between deltoid/Infraspinatus the co-activation was higher than 50% of co-contraction (56,1%), which antagonist muscles show a slight superior contraction comparing to agonist muscle.

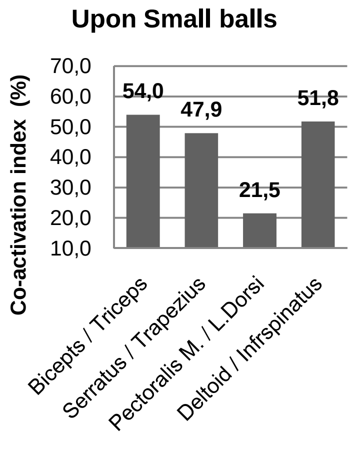
The lowest value found was for pectoralis/latissimus dorsi co-activation, where the agonist muscular contraction prevailed through antagonist with a percentage lower than 25% of co-activation (23,7%).

## 5.3 Muscular Activation During Training Exercises

The graphics 3 and 4 respectively represent the muscular activation of each muscle analysed and the muscular co-activation of agonist/antagonist muscles during “upon small balls” exercise.




Graphic 3 – Percentage distribution of muscular RMS activity during “upon small balls” exercise.



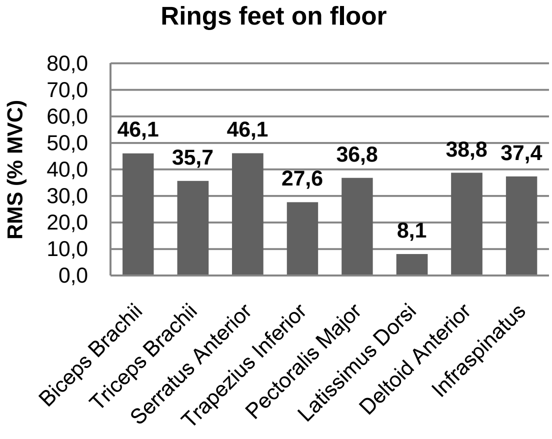

Graphic 4 – Co-activation index of agonist/antagonist muscles during “upon small balls” exercise.

Looking at graphic 3, we are able to see that the activation values for each muscle analysed during the execution of swallow “upon the small balls”, are all lower than 50% of MVC. The highest activation values were achieved by Infraspinatus (46,9%), pectoralis major (44,4%) triceps brachii (44,1%) and deltoid anterior (43,5%); followed by biceps brachii (37,6%), serratus anterior (36,6%) and trapezius inferior (33,8%) that didn’t achieved 40% of MVC during this exercise. The lowest activation value found on this exercise was for latissimus dorsi muscle with 12% of MVC.

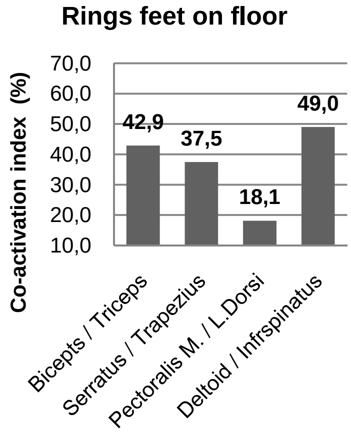
Analysing graphic 4, the co-activation index between biceps/triceps (54%) and deltoid/infraspinatus (51,8%) were slight higher than 50% of contraction, showing that antagonist muscle had a slight superior contraction comparing to agonist. On the other hand, the serratus/trapezius co-activation (47,9%), indicates a similar level of co-contraction between muscles, with the agonist muscles slight exceeding the antagonist muscular contraction.

The lowest value found was for pectoralis/latissimus dorsi co-activation, where the agonist muscle had a superior contraction prevail through antagonist muscle during the execution of swallow “upon small balls” exercise.

The following graphics (5 and 6), respectively illustrate the muscular activation of each muscle analysed and the muscular co-activation of agonist/antagonist muscles during “rings feet on floor” exercise.




Graphic 5 – Percentage distribution of muscular RMS activity during “rings feet on floor” exercise.




Graphic 6 – Co-activation index of agonist/antagonist muscles during “rings feet on floor” exercise.

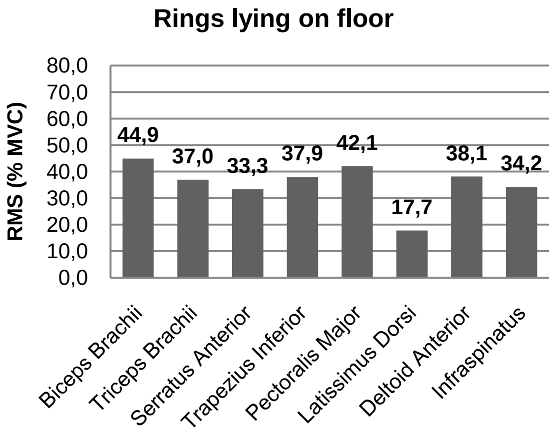
Graphic 5 shows that during swallow execution the muscular activation were inferior to 50% of MVC in every muscle analysed.

The highest activation values found in graphic 5 came from biceps brachii and serratus anterior, both with 46,1% of MVC. Between 40% and 30% of MVC were found the deltoid anterior (38,8%), Infraspinatus (37,4%), pectoralis major (36,8%) and triceps brachii (35,7%). Below to 30% of MVC, were found the Trapezius inferior with 27,6% and latissimus dorsi with 8,1%, being this last the lowest activated muscle during “rings feet on floor” exercise.

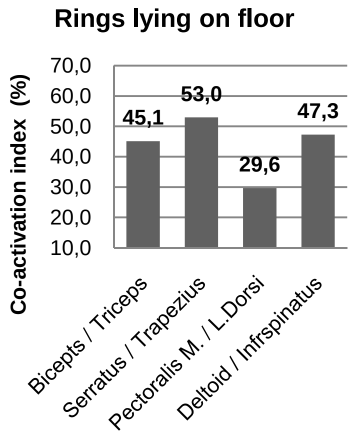
The co-activation index represented on graphic 6, shows that all agonist muscles had superior levels of muscular contraction. However, 49% of co-activation between deltoid/infraspinatus indicates approximately an equal level of co-contraction between these two muscles. Although in this relation the deltoid anterior as agonist muscle had shown a slight superior contraction comparing to infraspinatus as antagonist muscle. The co-activation index for biceps/triceps and for serratus/trapezius were correspondingly 42,9% and 37,5% during this exercise.

At last the co-activation index for pectoralis major/latissimus dorsi stand on 18,1%, where pectoralis major as agonist muscle had superior level of contraction than latissimus dorsi as antagonist during “rings feet on floor” exercise.

The graphics 7 and 8 respectively demonstrate the muscular activation of each muscle analysed and the muscular co-activation of agonist/antagonist muscles during “rings lying on floor” exercise.




Graphic 7 – Percentage distribution of muscular RMS activity during “rings lying on floor” exercise.



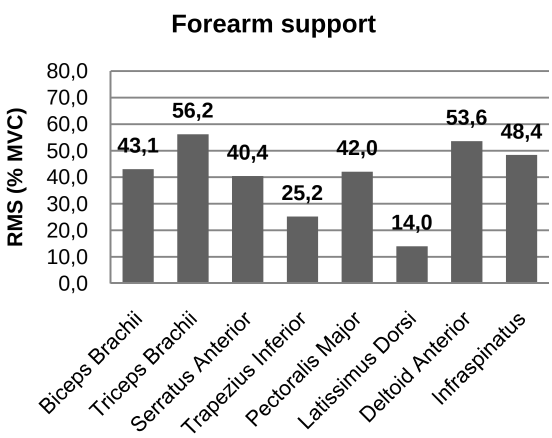

Graphic 8 – Co-activation index of agonist/antagonist muscles during “rings lying on floor” exercise.

Observing graphic 7 describing “rings lying on floor” exercise, the muscular activation in each analysed muscle was inferior to 50% of MVC.

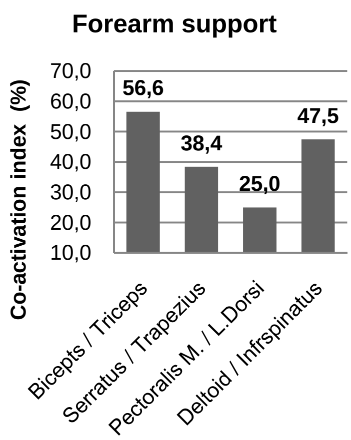
During this exercise, biceps brachii and pectoralis major were the most active muscles with respectively 44,9% and 42,1% of MVC. Most of the muscles were found with activations between 40% and 30% of MVC, in particular, deltoid anterior (38,1%), trapezius inferior (37,9%), triceps brachii (37%), infraspinatus (34,2%), and serratus anterior (33,3%). The lowest activated muscle during swallow execution with body lying on floor was the latissimus dorsi muscle with 17,7% of MVC.

In a general observation of graphic 8, serratus/trapezius co-activation achieved 53% co-contraction between muscles, where trapezius muscles shown a slight superior level of co-contraction comparing to serratus anterior. On the other hand deltoid/Infraspinatus and biceps/triceps co-activation achieved respectively 47,3% and 45,1% of co-contraction, where agonist had a slight superior level of co-contraction comparing to antagonist. Although, this tree co-activation levels shown that muscular co-contractions are sensibly similar between agonist/antagonist muscles. The co-activation index for pectoralis/latissimus dorsi stand on 29,6% of co-contraction, with pectoralis major having superior level of contraction than latissimus dorsi during "rings lying on floor" exercise.

In the following graphics (9 and 10), are respectively represented the muscular activation of each muscle analysed and the muscular co-activation of agonist/antagonist muscles during "forearm support" exercise.




Graphic 9 – Percentage distribution of muscular RMS activity during "forearm support" exercise.




Graphic 10 – Co-activation index of agonist/antagonist muscles during "forearm support" exercise.

The graphic 9 shows that triceps brachii and deltoid anterior were the most activate muscles during the exercise “forearm support”, achieving respectively 56,2% and 53,6% of MVC. Between 50% and 40% of MVC, were found the Infraspinatus (48,4%), biceps brachii (43,1%), pectoralis major (42%) and serratus anterior (40,4%).

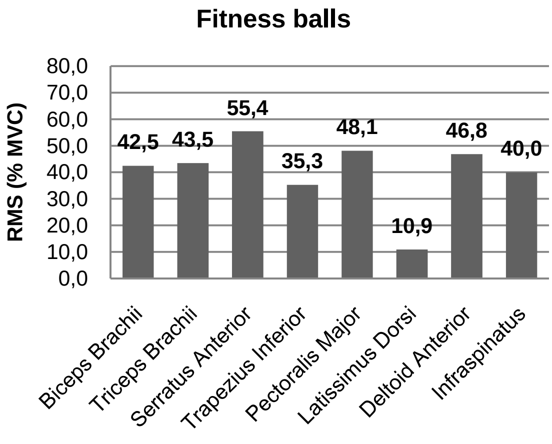
The lowest values of muscular activation during this exercise were collected from trapezius inferior and latissimus dorsi, with correspondingly 25,2% and 14% of MVC.

Analysing graphic 10, the co-activation index between biceps/triceps (56,6%) and deltoid/Infraspinatus (47,5%), indicates an equal level of co-contraction, where in the first case the antagonist slight exceed the agonist muscular contraction, and in the second case is the agonist that surpasses the antagonist muscular contraction.

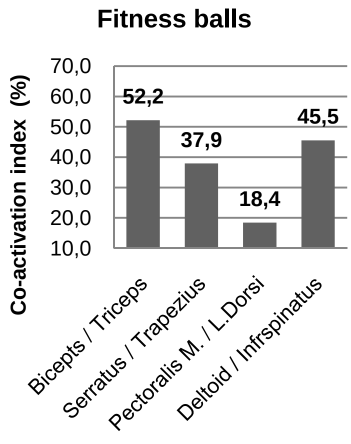
The muscular co-activation of serratus/trapezius achieved 38,4% of co-contraction, showing that serratus anterior as agonist muscle had a superior contraction than trapezius inferior as antagonist.

The lowest co-activation found was for pectoralis/latissimus dorsi muscles, which indicates that pectoral’s contraction was highly superior to latissimus dorsi during “forearm support” exercise.

The graphics 11 and 12 presented below, respectively illustrate the muscular activation of each muscle analysed and the muscular co-activation of agonist/antagonist muscles during “fitness balls” exercise.




Graphic 11 – Percentage distribution of muscular RMS activity during "fitness balls" exercise.




Graphic 12 – Co-activation index of agonist/antagonist muscles during "fitness balls" exercise.

The graphic 11 shows that serratus anterior was the muscle with the higher muscular activity, presenting 55,4% of MVC. During the execution of "fitness balls" exercise, most of the muscles achieved values between 40% and 50% of MVC. In this case are the pectoralis major (48,1%), deltoid anterior (46,8%), triceps brachii (43,5%), biceps brachii (37,6%), and Infraspinatus (40%).

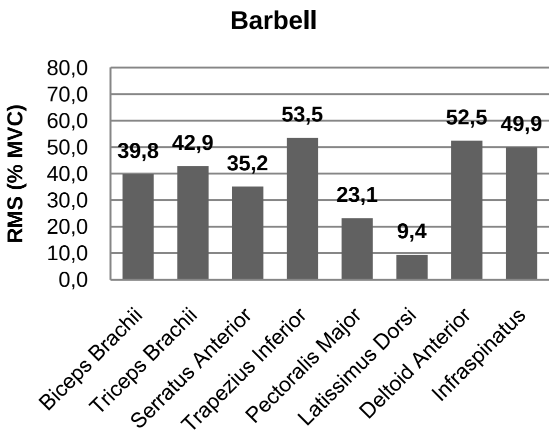
The lowest activation value found on this exercise was for latissimus dorsi muscle with 10,9% of MVC.

Looking at graphic 12, the co-activation index between biceps/triceps (52,2%) and deltoid/Infraspinatus (45,5%), indicates a identical level of co-contraction, where in the first case the antagonist slight exceed the agonist muscular contraction, and in the second case is the agonist that supers the antagonist muscular contraction.

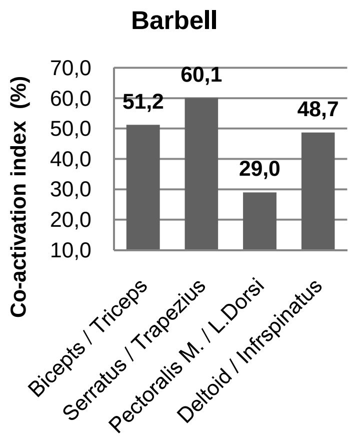
The co-activation value for serratus/trapezius was 37,9%, indicating a superior muscular co-contraction coming from serratus anterior than trapezius inferior during "fitness balls" exercise.

Once more the co-activation value for pectoralis/latissimus dorsi was the lowest one with 18,4% of co-contraction, indicating a substantial superior contraction coming from pectoralis major than latissimus dorsi during the performance of this exercise.

In the following graphics (13 and 14), are respectively presented the muscular activation of each muscle analysed and the muscular co-activation of agonist/antagonist muscles during “barbell” exercise.




Graphic 13 – Percentage distribution of muscular RMS activity during “barbell” exercise.




Graphic 14 – Co-activation index of agonist/antagonist muscles during “barbell” exercise.

Observing graphic 13, the trapezius inferior, deltoid anterior and infraspinatus were the muscles with the highest muscular activity, with respectively 53,5%, 52,5% and 49,9% of MVC during “barbell” exercise.

Just below were found the triceps brachii (42,9%), biceps brachii (39,8%) and serratus anterior (35,2%), that didn’t achieved 45% of MVC.

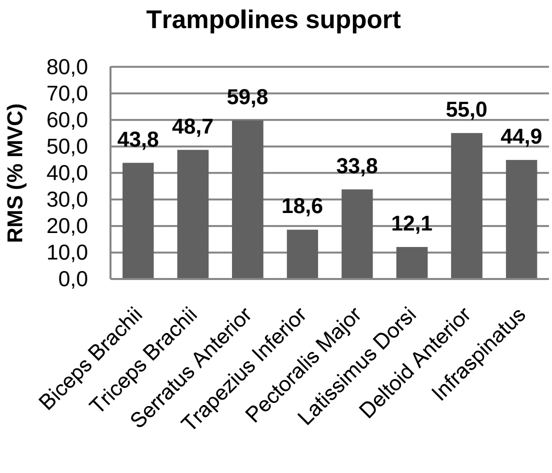
The lowest activation values belong to pectoralis major and latissimus dorsi, with correspondingly 23,1% and 9,4% of MVC.

Analysing graphic 14, the co-activation between serratus/trapezius muscles indicates that there is a superior contraction coming from trapezius inferior than serratus anterior with 60,1% of co-contraction those muscles during “barbell” exercise.

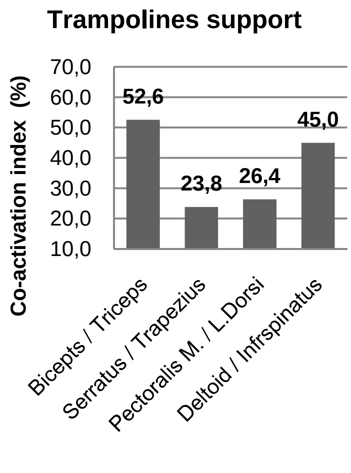
On the other hand, a co-activation of 29% from pectoralis/latissimus dorsi expresses that there is a superior co-contraction coming from pectoralis major than from latissimus dorsi.

At last, the values of biceps/triceps and deltoid/infraspinatus represented on graphic 14, indicates an identical level of co-contraction with values rounding 50% of co-activation. In the first case the triceps as antagonist slight surpasses the biceps muscular co-contraction presenting a co-activation of 51,2%, and in the second case is the deltoid as agonist that surpasses the infraspinatus muscular co-contraction with the co-activation of 48,7%.

The graphics 15 and 16 respectively show the muscular activation of each muscle analysed and the muscular co-activation of agonist/antagonist muscles during “trampolines support” exercise.




Graphic 15 – Percentage distribution of muscular RMS activity during “trampolines support” exercise.




Graphic 16 – Co-activation index of agonist/antagonist muscles during “trampolines support” exercise.

According to graphic 15, the “trampolines support” exercise demanded a higher muscular activation for serratus anterior and deltoid anterior muscles, achieving on this exercise respectively 59,8% and 55% of MVC.

Giving a contribution around 45% of MVC, were found the triceps brachii (48,7%), infraspinatus (44,9%) and biceps brachii (43,8%) muscles, during “trampolines support” exercise.

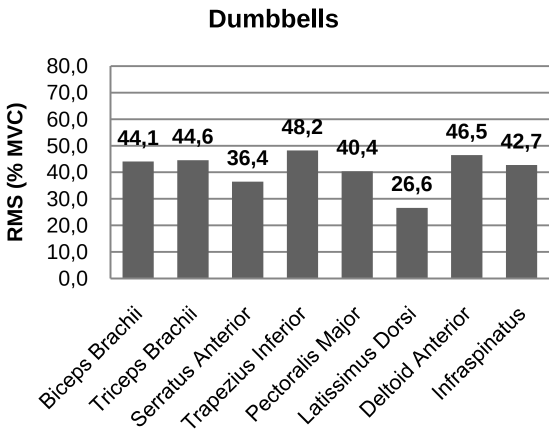
The pectoralis major was the anterior muscle that less contributed for the execution of this exercise, with an activation of 33,8% of MVC.

The muscles with the lowest activation were trapezius inferior and latissimus dorsi, which as posteriors muscles achieved respectively 18,6% and 12,1% of their MVC.

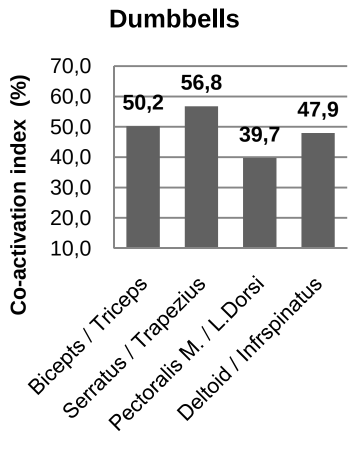
Observing graphic 16, the muscular co-activation of biceps/triceps and deltoid/infraspinatus, indicates an identical level of co-contraction with values rounding 50% of co-activation. In the first case the triceps as antagonist muscle slight exceeds the biceps muscular co-contraction presenting a co-activation of 52,6%; and in the second case is the deltoid as agonist muscle that surpasses the infraspinatus muscular co-contraction with a co-activation of 45%.

The lower values of serratus/trapezius - 23,8% and pectoralis/latissimus dorsi - 26,4% co-activation index, indicates that there is a respectively superior co-contraction coming from serratus anterior and pectoralis major than from trapezius inferior and latissimus dorsi muscles during “trampolines support” exercise.

The graphics 17 and 18 respectively demonstrate the muscular activation of each muscle analysed and the muscular co-activation of agonist/antagonist muscles during “dumbbells” exercise.




Graphic 17 – Percentage distribution of muscular RMS activity during "dumbbells" exercise.




Graphic 18 – Co-activation index of agonist/antagonist muscles during "dumbbells" exercise.

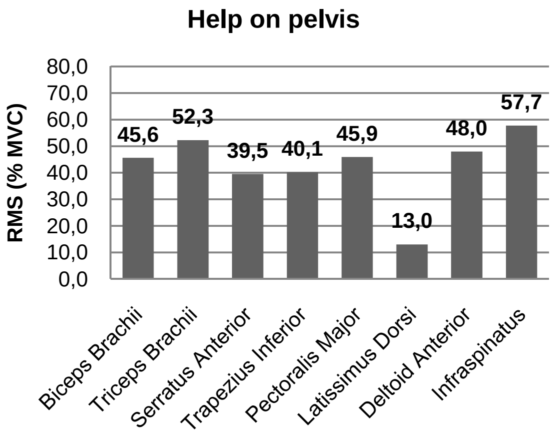
In a general observation graphic 17 shows muscular activities below 50% of MVC for each muscle analysed. Also, most of the muscles presented activation values around 45% of their MVC. With small variations on the activation values, trapezius inferior – 48,2%, was the muscle with higher activation index, followed by deltoid anterior – 46,5%, triceps brachii – 44,6%, biceps brachii – 44,1%, infraspinatus – 42,7%, and pectoralis major – 40,4%.

The lowest muscular activation value found for the "dumbbells" exercise belongs to serratus anterior and latissimus dorsi, with respectively 36,4% and 26,6% of their MVC.

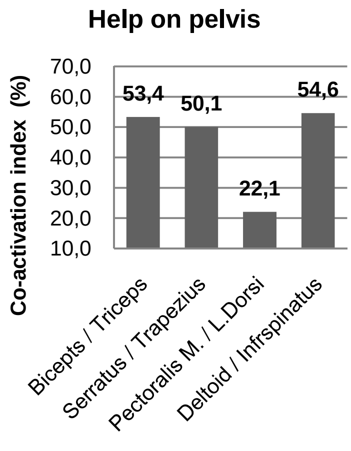
The graphic 18 shows an identical level of co-contraction between agonist/antagonist for tree muscular groups, with values rounding 50% of co-activation index. In this case, are included the trapezius inferior that surpasses the serratus muscular contraction with a co-activation of 56,8%; triceps brachii that slightly surpass the biceps muscular contraction with a co-activation of 50,2%; and the deltoid that slightly exceeds the infraspinatus muscular contraction with a co-activation of 47,9%. So, in the first two cases is the antagonist that surpasses the agonist and in the third case is the agonist that surpasses the antagonist.

Comparing pectoralis with latissimus dorsi, the co-activation index of 39,7%, indicates that pectoralis major contracts more than latissimus dorsi during swallow execution with dumbbells.

The graphics 19 and 20 respectively show the muscular activation of each muscle analysed and the muscular co-activation of agonist/antagonist muscles during "help on pelvis" exercise.




Graphic 19 – Percentage distribution of muscular RMS activity during "help on pelvis" exercise.




Graphic 20 – Co-activation index of agonist/antagonist muscles during "help on pelvis" exercise.

Observing graphic 19, the highest values found belong to two posterior muscles, infraspinatus with 57,7% and triceps brachii with 52,3% of their MVC. In the same perspective, the anterior muscles, such as deltoid anterior, pectoralis major and biceps brachii came just after, contributing with 48%, 45,9% and 45,6% of their MVC.

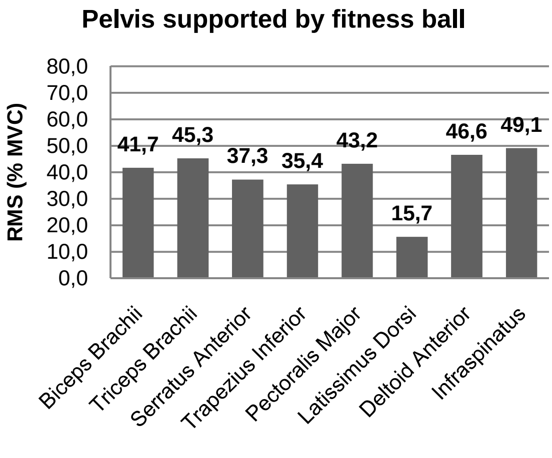
The muscular activation of trapezius inferior and serratus anterior were very similar, achieving respectively 40,1% and 39,5% of their MVC.

The latissimus dorsi was the muscle that less contributed for the execution of this exercise, with an activation of 13% of MVC.

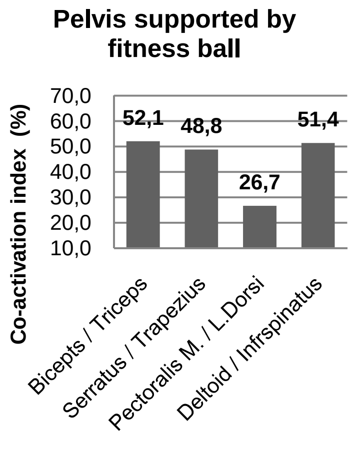
Graphic 20 shows identical levels of co-contraction for tree muscular groups, with 50% of co-activation index between agonist/antagonist. For deltoid/infraspinatus (54,6%) and biceps/triceps (53,4%) co-activation, the antagonist contributed slightly more for the contraction than the agonist. The co-activation of serratus/trapezius with 50,1%, indicates a similar co-contraction between agonist/antagonist muscles.

Once more, the pectoralis/latissimus dorsi co-activation index was lower, achieving 22,1% of co-contraction, which indicates that pectoralis muscle contributes more than latissimus dorsi to perform “help on pelvis” exercise.

The graphics 21 and 22 presented below respectively describe the muscular activation of each muscle analysed and the muscular co-activation of agonist/antagonist muscles during “pelvis supported by fitness ball” exercise.




Graphic 21 – Percentage distribution of muscular RMS activity during “pelvis supported by fitness ball” exercise.




Graphic 22 – Co-activation index of agonist/antagonist muscles during “pelvis supported by fitness ball” exercise.

Looking at graphic 21, the muscular activation of evaluated muscles situated below 50% of the MVC. However, most of them presented activation values around 45% of their MVC. During the execution of “pelvis supported by fitness ball” exercise, the infraspinatus was the muscle with higher activation – 49,1%, followed by deltoid anterior – 46,6%; triceps brachii – 45,3%; pectoralis major – 43,2% and biceps brachii with 41,7% of MVC.

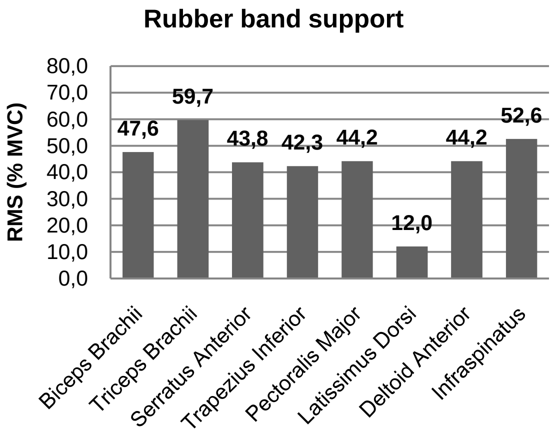
In a lower level and with a similar muscular activation, are the serratus anterior and trapezius inferior that respectively achieved 37,3% and 35,4% of the MVC.

Latissimus dorsi was the muscle with less muscular activation during this exercise, contributing with 15,7% of their MVC.

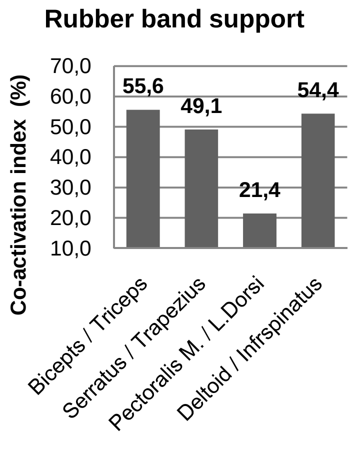
The graphic 22 shows that the muscular co-activation of biceps/triceps, deltoid/Infraspinatus and serratus/trapezius, indicates an identical level of co-contraction between muscles, with values rounding 50% of co-activation. So, in the first two cases is the antagonist (triceps and infraspinatus) that slightly surpasses the agonist contraction (biceps and deltoid) with a corresponding co-activation of 52,1% and 51,4%; and in the third case, the situation inverts and the serratus slightly surpasses the trapezius co-contraction with a co-activation of 48,8%.

The co-activation value for pectoralis/latissimus dorsi was the lowest one with 26,7%, indicating a superior co-contraction coming from pectoralis major than latissimus dorsi during “pelvis supported by fitness ball” exercise.

The following graphics (23 and 24), respectively describe the muscular activation of each muscle analysed and the muscular co-activation of agonist/antagonist muscles during “rubber band support” exercise.




Graphic 23 – Percentage distribution of muscular RMS activity during “rubber band support” exercise.




Graphic 24 – Co-activation index of agonist/antagonist muscles during “rubber band support” exercise.

The highest muscular activations represented in graphic 23 belongs to posterior muscles, the triceps brachii muscle with 59,7% and infraspinatus muscle with 52,6% of MVC.

Below 50% of MVC and with similar levels of muscular activation came the biceps brachii with 47,6%; pectoralis major and deltoid anterior both with 44,2%, serratus anterior with 43,8%, and trapezius inferior with 42,3% of MVC.

The latissimus dorsi muscle contributed with 12% of their MVC for the execution of “rubber band support” exercise.

The graphic 24 shows tree muscular co-activations around 50% which indicates an identical level of co-contraction between agonist/antagonist. The highest values found in this analysis, belong to biceps/triceps and deltoid/infraspinatus muscles with respectively 55,6% and 54,4% of co-activation, indicating that the co-contraction of triceps and infraspinatus as antagonist muscles are slightly superior to biceps and deltoids as agonist on this contraction. The other value found, with a co-activation index close to 50% belongs to serratus/trapezius muscles with 49,1%, representing an identical co-contractions between agonist/antagonist muscles.

Below 25% of co-activation were found the pectoralis/latissimus dorsi muscles with 21,4% of co-activation which demonstrates a superior co-contraction coming from pectoralis than latissimus dorsi muscle during the execution of “rubber band support” exercise.

# 6. Discussion

## 6.1 Muscular Relations During Exercises

To understand the muscular coordination performed during the different exercises tested, we will start the discussion explaining the muscular behaviour in each correlation found.

The correlation found between triceps brachii and infraspinatus muscles during the twelve exercises (table 3), is a positive high correlation (r=0,748) with statistical significance of p=0,005 at p<0,01 level of significance. Same is to say that as much as triceps brachii contracts, more muscular fibres of infraspinatus muscle are activated. So, this relation seems to proof Kapandji (2007) theory about triceps brachii (long head) that during the elbow extension helps to take humerus head forward. Furthermore, it confirms the infraspinatus hard work, not only on maintaining the humerus head into glenoid cavity but also on preventing forward dislocation at shoulder’s joint (Brukner & Khan, 1994; Kapandji, 2007; Kendall, et al., 1993).

Another statistically significant (p=0,042) correlation was found between co-activations of serratus/trapezius and pectoralis/latissimus dorsi, at p<0,05 level of significance. This positive substantial correlation (r=0,594) is presented in table 4 and indicates that as much as serratus/trapezius increase their loads of co-contraction, more muscular co-activation is performed between pectoralis/latissimus dorsi muscles. According to Brukner and Khan (1994) and Kapandji (2007), both muscular groups participate in the scapula stabilization, exerting the shoulder’s protraction and scapula’s depression.

Same is to say that while serratus co-option the scapula to thorax, pectoralis major is able to perform higher muscular loads; and as much as trapezius helps on scapula depression, more latissimus dorsi participates in scapula depression with a slight abduction.

Observing table 5 we found six correlation statistically significant, tree at p<0,01 level of significance and other tree at p<0,05 level of significance.

Looking to table 5, we are able to identify a positive substantial correlation (r=0,608 at p<0,05 level of significance) between co-activation of biceps/triceps and triceps muscle, indicating as much as triceps brachii achieve higher muscular loads, higher is the co-contraction between biceps/triceps. Understanding that triceps brachii is doing the antagonist role, values superiors to 50% of co-activation indicate a superior co-contraction from triceps brachii than from biceps brachii. Also means that elbow joint is fully extended and the humerus head is pushed forward, every time the co-contraction index surpasses 50% of co-activation (Kapandji, 2007).

Following the same logic, the correlation between pectoralis/latissimus dorsi co-activation and latissimus dorsi muscle (r=0,697 at p<0,05 level of significance), corresponds to a positive substantial correlation, indicating that as much as latissimus dorsi achieve higher muscular loads, higher is the co-contraction between pectoralis/latissimus dorsi. In this relation pectoralis was always superior to latissimus dorsi, with co-activation loads between 18,1% and 39,7% along the different exercises tested. These results confirm both theories, that pectoralis major and latissimus dorsi with a simultaneous activation cause the scapula depression and, that latissimus dorsi only performs a slight abduction of the UL because pectoralis major activation is superior in every tested exercise counteracting the latissimus dorsi movement with a stronger adduction (Brukner & Khan, 1994; Kapandji, 2007; Kendall, et al., 1993).

On the other hand, table 5 shows that serratus anterior muscle presented a negative substantial correlation (r=-0,622 at p<0,05 level of significance) between pectoralis/latissimus dorsi co-activation. This result confirms the importance of serratus anterior in scapula stabilization corroborating with the findings in other studies (Bernasconi & Tordi, 2005; Bernasconi, et al., 2009). Same is to say, as much as lower is the pectoralis/latissimus dorsi co-activation, higher is the serratus anterior activation, showing that pectoralis major is able to increase their muscular loads every time that serratus anterior improves the scapula stabilization co-optioning it to thorax.

In the same context, serratus anterior presents a negative high correlation (r=-0,853), while trapezius inferior presents a positive high correlation (r=0,825) with serratus/trapezius co-activation at p<0,01 level of significance. Curiously this result indicates that both muscles contribute simultaneously to scapula stabilization in every exercise analysed. The mutual work is expressed by the relation established between the muscular co-activation and the muscular activation of each of those muscles. In other words, higher muscular activation from serratus anterior will decrease the antagonist (trapezius inferior) co-contraction showing values inferiors to 50% of co-activation, while the opposite will increase the trapezius inferior participation in co-contraction showing values superiors to 50% of co-activation. This means that a similar co-contraction between both muscles (values close to 50% of co-activation), will lead to shoulder protraction by scapula co-option from serratus anterior's action combined with scapula stabilization and depression by trapezius inferior's action (Brukner & Khan, 1994; Kapandji, 2007; Kendall, et al., 1993).

This relation is essential to explain the muscular coordination through training exercises, meaning that, a superior activation from trapezius inferior than serratus anterior, causes a change on muscular activation that could result in shoulder's changing position, such as shoulder retraction (Kapandji, 2007; Kendall, et al., 1993).

At last, table 5 shows a high positive correlation (r=0,741 at p<0,01 level of significance) between infraspinatus muscle and deltoid/infraspinatus muscular co-activation. This is another interesting result, which once more confirms the importance of infraspinatus on shoulder's joint stabilization. The co-activation index of deltoid/infraspinatus muscles increases proportionality to the infraspinatus muscular activation, indicating that higher levels of contraction from deltoid anterior demand higher levels of contraction from infraspinatus that works to maintain the humerus head in glenoid cavity (Brukner & Khan, 1994; Kapandji, 2007).

## 6.2 “Swallow on rings”

Facing the results as a development perspective to increase and adapt the learning process of swallow element, we will start our discussion describing and analysing the results, linking the muscular actions to swallow element performed in a competitive context.

Some studies demonstrate that the execution of swallow on rings demands a high among of strength and coordination between shoulders muscles to support the body weight in a complete horizontal extended position (Bernasconi & Tordi, 2005; Bernasconi, et al., 2009; Sands, et al., 2006).

Knowing that shoulders joint functionality was not fully designed to support the body weight on this position, the muscles must work together to provide joint stability (Kapandji, 2007).

Looking to the results exposed on graphics 1 and 2 it seems that each analysed muscles work in a mutual way to produce a torque that equals the external forces to achieve the body balance and perform swallow on rings (Gluck, 1982). The graphic 2 confirms the mutual relation between muscles. The deltoid/infraspinatus, biceps/triceps and serratus/trapezius muscles demonstrate a similar co-contraction between agonist/antagonist, presenting loadings around 50% of co-activation.

In serratus/trapezius case, the co-contraction of 45,9%, seems to indicate the necessity to stabilize the scapula. Analysing the muscular functionality, when trapezius inferior contracts it acts as a scapula stabilizer and scapula depressor, while serratus anterior acting as trapezius opponent, moves scapula forward and outward co-opting it to thorax, causing the shoulder protraction (Brukner & Khan, 1994; Kapandji, 2007; Kendall, et al., 1993). This is a curious relation, because even with a similar co-contraction, the serratus anterior achieved higher muscular activation, with 53,3% for 45,1% of MVC comparing to trapezius inferior. The superior activation of serratus anterior might be related with scapula co-optation confirming the findings from other authors (Bernasconi & Tordi, 2005; Bernasconi, et al., 2009). On the other hand, the muscular activation of trapezius inferior, is certainly related with the scapula stabilization held in a depression position, mainly overdue to trapezius fibres orientation (Kendall, et al., 1993).

Following the same idea, pectoralis major and latissimus dorsi, are also scapula depressors when working together (Kendall, et al., 1993). The lower co-activation between pectoralis/latissimus dorsi (23,7%) could indicate that pectoralis major with a 48,5% of MVC is more requested during swallow performance than latissimus dorsi muscle that only achieves 15% of MVC. This results seem to indicate that pectoralis major is use to perform the adduction and the UL depression, while latissimus dorsi slight abduct the UL, participating in scapula depression (Brukner & Khan, 1994; Kendall, et al., 1993). Following this logic, the co-contraction between deltoid/infraspinatus with 56,1% of co-activation index combined with infraspinatus loads of 69,3% of MVC, demonstrates that infraspinatus works hardly to maintain the humerus on the glenoid cavity while stabilize the UL in external rotation (Brukner & Khan, 1994; Kapandji, 2007; Kendall, et al., 1993). We believe that this action allows deltoid anterior as antagonist muscle to flex the shoulder joint. This logic might be confirmed by the muscular activation performed by the anterior muscles, such as biceps brachii, deltoid anterior and pectoralis major, which respectively contributed with 60,9%, 54,3% and 48,5% of their MVC. The co-contraction between biceps/triceps with 48,8% of co-activation, shows that triceps acts to extend elbow joint while biceps flex the shoulder joint and helps infraspinatus on the external rotation of the UL (Kapandji, 2007). The superior activation of biceps brachii comparing to triceps brachii, prevents also an excessive extension of elbow joint (Kendall, et al., 1993). According to Kapandji (2007), triceps brachii is also responsible to push the humerus head forward during the elbow extension, which reinforces the protraction of shoulder joint performed by serratus anterior. Combining shoulder's protraction and scapula's depression with UL in external rotation for supination support, will lead to slight abduction of UL, distancing the hands from the body and approximating the angle of contraction of pectoralis major and deltoid anterior. In this logic, Kapandji (2007) defends that deltoid anterior (clavicular head) acts as muscular adductor of the

UL when this is along the body. This mean that deltoid anterior will join to pectoralis major performing the UL adduction and then to biceps brachii performing all together the shoulders flexion.

So, in action-reaction concept of Newton's third law, the swallow element is achieved thanks to a specific muscular coordination, involving a set of actions well engaged that are transformed on a single applied force through rings support, acting on the same direction of the body weigh, equating forces and sustaining the balance (Arkaev & Suchilin, 2004; Gluck, 1982).

Looking to Arkaev and Suchilin (2004) perspective, the difficulty depends on the effort or the required time to learn a certain element, and the complexity depends on the parts number or skills structure that compose the element. The results overview shown that swallow difficulty remains in swallow complexity, where the muscular coordination seems to be the main difficult factor of swallow learning process. Probably that is the justification for Cuk and Karácsony (2002), which in a learning scale of fifteen levels of difficulty, placed swallow at the last strength hold element to be learned. This means that swallow should be one of the last strength elements to be learned due to the muscular coordination complexity involved on their execution.

At the end, stands the image of a swallow element achieved by shoulder joint in protraction position from muscular activation of triceps brachii and scapula co-option done by serratus anterior; followed by UL depression from the muscular contraction of pectoralis major, latissimus dorsi and trapezius inferior; with infraspinatus working to maintain the humerus in glenoid cavity while helps on lateral rotation of the UL supported also by biceps brachii. These muscular combinations allows the anterior muscles, such as biceps brachii, deltoid anterior and pectoralis major to flex the shoulder joint and support the body mass in swallow position upon the rings.

In a training perspective, the general image that coach and gymnasts should focus on, is shoulder protraction with UL extended at elbow joint; the UL along the body performing simultaneously the scapula depression and a slight abduction of UL, and then, make use of anterior muscles to sustain the body mass at rings level.

## 6.3 Swallow Element Vs Training Exercises

In this section we will compare the muscular activations and co-activations of each training exercise with the swallow element performed on rings. In order to identify and transfer the technical aspects to improve swallow learning process, we will centralise the discussion on the muscular differences for each training exercise.

### 6.3.1 "UPON SMALL BALLS"

Observing graphic 3, we are able to see that the muscular loads for all analysed muscles are inferior to ones performed during "swallow on rings" exercise. The main difference remains in the lower level of biceps brachii activation with 37,6% of MVC, which is surpassed by triceps brachii activation 44,1% of MVC, causing a changing in co-contraction of biceps/triceps co-activation (54%), comparing to the competition element co-activation (48,8%). This coordination between biceps/triceps during "upon small balls" exercise could be related with the fact of being executed with feet support, which could cause a slight backward rotation of the body demanding higher levels of contraction from triceps brachii. Although graphic 4, show not only similar co-contractions between the agonist/antagonist muscles, but also identical oscillations in co-activation between this exercise and "swallow on rings" exercise, demonstrating that swallow performed like "upon small balls" exercise, maintain the same functional coordination as competitive element performed on rings. So, those muscular co-activations are performed with serratus anterior stabilizing the scapula and holding shoulder in protraction position with the help of triceps brachii (pushing humerus head forward), while pectoralis and latissimus dorsi perform the scapula depression; biceps brachii, deltoid anterior and pectoralis major participate on shoulder's flexion with infraspinatus preventing humerus head forward dislocation (Brukner & Khan, 1994; Kapandji, 2007; Kendall, et al., 1993).

The "upon small balls" exercise seems to be an excellent training exercise to develop swallow on rings. It is an excellent exercise to develop the muscular coordination of swallow, although we recommend not use it as first approach to swallow element because the small balls can cause support instability avoiding the correct muscular coordination between muscles.

### 6.3.2 "RINGS FEET ON FLOOR"

The activation values found during "rings feet on floor" exercise, were all inferior to ones performed during "swallow on rings" exercise. The major changes detected on this exercise when we analyse the graphic 5 remain, in the muscular activation of infraspinatus (37,4% of MVC) and trapezius inferior (27,6% of MVC) that were very low compare to competitive element; and the serratus anterior that didn't lowered as much as others muscles, presenting the highest activation together with biceps brachii achieving 46,1% of MVC. Looking to the co-activation values expressed on graphic 6, the major difference found belongs to deltoid/infraspinatus co-activation (49%), where the deltoid co-contraction was superior (38,8% of MVC) to the infraspinatus (37,4% of MVC). This alteration modifies the co-contraction between agonist/antagonist muscles, where deltoid is able to perform internal rotation of the UL and infraspinatus maintaining the hard task of shoulder stabilization, seems to abdicate from the external rotation of the UL, fact that could be explained by the lower activation shown (Kapandji, 2007). Although we believe that this inversion is not enough to dramatically change the muscular coordination between muscles and avoid the infraspinatus action in shoulder's stabilization. Looking to the results and comparing the "swallow on rings" with "rings feet on floor" exercise, in a general perspective we can identify almost the same relative flow between muscular co-activations, which indicates a similar level of coordination between muscles during the performance of this exercise. This explanation is also sustained by the relative muscular activation of anterior muscles (biceps, deltoid and pectoralis) and serratus anterior as scapula stabilizer, indicating that a stable coordination between muscles is achieved (Brukner & Khan, 1994).

The “rings feet on floor” seems to be an excellent exercise to develop the serratus anterior activation. Being an exercise that maintains almost the same conditions of “swallow on rings” exercise, we consider it an excellent exercise to develop the muscular coordination between muscles, while it provides a close approximation to swallow element performed on rings.

### 6.3.3 “RINGS LYING ON FLOOR”

In a general observation of graphic 7, it is easy to identify that infraspinatus (34,2% of MVC) and serratus anterior (33,3% of MVC) had lower activation values comparing to “swallow on rings”, while trapezius inferior (37,9% of MVC) didn’t decrease so much, maintained a relative level of contraction. The other muscles shown inferior levels of muscular activations but maintained approximately the same relative difference between each other. Graphic 8 helps us to understand that trapezius inferior performs a higher contraction (37,9% of MVC) in relation to serratus anterior (33,3% of MVC), causing a changing in the co-contraction coordination between muscles, which indicates that the scapula is depressed by trapezius action like in “swallow on rings” exercise, but the shoulder’s protraction might not be performed. According to Sands et al. (2006), adjustments in the head or shoulder position cold result considerable changes in the muscular activation, and therefore, in the muscular coordination pattern collected. Following this idea, the changes detected in muscular activation could be explained by body position, specifically the lay down position. In a situation that the body is lying on the floor and the support (rings) are slight higher than shoulders, a retraction on shoulder’s joint is needed to perform the exercise, changing the muscular coordination between muscles (Kapandji, 2007). On the other hand, we believe that the infraspinatus achieved only half of muscular activation in this exercise than in “swallow on rings”, because it needs to work less to prevent the forward dislocation of humerus head due to lay down position that retracts shoulder’s joint. The muscular co-activation between deltoid/infraspinatus (47,3%) shows identical co-contraction between those muscles, which confirms the shoulders retraction theory.

After all “rings lying on floor” exercise is not a good exercise to learn swallow element because the muscles are not activated the same way as in “swallow on rings” exercise. Changes in scapula and shoulder’s joint stabilization due to superior activation of trapezius inferior with the simultaneous inferior activation of serratus anterior and infraspinatus muscles determining different levels of coordination between muscles, facts that altered the muscular contraction pattern of swallow position.

Knowing that serratus anterior and infraspinatus activations are essential muscles to stabilize shoulder’s joint, allowing other muscles to work as supporters, we believe that the same exercise execute with body lying upon a higher stable surface with rings (support) positioned in slight lower level than body, could result in swallow’s muscular activation approach.

### 6.3.4 “FOREARM SUPPORT”

The “forearm support” exercise seems to follow the same pattern as “swallow on rings” exercise. Although, tree main differences can be identify in a first analyse. Lower levels of contraction were detected for biceps brachii (43,1% for 60,9% of MVC), infraspinatus (48,4% for 69,3% of MVC) and trapezius inferior (25,2% for 45,2% of MVC) comparing to “swallow on rings” exercise. Traducing these values in muscular co-activations, the biceps/triceps and deltoid/infraspinatus relations suffered an inversion in co-contraction. Triceps brachii with high level of activation (56,2% of MVC) surpasses the muscular activation of biceps brachii achieving 56,6% of co-activation, which indicates that elbow joint is fully extended and the humerus head is push forward (Kapandji, 2007). On the other hand, is deltoid anterior (53,6% of MVC) that slight surpasses the muscular activation of infraspinatus which results in 47,5% of co-activation between muscles, indicating that deltoid anterior could be using the internal rotation of shoulder's joint apart of the shoulder's flexion; while infraspinatus is activated only to maintain the humerus head at glenoid cavity, not performing the external rotation of the UL (Kapandji, 2007).

Both aspects, relative higher activation levels for triceps brachii and deltoid anterior during "forearm support" exercise, could be explained by the fact of use the forearm to support the body mass instead of use hands in supination like in "swallow on rings" exercise. This kind of support causes the UL internal rotation demanding higher levels of contraction by deltoid anterior muscle and avoiding the infraspinatus action of performing the UL external rotation (Kapandji, 2007). From this reflection we might confirm that high level of muscular activation performed by infraspinatus during "swallow on rings" is related with not only with the hard work to prevent humerus head dislocation, but also with the external rotation of UL performed essentially through the hands gripe.

Even with those explained differences, we consider "forearm support" a very good exercise for swallow element developing in an initial phase of learning. The main reason is the forearm support that provides an easy access to swallow position, which allows working with similar patterns of muscular co-contractions of "swallow on rings" exercise.

### 6.3.5 "FITNESS BALLS"

In general analyses, "fitness balls" exercise presents a reduction in muscular activation for all muscles excluding serratus anterior (55,4% of MVC) that surpassed the activation values detected in "swallow on rings" exercise. In turn, the infraspinatus activation achieved 40% of MVC, result that represents almost half of activation (69,3%) performed in "swallow on rings" exercise. Looking to the muscular co-activation, we can see a slight higher load of biceps/triceps co-contraction (52,2%), and lower loads of co-contractions for serratus/trapezius (37,9%) and deltoid/infraspinatus (45,5%) comparing to "swallow on rings" exercise. These differences could be explained by the support instability caused by balls rotation. In a manner to stabilize the support, we believe that gymnast tries to positioning the hands in a slight internal rotation, performing simultaneously shoulder's flexion and UL adduction, as an attempt to squeeze the fitness ball against each other. This movement demand a high muscular activation from serratus anterior to stabilize the scapula maintaining the shoulder's protraction (Kapandji, 2007). Those actions are confirmed by the serratus muscular activation that was superior in “fitness balls” than in “swallow on rings” exercise. In this circumstance the anterior muscles, such as biceps brachii, deltoid anterior and pectoralis major, were able to work together flexing the shoulder's joint to maintain the body mass in a isometric position (Kendall, et al., 1993). Also, the muscular co-contraction loads of deltoid/infraspinatus were near to 50% of co-activation, confirming that infraspinatus worked as shoulder's stabilizer (Kendall, et al., 1993). The less muscular activation found for infraspinatus can be explained by gripe type used during “fitness balls” exercise, preventing the muscle to execute the UL external rotation. Comparing this exercise with “swallow on rings”, we are able to verify that the muscular co-activation had identical oscillations, indicating that the muscular coordination is similar to swallow element.

At last, we are able to consider the “fitness balls” an excellent exercise to develop the muscular activation of serratus anterior, but an incomplete exercise at infraspinatus activation. Although with some technical adjustments on body segments position during the execution of this exercise, we can consider it a very helpful exercise on swallow muscular coordination development.

#### 6.3.6 “BARBELL”

Observing graphic 13, we verify that biceps brachii (39,8% of MVC) and pectoralis (23,1% of MVC) presented low activation loads, while trapezius inferior (53,5% of MVC) surpassed and deltoid anterior (52,5% of MVC) achieved almost the same activation as in “swallow on rings” exercise. These results had shown a different level of muscular activation between serratus/trapezius muscles, changing the muscular coordination between those muscles during this exercise. Those muscular changes between “barbell” and “swallow on rings” exercise, indicate that scapula is depressed due to trapezius action, while serratus anterior is use to stabilize scapula opposing the trapezius inferior action but without promoting shoulder’s protraction, which is demonstrated by the low muscular activation of serratus anterior (35,2% of MVC) and pectoralis major muscles (23,1% of MVC), (Brukner & Khan, 1994; Kapandji, 2007; Kendall, et al., 1993). Following this idea, pectoralis major works less due to shoulder’s retraction, and the shoulder’s flexion stands all over the deltoid anterior muscle, explaining the muscular loads of both muscles in this exercise. Also, infraspinatus works here as deltoid anterior antagonist, preventing shoulder’s dislocation, fact that explains the similar co-contraction found between these muscles (Kapandji, 2007). We believe that these changes in muscular coordination are related with the fact of this exercise being done in dorsal position (swallow inverted position).

In particular, “barbell” exercise is a good exercise to develop the muscular contraction of deltoid anterior muscle, but as a whole exercise, it presents many differences in muscular activations, modifying the muscular coordination between muscles. Knowing that factors as, scapula stabilization and shoulder’s protraction are fundamental requisites for swallow perfect performance, we consider that “barbell” could be used as complementary exercise in physical preparation but it is not recommended as specific exercise to develop swallow’s element.

### 6.3.7 “TRAMPOLINES SUPPORT”

Looking to graphic 15, we can observe that all muscular activation were lower than ones performed in “swallow on rings” exercise, with the exception of serratus anterior and deltoid anterior muscles that presented higher activation values with respectively 59,8% and 55% of MVC. On the opposite side were found trapezius inferior (18,6% of MVC) and pectoralis major (33,8% of MVC) with lower muscular activations during “trampolines support” exercise. Obviously that higher activation from serratus anterior and lower from trapezius inferior would result in a lower level of co-activation (23,8%), changing the co-contraction between both muscles. In this logic serratus anterior is able to co-opt the scapula to thorax causing shoulder protraction, and trapezius inferior with low muscular activation seems to prevent the excessive forward and outward movement of scapula during serratus action (Kapandji, 2007). The scapula depression might not be performed by trapezius inferior in this exercise, because the griping is done through a fixed surface using the forearm and the palmar part of the hand to support the body during “trampolines support” exercise. This factor could restricted the trapezius inferior’s action, lowering their muscular activation in this exercise, aspect that is not relevant that this is not a Following the same logic, pectoralis major doesn’t need to perform the same activation as in “swallow on rings” exercise because with stable support less adduction is needed. Another important aspect was the deltoid anterior muscular activation being higher than other anterior muscles, such biceps brachii (43,8% of MVC) and pectoralis major (33,8% of MVC), fact that could indicate that deltoid anterior performed both actions, shoulder’s flexion and internal rotation to maintain the body in swallow position during this exercise (Kapandji, 2007). On the other hand, infraspinatus seems to maintain the same work on shoulders joint stabilization, fact that is confirmed by the co-contraction of 45% in relation to deltoid anterior muscle. The lower muscular activation found for infraspinatus during “trampolines support” comparing to “swallow on rings”, might be related with the inability to perform the UL external rotation caused by the griping changes.

We believe that “trampolines support” is a good exercise to develop swallow element in the first phase of the learning process, because it presents a stable surface of support, allowing to place the body in a correct position, which provides a easy understanding of muscular coordination. It is also a good exercise to develop the muscular contraction of serratus anterior and deltoid anterior muscles. In fact the lower activation of trapezius inferior could be the most limitative aspect of this exercise, but we believe that the muscular coordination got from this exercise is more relevant in swallow's learning process than this alteration in trapezius muscular activation.

### 6.3.8 "DUMBBELLS"

The values expressed on graphic 17, demonstrate that muscles were less activated in "dumbbells" than "swallow on rings" exercise, with the exception of trapezius inferior and latissimus dorsi muscles that presented higher muscular activation with respectively 48,2% and 26,6% of MVC. In a general observation, we verify that serratus anterior and infraspinatus suffered higher decrease in muscular activation than other muscles. The lower contraction of serratus anterior combined with the higher activation of trapezius inferior, caused a change in muscular co-activation, where trapezius inferior surpassed the co-contraction of serratus anterior muscle. This could mean that the scapula depression is more need in this exercise than shoulder's protraction to maintain the dumbbells weigh in an isometric position (Kapandji, 2007; Kendall, et al., 1993). In turn, a higher activation from latissimus dorsi could indicate that the isometric position (dorsal position of swallow) was performed with UL more abduct than in "swallow on rings" exercise (Kendall, et al., 1993). In fact the intrinsic characteristics of this exercise demands the performance of swallow in dorsal position holding the dumbbells weight, position that changes the muscular coordination between agonist/antagonist muscles, as is shown in the muscular co-contraction of serratus/trapezius (56,8%), deltoid/infraspinatus (47,9%) and pectoralis/latissimus dorsi (39,7%).

In our opinion this exercise could be a useful complement for physical preparation, because it gives the possibility to use different levels of charges (weigh). Following the Arkaev and Suchilin (2004) concept, the physical preparation's goal is to promote physical qualities that ensure mastery on exercises performance. Therefore as training exercise, "dumbbells" exercise is not recommended for swallow position development because it has the limitation to providing a different muscular coordination between muscles, altering or decreasing the muscular participation of scapula and shoulders stabilizers.

### 6.3.9 "HELP ON PELVIS"

Observing graphic 19, we verify that all muscular activations were lower than ones observed in "swallow on rings" exercise. Conserving almost the same relative muscular oscillation between them, biceps brachii (45,6% of MVC) and serratus anterior (39,5% of MVC) were the muscles that presented higher decreases in muscular activation in this exercise. These results changed the co-activation of biceps/triceps (53,4%) and serratus/trapezius (50,1%), altering the co-contraction between muscles, where the antagonist muscle slight plays more effort than the agonist. Although, these changes in co-contractions expressed in graphic 20, seem not to affect the muscular coordination because, the co-activation values stand similar to "swallow on rings" and very close to 50% of co-activation, indicating a synergic action between muscles. So, same is to say that even with less muscular activation, biceps brachii seem to preserve the main action of shoulders flexion, while serratus anterior plays the scapula co-option and shoulder protraction in a "close up" combination with trapezius inferior (Kapandji, 2007; Kendall, et al., 1993). The other muscular co-activations, pectoralis/latissimus dorsi and deltoid/infraspinatus, were also very similar to ones presented in competitive element. Maintained the same coordination between muscles, pectoralis should help in shoulders flexion while performs the adduction of UL, participating also in scapula depression with latissimus dorsi help (Kapandji, 2007; Kendall, et al., 1993). Deltoid anterior should flex shoulders join supported by infraspinatus that prevents the humerus dislocation and maintains the UL in external rotation through rings support (Brukner & Khan, 1994; Kapandji, 2007).

In particular "help on pelvis" exercise seems to be a very good exercise to develop swallow position. Congregating an identical muscular coordination between muscles and the possibility to be used with higher or lower support on pelvis, depending on the stage of learning, makes it an excellent training exercise to develop swallow element. Following the Cuk and Karácsony (2002) perspective, knowing that the stages of learning should be performed in a ascendant scale, we believe that “help on pelvis” exercise should be used in a phase were gymnast as already understand the standard position of each joint, to be able to coordinate the muscular actions.

#### 6.3.10 “PELVIS SUPPORTED BY FITNESS BALL”

The muscular activations during “pelvis supported by fitness ball” exercise were all lower than “swallow on rings” exercise. Once more, biceps brachii (41,7% of MVC), serratus anterior (37,3% of MVC) and infraspinatus (49,1% of MVC) were the muscles that relatively had higher muscular activation decrease during “pelvis supported by fitness ball” exercise. Although, the muscular co-activations seem to remain identical comparing to “swallow on rings” exercise, even with the slight superior result for biceps/triceps (52,1%) co-activation, where triceps brachii slight surpasses the co-contraction of biceps brachii muscle, as shown graphic 22. Since the co-activation values remain very close to 50% of co-contraction for biceps/triceps, serratus/trapezius and deltoid/infraspinatus; and with the same relative oscillation for pectoralis/latissimus dorsi (26,7%), we are able to say that the identical muscular coordination is maintained along the muscles during the execution of this exercise. Looking to the muscular function, shoulder’s flexion is performed by biceps brachii, deltoid anterior and pectoralis major; assisted by serratus anterior that stabilizes the scapula holding shoulder in protraction with triceps brachii help and infraspinatus that prevents humerus head forward dislocation, while pectoralis and latissimus dorsi perform the scapula depression (Brukner & Khan, 1994; Kapandji, 2007; Kendall, et al., 1993).

Finally, we consider that “pelvis supported by fitness ball” exercise, is an excellent training exercise to develop swallow element on rings. With results confirming identical levels of coordination between muscles, we believe that this is a great exercise to develop muscular coordination during the start or the end stage learning process. Confirming our suggestion, the intrinsic characteristics of this exercise provides the advantage of performing it as long as we wish with the same level of supporting, and also, with the possibility of changing the task level difficulty by fixating or not the fitness ball.

Bearing in mind Bompa's suggestion of the necessity to perform 6-12 seconds of isometric contraction with a rest interval of 60-90 seconds to develop static contractions, "pelvis supported by fitness ball" exercise represents an excellent mean to put those conditions in action, promoting muscular adaptation targeted with swallow element specifications (Bompa, 1997).

### 6.3.11 "RUBBER BAND SUPPORT"

In a general overview through graphic 23, we verify that all muscular activations were lower than "swallow on rings" exercise, with the exception of triceps brachii activation (59,7% of MVC) that was slight higher. Comparing the muscular activations and co-activations represented in graphic 24, we verify that there is an identical level of co-contraction with the similar oscillations between muscles during this exercise and "swallow on rings" exercise. The muscular loads presented, demonstrate co-contractions close to 50% of co-activation between biceps/triceps, serratus/trapezius and deltoid/infraspinatus, and the same relative oscillation for pectoralis/latissimus dorsi (21,4%), fact that seems to confirm the existence of an identical muscular coordination along the muscles during the execution of this exercise. Anatomically speaking, the muscular coordination is performed with serratus anterior stabilizing the scapula and holding shoulder in protraction with the help of triceps brachii (pushing humerus head forward) while pectoralis and latissimus dorsi perform the scapula depression (Brukner & Khan, 1994; Kapandji, 2007; Kendall, et al., 1993). The anterior muscles, such as biceps brachii, deltoid anterior and pectoralis major participate on shoulder’s flexion with infraspinatus preventing humerus head forward dislocation (Kapandji, 2007; Kendall, et al., 1993).

Based on the results, the only explanation for finding superior muscular activation from triceps brachii, is to consider it an isolated act to maintain the body balance during the exercise. Following Gluck (1982) suggestion, a single adjustment on body segment or part could be sufficient to maintain the body balance. Therefore and knowing that all other muscles stand with similar level of contraction, this muscular activation might be consider an isolated load to prevent body rotation (forward or backward) during the performance of “rubber band support” exercise.

In a general review, the “rubber band support” exercise became an excellent training exercise to develop swallow element on rings. It is an interesting exercise to use during all learning process, because by changing rubber bands it offers the possibility to work with different levels of hardiness while preserving the muscular coordination between muscles.

# 7. Conclusions

From the results reviewed along this study, we reach the following conclusions:

- Swallow element is performed by the coordinated action between the following muscles: biceps brachii, triceps brachii, serratus anterior, trapezius inferior, pectoralis major, latissimus dorsi deltoid anterior and infraspinatus muscles.

- The most important actions to promote the typical pattern of swallow's muscular coordination are: shoulder's protraction, scapula depression and UL's external rotation with elbow joint extended.

- The serratus anterior and trapezius inferior are the responsible muscles for scapula stabilization.

- The infraspinatus is the responsible muscle for shoulder's stabilization.

- The triceps brachii is the responsible muscle for elbow's extension and humerus head forward movement.

- The pectoralis major, trapezius inferior and latissimus dorsi are the responsible muscles for scapula depression.

- The infraspinatus and biceps brachii are the responsible muscles for UL external rotation.

- The biceps brachii, pectoralis major and deltoid anterior are the responsible muscles for shoulder's flexion.

- The training exercises specifically recommended for developing swallow element on rings are: "upon small balls", "rings feet on floor", "forearm support", "fitness balls", "trampolines support", "help on pelvis"; "pelvis supported by fitness ball" and "rubber band support" exercises.

- The training exercises recommended as complementary help for developing swallow element on rings are: "barbell" and "dumbbells" exercises.

- The "rings lying on floor" exercise is not recommended for developing swallow element on rings.

- The training exercises that expressed identical levels of muscular coordination to "swallow on rings" exercise were the ones performed upon the rings and upon balls, fact that does not confirm the H1.

- The highest muscular activation belongs to infraspinatus muscle during "swallow on rings" exercises, fact that does not confirm the H2.

These are the main directions that should be followed by coaches and gymnasts during swallow approach. Bearing in mind that this is a study case and therefore, reclaims further investigation, we still recommend that every isometric position performed in order to develop swallow on rings, should follow these technical indications: shoulder's protraction; scapula depression with UL extended at elbow joint in external rotation and with a slight abduction.

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