**JOÃO PAULO AZINHEIRA MARTINS MOITA**

# PATHOMECHANICS OF POSTERIOR ANKLE IMPINGEMENT SYNDROME IN FEMALE BALLET DANCERS

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## Abstract

Dance is a high performance athletic activity that leads to great numbers of injuries, particularly in the ankle region possibly due to extreme range of ankle motion required of dancers, especially females in classical ballet in the *en pointe* and *demi-pointe* positions (Kadel, 2006; Motta-Valencia, 2006; Russel, Kruse, Koutedakis, McEwan, Wyon, 2010). These positions of extreme plantar flexion produce excessive force on the posterior ankle that often result in impingement, pain, and disability, and may represent a diagnostic challenge. Posterior ankle impingement syndrome (PAIS) refers to a group of pathologic entities that result from repetitive or acute forced plantar flexion of the ankle and foot, causing bony and/or soft tissues alterations (Hamilton, Geppert, Thompson, 1996; Hamilton, 2008). The goals of this project are to understand the injury pathomechanical factors displayed in literature, and assess the ankle plantar flexion kinetics of four pré-professional female ballet dancers. *Methods*. To conduct a systematical review of literature concerning the PAIS Pathomechanics and to conduct a case-control study, which objective is to assess, compare and describe the ankle plantar flexion kinetics performed on *pointe* and *demi-pointe*, in pré-professional female ballet dancers with and without recurrent PAIS . *Results*. No studies were found relating specifically the PAIS Pathomechanics, however the reviewed studies concerning clinical and anatomical features as well as treatment procedures, indicate that two major groups of risk factors such as mechanical and functional factors interact allowing PAIS to arise, being the functional factors more related to PAIS by overuse, which is the most common among ballet dancers, and also the one with better prognosis. They were observed differences in muscle activity between PAIS subjects and controls. Postural sway and ankle stiffness also allowed observing differences between subjects and performed positions. *Conclusion*. It was concluded that not being possible to change the ballet dancer anatomy, it's sometimes possible to intervene at a functional level for preventing injury. The study outcomes demonstrated that there were differences between subjects with PAIS and controls, in plantar flexion muscle activity, postural sway and ankle stiffness while performing *pointe* and *demi-pointe*.


***Key words***: posterior ankle impingement syndrome; female ballet dancers; biomechanics

## Resumo

A dança é uma actividade de grande exigência atlética, que pode conduzir a um elevado número de lesões, particularmente na região do tornozelo, possivelmente devido à amplitude extrema do movimento articular de flexão plantar do mesmo, que os bailarinos, especialmente do sexo feminino possuem, para realizar a ponta e meia ponta tão características do *ballet* clássico (Kadel, 2006; Motta-Valencia, 2006; Russel, Kruse, Koutedakis, McEwan, Wyon, 2010). Estas posições de flexão plantar extrema produzem força excessiva na região posterior do tornozelo, o que muitas vezes pode resultar em conflito, dor e incapacidade, representando na maioria das vezes um desafio de diagnóstico. O síndrome do conflito posterior do tornozelo refere-se a um grupo de entidades patológicas que resultam da flexão plantar forçada do tornozelo, de forma repetitiva ou traumática, causando um conflito das estruturas ósseas e/ou de tecidos moles (Hamilton, Geppert, Thompson, 1996; Hamilton, 2008) . Os objectivos deste projecto são compreender os quais os factores de risco, mecânicos e funcionais que contribuem para a mecânica patológica da lesão descritos na literatura, e proceder a uma avaliação biomecânica do movimento de flexão plantar do tornozelo. *Método*. Realizar uma revisão sistemática de literatura dirigida á mecânica patológica do síndrome do conflito posterior do tornozelo em bailarinas e conduzir um estudo caso-controlo, cujo objectivo é avaliar, comparar e descrever o movimento da flexão plantar do tornozelo realizado ao efectuar os movimentos de ponta e meia-ponta, em bailarinas pré-profissionais com e sem lesão recorrente resultante do conflito posterior do tornozelo. *Resultados*. Não foram encontrados estudos relacionados especificamente com a mecânica patológica do tornozelo, no entanto vários estudos foram encontrados considerando as características clínicas e anatómicas assim como os procedimentos de tratamento, indicando que os principais factores de risco relacionados com a lesão se dividem em factores mecânicos e funcionais que quando combinados entre si e associados ao sobre-uso podem resultar no conflito posterior do tornozelo. Na avaliação do movimento foram observadas diferenças na actividade muscular entre os sujeitos com lesão e controlos, tendo sido possível a observação de um padrão na sequência de activação para um dos movimentos testados. Na oscilação postural e na rigidez do tornozelo foram também observadas diferenças entre os sujeitos bem como entre as posições realizadas. *Conclusão*. Concluiu-se que não sendo possível alterar a anatomia do bailarino, por vezes é possível intervir a nível funcional melhorando a capacidade técnica de forma obter um melhor desempenho e a actuar preventivamente em

relação às lesões, uma vez que estas podem apresentar padrões cinéticos próprios, relacionados com a função muscular, a estabilidade postural e a rigidez articular.

***Palavras-chave*****:** conflito posterior do tornozelo; bailarinas; biomecânica

## Abreviattions

ACC X - Accelerometer anterior/posterior axis

ACC Y - Accelerometer  inferior/superior axis

ACC Z - Accelerometer medial/lateral axis

ATFL - Anterior Talo-Fibular Ligament

BMI - Body Mass Index

BOS - Base of Support

COF - Center of Force

COG - Center of Gravity

DLDP - Double Leg Demi-Pointe

DLP - Double Leg Pointe

EDCN - Escola de Dança do Conservatório Nacional

EMG - Electromyography

EMG AS - Electromyography Activation Sequence

ESSA - Escola Superior de Saúde do Alcoitão

F - Female

FDL - Flexor Digitorum Longus

FHL - Flexor Hallucis Longus

FTC – Fibrous Tarsal Coalition

GON - Goniometer

LG - Lateral Gastrocnemius

LOE - Level of Evidence

M - Male

MG - Medial Gastrocnemius

MRI - Magnetic Ressonance Imaging

NWBPF - Non-Weight Bearing Plantar Flexion

OT - Os Trigonum

PAI - Posterior Ankle Impingement

PAIS - Posterior Ankle Impingement syndrome

PB - Peroneus Brevis

PL - Peroneus Longus

ROM - Range of Motion

S - Soleus

SLDP - Single Leg Demi-Pointe

SLP - Single Leg Pointe

TP - Tibialis Posterior

TTL - Trigger

WBANP - Weight Bearing Ankle Neutral Position

WBE - Weight Bearing *En Pointe*

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# Chapter 1

# General Introduction

## 1.1. Introduction

The art of performing ballet is very stressful and demanding on the body (Bauman, Gallagher & Hamilton, 1996; Aalten, 2007; Kennedy, Hodgkins, Colombier, Guyette & Hamilton, 2007; Hamilton, 2008; Russell, Kruse, Koutedakis, McEawn & Wyon, 2010). Dancers must be able to execute complicated dance positions and still maintain grace and flow as they move from one position to the next. As a result, dancers place considerable stress on their skeletal system and joints as they attempt these difficult ballet positions. Dancing on the balls of the feet or the tips of the toes is extremely demanding, causing considerable biomechanical loads on the skeletal elements of the lower leg and foot (Hamilton, Geppert &Thompson, 1996; Robinson & White, 2002; Howse, 2004; Peace, Hillier, Hulme & Healy, 2004; Maquirriain, 2005; Kadel, 2006; Motta-Valencia, 2006; van Dijk, 2006; Kennedy et al., 2007; Hamilton, 2008; Abisseti, Ometi, Pascale & De Bartolomeu, 2009; Russell et al.,2010). Consequently, due to the repetitive nature of ballet training, young ballet dancers often incur into overuse injuries most often along with technique dysfunction, that when not properly diagnosed and treated, may become recidivist conditioning dance performance (Bauman et al., 1996; Batson, 2007).

Because ballet dancers spending numerous hours performing the same or similar movement patterns, every day for several years, on the beginning of their dance practice, it is important to consider that, proper technique, alignment, and motor patterning are some of the most important issues for preventing injury and develop a skilled performance of movement (Bauman et al., 1996; Howse, 2004; Hamilton, 2008; Wilson & Kwon, 2008), otherwise the prospects for an injury to occur increases exponentially.

According to previous studies, the foot and ankle are the most vulnerable anatomical segments of the ballet dancer prone to injury and represent 34% to 62% of all injuries reported (Motta-Valencia, 2006; Hincapié et al., 2008). Several studies place the incidence of ankle injuries suffered by dancers, between 4.7% and 22.2%, with higher incidence in female ballet dancers, comparing to male ballet dancers or modern dancers, in part because of the repetitive use of forced plantar flexion at extremes ranges of motion of the ankle and foot, *en pointe* and *demi-pointe* positions (IADMS, 2000; Hincapié et al., 2008; Kadel, 2006; Russel et al., 2010a).

Whether the injury results from dysfunctional alignment, proprioceptive or muscle imbalance, or movement dysfunctions in a joint, the whole kinetic chain should be considered when treating a foot or ankle injury, once the kinematic chain of the lower extremity has

greater than 25 degrees of freedom from the foot to the hip, thus allowing compensations to occur easily, including restriction of joints or structural anomalies, while performing dance-specific movement patterns. Over time, these compensations may also be the cause of pathological hypermobility, instability, and pain in the compensating joints (Bauman et al., 1996; Bureau, Cardinal, Hobden & Aubin, 2000; Hertel, 2002; Batson, 2007; Hamilton, 2008; Abisseti et al., 2009).

Pain in the posterior ankle of female ballet dancers can result from many causes and may represent a diagnostic challenge. The posterior ankle impingement syndrome (PAIS), refers to a group of pathologic entities that result from repetitive or acute forced plantar flexion of the ankle into extreme ranges of motion, and is a frequent clinical situation among ballet dancers, especially females, due to the abusive use of ankle plantar flexion while performing *pointe* and *demi-pointe* positions. This intentional abuse, performed repeatedly, leads to an overuse event, that often is characterized by altered kinetics in muscle and joint function that may predispose for PAIS by decreasing the space between the tibia and the calcaneus, compressing the soft tissues or bony structures sometimes found in the posterior ankle anatomy (Hamilton, Geppert &Thompson, 1996; Robinson & White, 2002; Howse, 2004; Peace, Hillier, Hulme & Healy, 2004; Maquirriain, 2005; Kadel, 2006; Motta-Valencia, 2006; van Dijk, 2006; Kennedy et al., 2007; Hamilton, 2008; Abisseti et al., 2009; Russell et al., 2010a; Russel et al., 2010b).

Because PAIS is one of the most misdiagnosed ankle injuries among ballet dancers which may lead to serious restrictions in technical progression, or even to career end, it´s urgent to design studies with targeted research objectives, to be able to act preventively, being necessary to direct new research protocols for the injury free periods, since most of the available papers on case studies, report to the acute phase of injury describing the clinical findings and treatment procedures (Marotta & Micheli, 1992; Hamilton et al., 1996; Bureau et al., 2000; Peace et al., 2004; Abisseti et al., 2009; Russell et al., 2010a; Russel et al., 2010b), which does not allow to determine accurately a predictive pre-injury profile in order to act preventively.

### 1.2. Aims of the Study

The main goal of this research is to understand PAIS clinical and functional features within the dance practice, especially considering classical ballet. Some of those features will be more favorable to injury than others, and the understanding of which of them can be

modified is essential for designing targeted strategies for prevention and treatment of ballet dancers prone to PAIS by overuse.

For that we consider two research objectives:

1. **First objective**

To conduct a systematical review of literature aiming to characterize PAIS, by cross-checking the available data found, on ankle clinical anatomy and their functional and technical aspects within the classical ballet context. It is expected that the review outcomes, may provide useful data in order to develop a research protocol that allows profiling PAIS pathomechanics in female ballet dancers, focusing on ankle kinetics of extreme plantar flexion while performing *en pointe* and *demi-pointe*.

2. **Second objective**

To conduct a descriptive, exploratory, case-control study, regarding ankle kinetics, ankle stability and postural sway in pre-professional female ballet dancers with and without PAIS, while performing full *pointe* and full *demi-pointe* movements, concerning the differences between movements and between groups.

# Chapter 2

# Manuscript 1
# Pathomechanics of Posterior Ankle Impingement in Female Ballet Dancers – A Systematic Review

## Abstract

Pain in the posterior ankle of female ballet dancers can result from many causes and may represent a diagnostic challenge. Posterior ankle impingement syndrome (PAIS) refers to a group of pathologic entities that result from repetitive or acute forced plantar flexion of the foot and ankle. The repetitive event most of the time is characterized by altered kinetics in muscle and joint function that may predispose for PAIS to settle through ankle instability and/or decreased space between tibia and calcaneus, compressing the soft tissues or bony structures sometimes found in the posterior ankle anatomy (Bauman, Gallagher & Hamilton, 1996; Hamilton, Geppert &Thompson, 1996; Robinson & White, 2002; Howse, 2004; Peace, Hillier, Hulme & Healy, 2004; Maquirriain, 2005; Kadel, 2006; Motta-Valencia, 2006; van Dijk, 2006; Kennedy, Hodgkins, Colombier, Guyette & Hamilton, 2007; Hamilton, 2008; Abisseti, Ometi, Pascale & De Bartolomeu, 2009; Russell, Kruse, Koutedakis, McEawn & Wyon, 2010; Russel, Shave, Yoshioka, Kruse, Koutedakis & Wyon 2010). *Objective*. To assemble and synthesize evidence about the association between the ankle joint mechanical and functional features, with PAIS and co-existing clinics related to overuse in female ballet dancers. *Data Sources*. Medline and other electronic databases such as Embase and PsycINFO were searched, from 1986 to December 2010, using key words such as Posterior ankle impingement syndrome/ Ankle pain in female ballet dancers/ Pathomechanics/ Talar compression syndrome/ Review. Specialized journals were hand-searched, and the websites of major dance associations were scanned for unpublished literature. *Study Selection*. Citations were screened for relevance using a priori criteria, and relevant studies were critically reviewed. After 157 abstracts were screened, 22 articles were reviewed, and 12 (55%) of these were considered eligible for the present review. *Data Extraction*. Data from the accepted studies were abstracted into evidence tables, reporting the study level of evidence (LOE), clinical anatomy, mechanical and functional features and patient follow ups. *Data Synthesis*. The included studies consisted of, 6 (50%) review articles, 1 theme description article (8%), 1 original article (8%), 1 case report study (8%), 2 retrospective review studies (18%), 1 case series article (8%).The principal mechanical risk factors for injury related to ankle movement, such as *pointe* and *demi-pointe*, are suggested by the literature, like being the main causes for develop this injury condition, but conclusive evidence on specific biomechanical patterns correlated to PAIS is lacking. *Conclusions*. Targeted research is needed in this specialized area, being it such an important health issue for dancers at all skill levels. Future research would benefit from clear and relevant research

questions being addressed with appropriate study designs and the use of conceptually valid instruments as well as clinically meaningful case definitions of the injury mechanism and disability, and better report on study follow-ups in line with current scientific standards.

***Key Words*:** posterior ankle impingement syndrome; ankle pain in female ballet dancers; pathomechanics; talar compression syndrome; review

## Resumo

Os sintomas de dor na região posterior do tornozelo das bailarinas têm origem em diversos factores e constituem um desafio de diagnóstico. O conflito posterior do tornozelo, é uma síndrome que se refere a um grupo de entidades patológicas que resultam da flexão plantar forçada do tornozelo na maioria das vezes resultante de um evento repetitivo desse movimento o qual irá comprimir os tecidos moles ou estruturas ósseas presentes nessa região anatómica (Bauman, Gallagher & Hamilton, 1996; Hamilton, Geppert & Thompson, 1996; Robinson & White, 2002; Howse, 2004; Paz, Hulme Hillier, & Healy, 2004; Maquirriain, 2005; Kadel, 2006; Motta-Valência de 2006 ; van Dijk, 2006; Kennedy, Hodgkins, Colombier, Guyette & Hamilton, 2007; Hamilton, 2008; Abisseti, Ometi, Pascale & De Bartolomeu, 2009; Russell, Kruse, Koutedakis, McEawn & Wyon, 2010; Russel, Shave, Yoshioka , Kruse, Koutedakis & Wyon 2010). *Objectivo*. Reunir e sintetizar evidências que relacionem as características mecânicas e funcionais do tornozelo com a lesão. *Fontes de dados*. Medline e outras bases de dados electrónicas, como Embase e PsycINFO foram pesquisadas cronologicamente entre 1986 e Dezembro de 2010, usando palavras-chave como: Síndrome do conflito posterior / Bailarinas / mecânica patológica / Revisão sistemática. Foram igualmente pesquisadas revistas especializadas, e sites de associações de dança procurando fontes de literatura não publicada. *Selecção de estudos*. Os estudos foram seleccionados de acordo com critérios previamente estabelecidos onde 157 resumos foram seleccionados, dos quais 22 artigos foram revistos, e desses 12 (55%) destes foram considerados elegíveis para a presente revisão. *Extracção de dados*. Os dados extraídos dos estudos foram reportados em tabelas evidências, considerando o nível de evidência do estudo, as características anatómicas, mecânicas e funcionais bem como os seguimentos clínicos. *Síntese de dados*. Os estudos incluídos consistiram em 6 (50%) artigos de revisão, um artigo descritivo do tema (8%), um artigo original (8%), um relato de estudo de caso (8%), dois estudos de revisão retrospectiva (18%), 1 artigo sobre vários estudos de caso (8%). Os principais factores de risco sugeridos pela literatura para o conflito posterior do tornozelo são o uso abusivo da ponta e da meia-ponta associado a condições anatómicas desfavoráveis. No entanto não foram encontrados estudos que relacionassem questões funcionais do movimento de flexão plantar nestas posições com a lesão. *Conclusões*. Sendo esta uma importante questão de saúde para as bailarinas/os de todos os níveis, são necessárias investigações direccionadas com desenhos de estudo apropriados, bem como a utilização de instrumentos de avaliação válidos e fidedignos

no sentido obter resultados representativos que permitam caracterizar este tipo de condição clínica.

***Palavras-chave:*** síndrome do conflito posterior do tornozelo, dor no tornozelo em bailarinas; mecânica patológica; revisão sistemática.

## 2.1. Introduction

Classical ballet is more than an art form, ballet dancers are both artists and athletes. While the musician has his instrument and the painter has his brush, the ballet dancer has his body as his working tool to sculpt compositions of expressive motion through space.

It has been found that ballet can be more physically demanding than most sports, as it requires the mastery of very specific and precise training techniques, especially to accomplish aesthetic demands by developing extreme joint ranges of motion that differ immensely from normal joint movement (Bauman, Gallagher & Hamilton, 1996; Kennedy, Hodgkins, Colombier, Guyette & Hamilton, 2007).

The foot and ankle of a ballet dancer are the anatomical parts of their body that most characterize the nature of their activity, since much of the fundamental dance movements, related to aesthetical and functional components happen through this anatomical structures and their biomechanical capability to perform and achieve extremes ranges of motion, especially in plantar flexion movement (Bauman et al., 1996; Hamilton, 2008; Kennedy et al., 2007; Russel, Kruse, Koutedakis, McEawn & Wyon, 2010a).

The ankle joint in ballet has the dual function to accomplish functional and aesthetic demands. Functionally the ankle joint must provide support and stability when transfers the body weight into is base of support, the feet. Aesthetically it must provide the alignment of the dorsal aspect of the foot with the leg, creating an effect of continuity between them.

For proper mechanics and aesthetics, such as *en pointe* position, where the dorsal surface of the foot should be in parallel to the long axis of the leg and the toes should be in neutral position to the metatarsals, it is required that the ballet dancer must have between 90º to 100º of active ankle plantar flexion. For a high *demi-pointe* position it´s required plus 90º of extension of the hallux at the metatarsophalangeal joint besides the required ankle plantar flexion. (Gilbert, Gross & Klug, 1998; Koutedakis & Jamurtas, 2004; Clippinger, 2007). In fact, classical ballet is the only athletic activity and the only dance form, where the ankle and foot complex, requires simultaneously extreme range of motion from maximum forced plantar flexion to maximum forced dorsiflexion, during practice. These extreme ranges of motion can only be achieved with years of training from early ages that will mold the young ballet dancer bones and joints during the bone growing phase. (Russel, McEwan, Koutedakis & Wyon, 2008; Kennedy et al., 2007).

The demands placed on dancers' lower extremities, leave them at risk for musculoskeletal injuries, because quite often, they exceed the limits of their anatomic

capabilities (Motta-Valencia, 2006), fact frequently observed in young dancers during their learning process in part because most young dance students acquires basic motor skills, when many of them learn dance-specific skills before they have achieved a mature understanding of these basic techniques. As a result, immature patterns are being carried into dance training and may become a habitual part of the student's skill in performing dance-specific patterns. The resulting compensations can lead to many of the dysfunctional technique patterns that cause injuries seen in the more mature dancer as well as in the dance student (Bauman et al., 1996).

The cumulative incidence of musculoskeletal injury ranged from 40% to 94% in professional dancers and from 17% to 90% in pre-professional and school-level dancers (Hincapié et al., 2008). Previous studies have reported injury incidence rates of 67% to 95% among professional ballet dancers and 17% to 24% in modern dancers, being the foot and ankle the most vulnerable anatomical segments prone to injury and represent 34% to 62% of all injuries reported (Motta-Valencia, 2006; Hincapié et al., 2008) .

Several studies place the incidence of ankle injuries suffered by dancers, between 4.7% and 22.2%, with higher incidence in female ballet dancers, comparing to male ballet dancers or modern dancers, in part because of the repetitive use of forced plantar flexion at extremes ranges of motion of the ankle and foot, *en pointe* and *demi-pointe* positions (IADMS, 2000; Hincapié et al., 2008; Kadel, 2006; Russel et al., 2010a).

This intentional abuse of plantar flexion, for technique and aesthetic demands, may lead female ballet dancer into posterior ankle pain, impingement and disability (Russel et al., 2010a). Posterior ankle pain its highly correlated to posterior ankle impingement syndrome (PAIS), that is a clinical disorder, rare in most sports, but very common in female ballet dancers, characterized by pain in the posterior aspect of the ankle, that arises from traumatic or overuse, forced plantar flexion, or both combined, that will compress the tissues between the calcaneus and the posterior aspect of the tibia limiting the ankle movement (Bauman, Gallagher & Hamilton, 1996; Hamilton, Geppert &Thompson, 1996; Robinson & White, 2002; Howse, 2004; Peace, Hillier, Hulme & Healy, 2004; Maquirriain, 2005; Kadel, 2006; Motta-Valencia, 2006; van Dijk, 2006; Kennedy, Hodgkins, Colombier, Guyette & Hamilton, 2007; Hamilton, 2008; Abisseti, Ometi, Pascale & De Bartolomeu, 2009; Russell et al., 2010a; Russel, Shave, Yoshioka, Kruse, Koutedakis & Wyon 2010b). The pain condition may be acute, if results from one single event, where normal of insufficient tissue, is placed under sudden stress or strain, exceeding the tissue´s capacity for maintain is functionality, or could

be chronic if results from a repetitive micro-trauma event, driven to the bone or soft tissue structures, that will offend tissue, bone or joint functionality, when the injury mechanisms persists (Hamilton, Geppert & Thompson, 1996; Motta-Valencia, 2006). PAIS condition, is a hole body injury to a ballet dancer, that when misdiagnosed and without proper treatment, often results in chronic disability of the ankle that can lead to career end. Most of the times when chronic disability is settled, if conservative treatment fails, the only treatment option its surgery. PAIS resulting from overuse events have better prognosis, but may recur again if the causing factors are not eliminated, or may turn into a precipitating factor for acute injury (van Dijk, 2006).

The sources frequently associated to this clinical condition, found in literature, are multi-factorial, and can be differentiated between bony impingement lesions and soft tissue impingement lesions. The bony impingement causes are: pathology of the os trigonum-talar process, observed in 3% to 13% of the general population twice as common unilateral as bilateral (Marotta & Micheli, 1992), the protruding lateral process of talus or Stieda´s process, or other accessory bony structures existing in the posterior aspect of the ankle. The soft tissues impingement causes are: hypertrophic fibrosis of a previously injured posterior tibiotalar band of the deltoid ligament, sometimes in sequence of an acute ankle sprain, transverse tibiofibular ligament, or posterior capsule inflammation from repetitive stress. Adding to the above mentioned conditions, there are other clinical conditions that may also elicit pain and should be take into account in differential diagnosis, such as, flexor hallucis longus tenosynovitis that sometimes coexists with the PAIS, ankle osteochondritis, subtalar joint disease and fracture (Bauman et al., 1996; Watson, 2007; van Dijk, 2006; Maquirriain, 2005).

Despite of these well documented clinical issues related to PAIS, still needs to occur a triggering mechanism to elicit symptoms. The presence of morphological variations can predisposed for the condition to settle, but are not sufficient by themselves to cause pain or disability, like evidence found in a study made by van Dijk et al, (1995) where 19 retired dancers mean age 59 years, range 50-66 years, have their talar and subtalar joints examined, regarding the fact that, none of the dancers had experienced a posterior ankle impingement syndrome. In 18 of the 38 investigated ankle joints, a hypertrophic posterior talar process or os trigonum was present and in most cases the os trigonum was relatively large. Therefore, the presence of an os trigonum or prominent talar process in itself does not seem to be relevant.

An os trigonum must be combined with a traumatic event, such as a supination trauma, dancing on hard surfaces, or pushing beyond anatomic limits.

The soft tissue causes of impingement, whether they are primary or secondary to PAIS, still need to have a triggering mechanism associated in order to cause active symptomatology. Altered biomechanics associated to the increase amount of work load to the ankle joint and stiffness of mid-tarsal joints as well as lack of time for tissues to settle and recover between classes or rehearsals may be two possible causes (Howse, 2000; Russel at al., 2008; Ahoen, 2008).

Ballerinas have been dancing *en pointe* since the 19$^{th}$ century and most of the time the feet are above the floor, they're plantar flexed in full pointe position.

Ankle motion in dance or other activities, depend on how forces are applied to the levers of the skeleton. In mechanics, there are three types of levers: first, second and third class. All the three types can be seen in ankle joint depending on the motion being performed and the kinetic chain involved, open or closed if the lower extremity is whether or not weight bearing (Russel et al., 2008; Ahonen, 2008; Clippinger, 2007). Most of the reviewed studies attribute to the movement of weight bearing forced plantar flexion of the foot and ankle in closed kinetic chain, in the *en pointe* and *demi-pointe* positions, as being the most likely causing factors for PAIS. However, and despite these unnatural ankle and foot motion and positioning, information correlating their biomechanical aspects with risk potential for developing PAIS symptomatology is scarce.

Ankle and foot kinesiology and their muscle function in the dance context, can be found well documented in recent studies, but very few references are found about their relationship to the injury mechanism, especially when associated to the repetitive nature of classic ballet training. This kind of training produces mostly of the times morphological and functional changes that when symptomatic may become source of technical disability (Ahonen, 2008, Russell et al., 2010a).

The lack of case studies with targeted research objectives for the mechanical and functional performance of joint motion associated to injury, intending understand these very specific joint movements and how they are performed, may be the explanation for the scarce information on this subject. In other words, to be able to act preventively, it is necessary to direct new research protocols for the pre-injury periods since most of the available studies on case studies, report to the acute phase of injury describing the clinical findings and treatment procedures (Marotta & Micheli, 1992; Hamilton et al., 1996; Bureau, Cardinal, Hobden &

Aubin, 2000; Peace, Hillier, Hulme & Healy, 2004, Russell et al., 2010a; Russel et al., 2010b), which does not allow to determine a possible biomechanical predictive pre-injury profile.

In a study, where 12 ballet dancers suffered from posterior ankle pain and 6 of them had an os trigonum, at first they all were treated non-operatively, and 9 of them with good results(Abisseti, Ometi, Pascale & De Bartolomeu, 2009). Besides physical therapy, the treatment consisted in physical exercises to increase the space between the posterior tibia and the calcaneus by activate the deeper muscles of the lower leg, opposed to gastrocnemius muscles, when performing pointe and demi-pointe. This result with nonoperative treatment in PAIS rehabilitation, suggests that proper muscular participation patterns on ankle plantar flexion can help performing a more efficient joint motion in the *en pointe* and *demi-pointe* and may act preventively in this injury type incidence. Other functional issue that can predispose to PAIS incidence is lateral ankle instability (Watson, 2007; Kennedy et al., 2007; Russel et al., 2010a). In normal ankle motion the deeper lower leg muscles act on the ankle as secondary movers in ankle plantar flexion, but also as stabilizers specially in the demi-pointe position (Howse, 2000; Clippinger, 2007; Russel et al., 2008), therefore its necessary to establish a correlation between muscle function, joint motion and injury mechanics in order to develop better strategies for diagnosis, prevention and rehabilitation.

### 2.1.1. Aims of the Study

The present paper´s main goal is to undertake a systematical review of literature aiming to characterize PAIS by cross-checking data concerning ankle clinical-anatomy with their functional and technical aspects in classical ballet. It is expected that the review outcomes, may provide useful data in order to develop a research protocol that allows profiling PAIS pathomechanics in female ballet dancers, focusing on ankle kinetics of extreme plantar flexion on the en pointe and demi-pointe movements.

## 2.2. Methods

### 2.2.1. Literature Search

It was conducted a systematic search of scientific literature published between 1985 and 2010. The primary source of literature was the electronic database Medline (1985 to December 2010). Indexed terms and text words such as: posterior ankle impingement

syndrome; ankle pain in female ballet dancers; pathomechanics; talar compression syndrome, and others, were used to search the database. Additionally, the reference lists of all relevant studies were examined, specialized journals (ie, the Journal of Dance Medicine; Science and Medical Problems of Performing Artists and Clinics in Sports Medicine) were hand-searched, websites of major dance associations were scanned for unpublished literature (ie, Harkness Center for dance injuries, Rudolf Nureyev Foundation and others) and other electronic databases such as Embase and PsycINFO were also searched.

### 2.2.2. Screening for Relevance

All identified citations were screened through a search strategy that included: English-language reports; published reports of original research, review studies, conference proceedings, guidelines or unpublished grey literature manuscripts; studies examining incidence, biomechanical sources and associated factors, risk factors, diagnosis and treatment procedures, prognosis, or other aspects related to PAIS in female ballet dancers. Studies with no direct relation with PAIS, or studies where this clinical condition was secondary to other pathology were excluded, as well as studies that were not ballet dance related or related to other dance types or athletic activity, were also excluded.

With basis on the inclusion and exclusion criteria, the relevance of each citation found in the electronic search was appraised in a two screening level process. In the first-level screening, citations were categorized as probably relevant, of unknown relevance, or irrelevant. For each citation rated as probably relevant or of unknown relevance, the entire paper was obtained and, in the second-level screening, these were deemed to be either relevant or irrelevant to the systematic review. If a relevant citation wasn't possible to obtain in full, the article was excluded.

### 2.2.3. Critical Review of Literature

All studies judged relevant were critically appraised according to the type of study. For studies reporting to clinical or epidemiological outcomes, or studies where methodological procedures were described, the appraisal assessed scientific merit by study evidence level and clinical relevance by using a priori criteria (Von Holst et al, 2004), focusing on issues of study design, study population, issues related to conduct of the study, participation rates, follow-up rates (where relevant), measurement issues, and analysis. For non systematic review studies, author manuscripts, book chapters and others where

methodological procedures were not described, the main appraisal criteria for the included studies was, being a peer-reviewed published article, or author´s relevance by publications and citations in articles published on peer-reviewed journals.

The initial literature screening revealed two substantive and related themes: 1 - screening of ankle and foot injuries in dance, and 2 - clinics of PAIS in ballet dancers, concerning clinical assessments, treatment procedures and follow ups. In this review, both themes were considered to be relevant, the first for the correlation between risk factors and injury mechanics, and the second through the outcomes of the case studies. The studies were considered to be eligible when fit into the appraisal criteria.

### 2.2.4. Data Abstraction into Evidence Tables

Studies relevant to the development of PAIS condition in female ballet dancers were identified as relating to mechanical causes, anatomical sources, intrinsic and extrinsic risk factors, clinical features and diagnosis, treatment and prevention. Data from admissible studies was abstracted into evidence tables relating to these topic areas and the study Level of Evidence (LOE) according to the Oxford Centre for Evidence-Based Medicine. The evidence tables summarize the findings and form the basis of our discussion. In review studies or retrospective reviews based on observational case report studies, where PAIS was not the main theme, only the study portion related to PAIS was abstracted to the evidence tables (Shojania et al, 2007).

## 2.3. Results

After applying the study criteria to 157 identified article titles and abstracts to assess their relevance to PAIS in female ballet dancers, 135 articles were excluded basis on title and abstract analysis. From the 22 articles judged to be relevant for critical review, 9 were related to screening of ankle and foot injuries in dance, and 12 were related to PAIS clinical anatomy. Of these 22 articles, 12 (55%) were accepted as eligible after critical scientific appraisal (fig. 1). These studies were the basis for the review conclusions and consist of 6 (50%) review articles, 1 theme description article (8%), 1 original article (8%), 1 case report study (8%), 2 retrospective review studies (18%), 1 case series article (8%).

### 2.3.1. Excluded Studies

Of the 135 excluded articles, 58 were exclude because they focus other clinical conditions of the ankle than PAIS, 41 showed weak or superficial relation with PAIS, in fact PAIS was only superficially mentioned and not described. 32 articles report on traumatic posterior ankle impingement, not related to classical ballet, so they were excluded, and 4 articles reported solely to specific surgical procedures description in two impingement conditions, and so they weren´t considered relevant for study.

### 2.3.2. Included Studies

All the 12 articles meeting the inclusion criteria were direct or indirectly relate to PAIS through anatomical and clinical perspective. 10 studies are specifically dance related, from those, 2 reported to ankle and foot problems in ballet dancers focusing PAIS theme, and 8 reported specifically to PAIS theme. 2 studies aren't specifically dance related but fit the inclusion criteria because they focus and highlight ballet´s relation to posterior impingement of the ankle, taking into account the technical and aesthetic demands of extreme plantar flexion required of female ballet dancers. PAI abstracted from the review studies are resumed in Tables 1 and 2. Characteristics of retrospective reviews on case report results about case studies featuring clinic and treatment procedures, are reported on table 3, data from two studies reporting MRI assessment of PAI in ballet dancers, is resumed on table 4.

### 2.3.3. Outcomes

#### 2.3.3.1. PAIS features in female ballet dancers concerning injury mechanics and risk factors

All the reviewed articles are consistent with the fact that PAIS is a clinical condition arising from traumatic or repetitive ankle plantar flexion, or both combined, and that female ballet dancers are particularly prone to this injury because of their extreme ROM of ankle and foot joints. The forceful plantar flexion that occurs during the en pointe and full demi-pointe positions produces compression at the posterior aspect of the ankle joint. Either of these situations can put extreme pressure on the anatomic structures normally present between the calcaneus and the posterior part of the distal tibia. Through exercise, the joint mobility and range of motion gradually increase, progressively reducing the distance between the calcaneus and the posterior portion of the distal tibia (van Dijk, 2006).

Four articles focus functional instability of the ankle, in most cases following ankle sprains, as a major contributing factor for the development of posterior ankle impingement (Russel et al., 2010a; Motta-Valencia, 2006; Kennedy et al., 2007; Hamilton, 2008). From these four articles, two articles focus on a single key aspect of overuse injuries of the lower extremity, often seen in dance-specific movements, which is the compensation that occurs on the kinetic chain, due to joint restriction or joint abnormalities, inappropriate muscle patterns for specific movement like faulty dance technique (Kennedy et al., 2007), that over time, may also be the cause of pathological or undesirable hypermobility, instability, and pain in the compensating joints (Motta-Valencia, 2006). On PAIS in female ballet dancers, the functional aspects of foot and ankle complex during plantar flexion can be seen as the principal triggering device to elicit pain symptoms and disability, cause or consequence of pathologic conditions in the posterior ankle soft tissue or bone structures. The os trigonum is the most common bone structure associated to PAIS in ballet dancers. In weight bearing forced plantar flexion, the os trigonum, may became symptomatic if it gets irritated, most of the people who have os trigonum are not aware of its presence and is more often asymptomatic than symptomatic (Hamilton, 2008). It is present in a prevalence range of 13% to 25% of adults, depending on the study cited (Russel et al., 2010a), and 50% of the times is bilateral, (Hamilton, 2008; Kennedy et al., 2007). In ballet dancers the os trigonum showed higher prevalence than in normal population, up to 30% (Motta-Valencia, 2006; Russel et al., 2010a). It may be an actual part of the body of the talus or develop as a separate bone that may or may not be adherent to the talus by a cartilaginous articulation. Often mistaken as a fracture of the posterior process of the talus, it arises as a separate ossification center from the lateral process of the talus and appears between 8 and 14 years of age. If the lateral talus process is protruding, is designed as Stieda´s process (Russel et al., 2010a). In extreme plantar flexion this bony structures can be fractured or mechanically impinged, causing pain at the posterior aspect of the ankle. Other bony structures than os trigonum or Stieda´s process, not so frequent, but can also be present as source of impingement symptoms, are anatomical variations of tibia and calcaneus, that when present are highly correlated to PAIS. Accessory ossicles of the talus or loose bodies within the synovium can also be associated to impingement syndromes of the ankle, although more rarely (Russel et al., 2010a). The most common soft tissue causes of PAIS are best described in two studies where a MRI assessment was made in dancers with PAIS (Peace et al., 2004; Russel et al., 2010b). The findings suggest that the most prevalent clinical situations observed in PAIS are: impingement during

plantar flexion and posterior synovitis. FHL tendonitis is also a frequent finding in PAIS, associated to os trigonum or more rarely with tibialis posterior tendonitis. Usually this type of tendonitis can co-exist with os trigonum, but the pain is located in the posterior medial ankle.

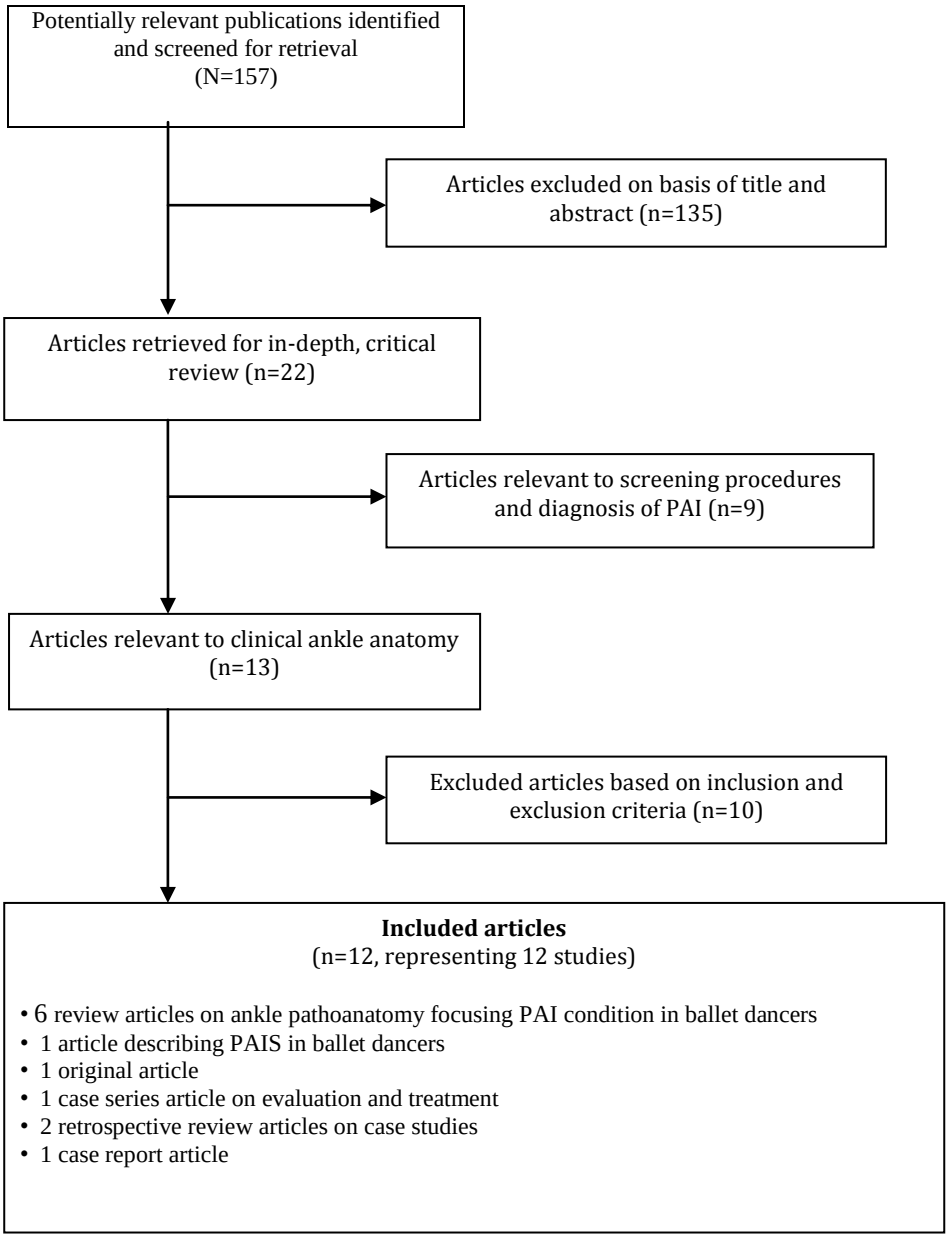


**Figure 1.** Flow diagram of systematic review inclusion and exclusion

**Table 1**
**Review studies featuring ankle and foot injuries in dancers**

| | | Study Outcomes concerning PAIS condition | | | | |
|---|---|---|---|---|---|---|
| | | Biomechanical Features | | | | |
| Study | Study Overview | Anatomical | Functional | Clinical Features | Conclusion | LOE* |
| Hamilton | Posterior ankle pain in dancers – posteromedial and posterolateral | Os trigonum<br>Stieda´s process | Full plantar flexion with foot and ankle in full equinus | Posterolateral - Trigonal impingement or fracture; stretching of lateral ligaments following ankle sprain; pseudomeniscus in posterior ankle; Peroneal tendinitis<br>Posteromedial - FHL tendinitis; TP tendinitis; Soleus syndrome; posteromedial FTC | Dancers often have unusual difficulties related to the altered kinesiology required by their individual dance form (ballet, modern dance, jazz, tap, ethnic, Broadway, and so forth). A thorough understanding of these movements helps guide the physician to the cause of the disability, particularly in the setting of overuse injuries. An careful physical examination, is essential for the accurate diagnosis and treatment of the dancer, who is both artist and athlete. | B(2c) |
| Motta-Valencia | Focus on selected lower extremity lesions in dancers and their injury patterns | Foot and ankle malalignements; co - existing os trigonum or Stieda process | Plantar flexion in *en pointe* and *demi-pointe* positions; rolling in of the foot to force turnout; slicking the foot in the demi-pointe | Bone marrow edema; bone contusion at the lateral tubercule of the talus; os trigonum; Stieda process Local synovitis in posterior capsular recess of tibiotalar and subtalar joints; fluid in FHL tendon sheat | There is a wide differential diagnosis for PAI, but os trigonum and FHL tendinitis, are frequent and should be take into account whenever symptoms are present; in rehabilitation and prevention, foot and ankle malalignements as weel as faulty technique, specially in pointe and demi-point, should be corrected. | D(5) |
| Kennedy et al | Dance injury type related to foot mechanics, training and performing techniques | Foot type; subtalar joint motion; turned-out position of the mild forefoot pronation and abduction; bony or fibrous posterior tarsal coalition | Extreme ankle range of motion in forced plantar flexion movement; secondary to ankle lateral sprain by lateral ligament laxity, causing instability | Os trigonum; pseudomeniscus (similar to plica); other bony bloc strutures<br>FHL tendonitis; | It must be emphasized that, when the ballet dancer is examined, the entire kinetic chain requires close inspection. Isolated injuries of the foot and ankle may precipitate additional injuries further up the kinetic chain as a compensatory response to the injury or inadequate and improper rehabilitation. | D(5) |
| Kadel | Characteristics of foot and ankle injuries in dance focusing foot and ankle extreme positions | Posterior ankle abnormal bone structures | Extreme plantar flexion in *en pointe* and *demi-pointe* positions; technical errors; pointe shoes style | Posterior bony block or accessory bone of the ankle; os trigonum; Stieda process; talus posterior lateral process fracture; talus bone marrow edema FHL tendon tenosynovitis | Posterior impingement symptoms are exacerbated by pointe work, releve´ s, or by any forced ankle plantar flexion maneuver. Some dancers may benefit by changing their pointe shoe style and fit to a shoe, such as a half or three-quarter shank that allows the dancer to achieve full pointe position with less compaction of the posterior structures. | D(5) |

Abbreviations: PAIS, Posterior Ankle Impingement Syndrome; ROM, Range of Motion; FHL, Flexor Hallicus Longus; TP, Tibial Tendinitis; FTC, Fibrous Tarsal Coalition;
*LOE, study Level of Evidence, according to the Oxford Centre for Evidence-Based Medicine

**Table 2**
**Review studies featuring ankle impingement**

| | | Study Outcomes concerning PAIS condition | | | | |
|---|---|---|---|---|---|---|
| | | Biomechanical Features | | | | |
| Study | Study Overview | Anatomical | Functional | Clinical Features | Conclusion | LOE* |
| Russel et al (a) | PAIS pathoanatomy and clinics | Posterior ankle anatomic variations | Forced plantar flexion in *en pointe* and *demi-pointe* positions; lateral ankle instability | Os trigonum; Stieda process; Fracture of lateral talar tubercule; Posteromedial talar ossicle; Post peroneal ossicle Synovium and Capsule; FHL tendon tenosynovitis; Ligaments | PAI may result from soft tissues or bony strutures wedged between tibia, talus and calcaneus during extreme plantar flexion, causing reduced plantar flexion and pain ; lateral ankle instability can also leed to secondary impingement | D(5) |
| van Dijk | Ankle impingement etiology, clinic and treatment results | Abnormal bone or soft tissues structures; increased ROM and mobility due training | Forced repetitive plantar flexion; combined supination and plantar flexion trauma | Os trigonum; hypertrophic posterior talar process; calcifications; loose body in ankle posterior aspect; osteophyte posterior distal tibia Thickned posterior joint capsule; posttraumatic scar tissue | If abnormal or morphological variations of posterior ankle joint, cause or consequence from hyperplantarflexion, are combined with overuse or traumatic event, impingement symptoms may appear | B(2c) |
| Watson | Ankle impingement following ankle sprain, resultant from instability | Foot and ankle joint arquitecture | Lateral ankle instability by failure of ATFL, after plantarflexed inversion ankle sprain | Unstable os trigonum; fracture or nonunion of the trigonal process of the talus; Post injury hipertrophic fibrosis of: posterior tibiotalar band of deltoid ligament; transverse tibiofibular ligament; posterior capsule inflamation from repetitive stress | Posterior impingement is frequently associated to ankle instability secondary to a plantarflex inversion ankle sprain. If impingement results mainly from ankle instability involving consequent soft tissues or bone alterations, sometimes surgery is needed to obtain ankle stability again | B(2c) |

Abbreviations: PAIS, Posterior Ankle Impingement; ROM, Range Of Motion; FHL, Flexor Hallicus Longus; ATFL, Anterior Talo-Fibular Ligament;
*LOE, study Level of Evidence, according to the Oxford Centre for Evidence-Based Medicine

**Table 3**
**Studies featuring clinical and treatment procedures in PAIS in ballet dancers**

| Study | Subjects and settings | Overview | Clinical features and diagnosis | Clinical procedures | Outcomes | Follow up | Conclusion | LOE* |
|---|---|---|---|---|---|---|---|---|
| Abisseti et al | 186 young trainee ballet dancers; 121 female/ 65 male; age 7 - 21;<br>12 suffered from pain in posterior aspect of the ankle between tibia and calcaneus | Clinical and treatment approach to PAI | Three types of causes can be attributable to posterior ankle pain: articular (capsule); intraarticular (os trigonum, Stieda´s process); periarticular (tendinitis) | From the 12 ballet dancers, 6 had os trigonum confirmed by RX. The other 6 ballet dancers had PL, TP and FHL, tendinopathy, confirmed by MRI | 3 from the 6 ballet dancers with os trigonum, had the os trigonum removed, by failure of conservative treatment.<br>The dancers with tendinopathies had good results with nonoperative treatment | 1 year follow up | Nine dancers were treated nonsurgically, with good results. We believe that posterior impingement should be always treated conservatively aiming to the activation of the deeper muscles of the lower leg in plantar flexion, instead gastrocnemius. Os trigonum or Stieda process, when present, should only be surgically removed in selected cases where conservative treatment fails. | B(2c) |
| Marotta et al | 16 patients; 3 male ; 9 female;<br>9 professional ballet dancers; 3 students of advanced ballet school | 16 patients underwent surgical excision of na impinging ossicle through a posterior lateral approach.<br>Only 12 were available for followup and survey. | Posterior ankle pain; limitation of motion; weakness; swelling; PAI secondary to os trigonum confirmed by radiology | Os trigonum resection after failure of non-surgical conservative measures to resolve symptoms | All patients had improvement in impimgement symptoms; 8 patients (67%) still have occasional discomfort; all professional dancers return to unrestricted dance activity; | Patients were followed 28 months after surgery; 3 months mean time to full activity; 4 patients were lost during follow up; 1 patient had superficial wound and other a transient tibial nerve neuropraxia | PAI in ballet dancers, caused by os trigonum and resistant to non-surgical therapies , is effectively treated with simple excision of the offending structure | B(2c) |
| Hamilton et al | 37 patients (31 professional dancers, 6 amateurs); average age 23 (range 15 to 39) 15 male dancers; average age 24 (range 17 to 34) ;<br>22 female dancers; average age 22 (range 15 to 39) | Retrospective review of the results of operative treatment in 37 dancers (41 operations; 22 performed in the left ankle; 19 in the rigth ankle) some dancers had bilateral surgery | The principal diagnosis were PAI and FHLT, combined or isolated, in some cases AI and recurrent instability were also found. | Surgical treatment after non-operative therapy failure. From the 41 operations 26 were for a combination of PAI and FHLT; 9 for isolated FHLT and 6 for isolated PAI | In all the 37 patients conservative treatment had failed.<br>The operative results were good or excellent for 28 of 34 ankles in professional dancers compared to 2 of 6 ankles in amateur dancers. | The goal of the treatment was to return the dancers to full functional capacity.<br>The follow up average was 7 years (range 2 to 13 years) | Dancer's tendinitis and posterior impingement syndrome are distinct entities, but they often coexist and usually respond to non-operative measures. However, operative treatment when indicated is usually successful in alleviating symptoms and in enabling patients to return to extreme demands of dance | B(2c) |

Abbreviations: PAIS, Posterior Ankle Impingement; PAI, Posterior Ankle Impingement; MRI, Magnetic Resonance Imaging; PL, Peroneus Longus; TP, Tibialis Posterior; FHL, Flexor Hallux Longus; FHLT, Flexor Hallux Longus Tendonitis
*LOE, study Level of Evidence, according to the Oxford Centre for Evidence-Based Medicine

**Table 4**
**Studies featuring MRI findings in PAI in ballet dancers**

| Study | Subjects and settings | MRI features: Non-Pathological Anatomical Variants | MRI features: PAI Pathological Findings | Conclusion | LOE* |
|---|---|---|---|---|---|
| Russel et al (b) | 23 ballet dancers; 9M, 14F; average age 18(range 14 – 35); presented with PAI diagnosis; 25 MRI examinations were made | • Os trigonum 28%(n=7)<br>• Stieda´s process 16%(n=4)<br>• Posterior intermalleolar ligament 48%(n=12)<br>• Down-sloping posterior tibia 25%(n=6)<br>• Calcaneal tuberosity 64%(n=16) | • Os trigonum 86%(n=6)[1]<br>• Posterior talus 40%(n=10)<br>• Talar dome 20%(n=5)<br>• Posterior calcaneum 24%(n=6)<br>• Posterior tibia 8%(n=2)<br>• Generalized patchy 40%(n=10)<br>• Posterior synovitis 100%(n=25)<br>• Posterior capsular thickening 52%(n=13)<br>• Tenosynovitis of FHL 68%(n=17)<br>• High signal at muscle/tendon junction FHL 36%(n=9)<br>• Impingement during plantar flexion 100%(n=11) [2]<br>• Tibiotalar joint effusion 44%(n=11) | MRI is a useful diagnostic tool in PAIS, and in the present series, clearly demonstrates the anatomical variants and range of osseous and soft-tissue abnormalities associated with this condition. Prospective studies are needed to understand the significance and importance of individual MRI findings in producing the symptoms of PAIS. | C(4) |
| Peace et al | 9 female ballet dancers age, 21±2.9 years; dance experience 16±4.1 years; *en pointe dance experience, 7±4.9 years* The ankle was scanned in three positions: supine with full plantar flexion, standing with the ankle in anatomical position, and standing *en pointe* . | Not reported | • Anterior capsular thickening 0%(n=0)<br>• Anterior tibial and/or talar spurs 44%(n=4)<br>• Convergence of the posterior edge of the tibial plafond, posterior talus, and superior calcaneus 100%(n=9)<br>• Bone marrow edema 11%(n=1)<br>• Downward sloping posterior malleolus of tibia 22%(n=2)<br>• Prominent superior calcaneal tuberosity 33%(n=3)<br>• Stieda's process 44%(n=4)<br>• Os trigonum 0%(n=0)<br>• Posterior capsular thickening 33%(n=3)<br>• Synovitis or joint effusion 6/9 67%<br>• Flexor hallucis longus tenosynovitis or tendinosis 22%(n=2)<br>• Widened anterior ankle joint congruity: NWBPF 71%(n=5)[3]<br>• Widened anterior ankle joint congruity: WBAN 0%(n=0)<br>• Widened anterior ankle joint congruity: WBEP 63%(n=5)[3] | This study successfully established an ankle imaging technique for ballet dancers *en pointe that can be used in the future to assess the relationship between en pointe* positioning and ankle pathoanatomy in ballet dancers. | C(4) |

Abbreviations: M, Male; F, Female; PAI, Posterior Ankle Impingement; MRI, Magnetic Resonance Imaging; NWBPF, supine non-weight-bearing plantar flexion; WBAN, standing weight-bearing ankle neutral position; WBEP, standing weight-bearing *en pointe*
[1] Only 7/25 scans demonstrated an os trigonum; [2] Only 11/25 scans were performed in plantar flexion; [3] Total case counts are less than nine because some images were not of sufficient quality to evaluate joint congruity.
*LOE, study Level of Evidence, according to the Oxford Centre for Evidence-Based Medicine

Not so frequent but also source of postero-lateral ankle pain, its peroneus longus muscle tendonitis. A thickened posterior joint capsule and posttraumatic scar tissue, result of forced and repetitive plantar flexion, are frequent soft tissues alterations to normal ankle morphology that can predispose for PAIS, when irritated or traumatized (Peace at al., 2004; van Dijk, 2006; Russel et al., 2010a; Russel et al., 2010b).

#### 2.3.3.2. PAIS clinics

Depending on the diagnosis based on clinics, there are two main treatment types when dealing with PAIS: operative treatment and non-operative treatment.

The operative procedure should be adopted in specific cases such as recurrent or unremitting symptoms; persistent decreased plantar flexion compared with the unaffected ankle; failure of physical and medical therapies; posterior impingement clinically suspected and indicated by both x-ray and MRI (Abisseti et al., 2009).

When impingement is resultant from ankle functional instability, surgery may also be performed to the ankle lateral ligaments. Four of the the reviewed studies, described the operative treatment (Marotta & Micheli 1992; Hamilton, 2008; van Dijk, 2006; Watson, 2007), being the main aspects to highlight, the type of surgical approach basis on diagnosis. When the source of impingement is os trigonum and must be removed, the advised approach should be on the ankle posterior lateral aspect. When the source of impingement or disability, is FHL tendon sheath that sometimes may co-exist with os trigonum, the surgical approach should be posterior medial. After surgery, physiotherapy and technical errors correction are recommended.

The non-operative or conservative treatment, consists initially of limitation of painful activities, including pointe work, and physical therapy to work on mobilization of the ankle joint. Having the dancer sleep with a night splint may help reduce stiffness and synovitis and some dancers benefit from changing their pointe shoe style and fit to a shoe, such as a half or three-quarter shank that allows the dancer to achieve full pointe position with less compaction of the posterior structures (Kadel, 2006). The use of non-steroidal anti-inflammatory drugs can help, but they should be used only as part of an overall treatment program and not as simply to kill the pain so that the dancer can continue dancing and ignore symptoms (Hamilton, 2008).

Only in one study, the non-operative procedures conducted in their case series, focusing on exercises to improve deep muscle action during pointe and demi-pointe work as

well as proprioceptive exercises on a tilt board to correct the ankle malalignment, were described (Abisseti et al., 2009). If the dancer performs *relevé* using the deep muscles of the lower leg, such as the tibialis posterior, flexor digitorum longus, flexor hallucis longus, and the peroneals, the talus may be shifted forward during plantar flexion of the ankle, delaying the impact of the os trigonum or hypertrophic scar tissue on the posterior tibia. If the gastrocnemius muscles, as opposed to the deep muscles, are used, the calcaneus is lifted and the os trigonum (or Stieda process) will be compressed between the tibia and the calcaneus itself triggering posterior impingement symptoms. The proprioceptive exercises consisted in performing various ballet positions on a tilt board to correct ankle-foot, knee or pelvic malalignments.

## 2.4. Discussion

During the literature search, no studies were found with detailed description of PAI mechanics in the dance context. Thus there was a need to obtain information on studies that characterize this clinical condition from multiple perspectives. Only in three studies of the twelve retrieved for review (Kennedy et al., 2007, Hamilton, 2008; Abisseti et al., 2009), mentioned the importance of dance technique in the execution of specific dance movements, in aspects such as dynamic joint alignment or the relationship between proprioceptive function, muscle function and ankle instability associated with PAIS.

Proprioceptive retraining is one of the most important considerations in the rehabilitation of the foot and ankle, considering that mechanoreceptor reflexes in the joint are affected when injury occurs (Hertel, 2002). Normal reflex coordination of muscle tone in posture and movement may also become disordered when injury occurs to the joint capsule. This disordering may be retrained with exercises directed at working the different joints of the foot and ankle to allow for positional understanding and awareness for each joint (Hertel, 2002; Batson, 2007). Female ballet dancers spend much of their time *en pointe* or *demi-pointe*, a position that is considered a small base of support by most standards. As a result, a high level of center-of-gravity training is required to provide a stable equilibrium in the kinetic chain. Stability is efficiently maintained if the center of gravity projects within the base of support, which, again, is quite small in the dancer, plus if the dancer works with a kinetic chain pattern that overloads the ankle, like gastrocnemius as the main ankle plantar flexor,

PAI may arise resulting from a early overuse event (Hamilton, 1990; Howse, 2004; Batson, 2007; Kennedy et al., 2007).

The daily battle of the dancer is to have control of his body while being extremely mobile. This requires efficient alignment, motor control, and functional placement of the kinetic chain, more than any sport or other activity. The ability to overcome an unstable equilibrium is best achieved by dynamic functional exercises that consider bony alignment, neural input, endurance, strength, and technique requirements, like evidence found in the rehabilitation protocol suggested by Abisseti and colleagues, (2009). The relationship between lateral ankle instability and PAIS is focused, in two other studies (Kennedy et al., 2007; Watson, 2007), and in two more studies the association between ankle instability, faulty dance technique like slicking the foot, were also attributable to one possible injury mechanism for PAIS (Motta-Valencia, 2006; Kadel, 2006).

An ankle injury in a ballet dancer is a whole body injury and sometimes certain anatomical variations, associated to kinetic chain dysfunction may result in injury. In PAIS, the anatomical variations of the posterior ankle can be a predisposing factor but not a crucial factor.

All the studies reported on the anatomical and clinical characteristics observed in PAIS, one study reported specifically about os trigonum in dancers (Marotta & Micheli, 1992) and is operative treatment. Other study presented full description of PAIS clinical anatomy (Russel et al., 2010a) highlighting the various sources of impingement, although no description on the triggering mechanism correlated with the *en pointe* and *demi-pointe* performance was made.

### 2.4.1. Limitations of the Review

The main limitations of this review were, during the screen for relevance process, the lack of studies found on this subject with high level of evidence, what in turn made it more difficult to establish the selection criteria. After the literature review, all the selected studies showed different approaches (clinical, physiological, biomechanical), focusing on the problem objectively from their single perspective. For example: clinical studies mostly relate to case studies or reviews on results of the clinical condition in itself and its pathology, the background causes and contributing factors to the injury, other than those in the clinical spectrum, such as dance technique or biomechanics, were mentioned superficially being the

results of follow-ups reported by rate of success and failure often without specifying the rehabilitation protocol.

Studies focused on ballet technical aspects, sometimes ignore some of the clinical aspects of injury. There is some lack of cross-checking data from the different fields which deal with this theme, making it difficult to objectify valid conclusions in order to enable an accurate appraisal on the PAIS biomechanical profile.

### 2.4.2. Future Directions

Because a properly functioning ankle and foot are fundamental to success in dance, their biomechanical aspects related to stability and motion, in *en pointe* and *demi-pointe,* are still fertile ground for research. In the particular case of PAIS, specific biomechanical features like muscle activation patterns in ankle motion during plantar flexion, ankle stability strategies and postural sway, still need to be studied within this context. The way how structural differences among dancers can adapt through training, also should be considered an essential issue, aiming for improved solutions concerning the function-related problems arising from practice.

## 2.5. Conclusion

PAIS is a clinical situation common between dancers due to abusive use of extreme plantar flexion, mostly of times misdiagnosed, causing an inappropriate targeting of the treatment protocol and rehabilitation program, increasing the time of ankle disability. It is of utmost importance in PAIS evaluation, to understand the current and previous history of injury by running accurate clinical assessments and dance screening protocols, ask for imaging exams especially when there is recurrence or persistence of injury is crucial, in order to establish differential diagnosis and confirm other clinical co-existing conditions. A proper diagnosis may avoid surgery in most cases, and less absence time. An early intervention may possible be the key for building targeted functional rehabilitation programs and also play a preventive role in PAIS recurrence.

The interdependent relation between functional and mechanical features of ankle and foot in ballet dancers still need to be overlooked in different perspectives, considering case studies with and without the injury, for deeper knowledge of injury mechanism and is risk factors.

The dance medicine literature is still young and heterogeneous, limiting the ability to draw consistent conclusions. Nonetheless, the best available evidence suggests that the proper ankle plantar flexion mechanics, required in order to obtain aesthetical alignment, especially in female ballerinas, depends on functional aspects of ankle stability and foot mechanics, as well as favorable anatomic conditions. Better quality research is needed in this specialized area, being it such an important health issue for dancers at all skill levels. Future research would benefit from clear and relevant research questions being addressed with appropriate study designs, use of conceptually valid and clinically meaningful case definitions of the injury mechanism and disability, and better report of studies follow-ups in line with current scientific standards.

The following diagram (fig.2) summarizes the relationship between the main mechanical and functional factors and their several aspects, that when combined may result in PAIS.

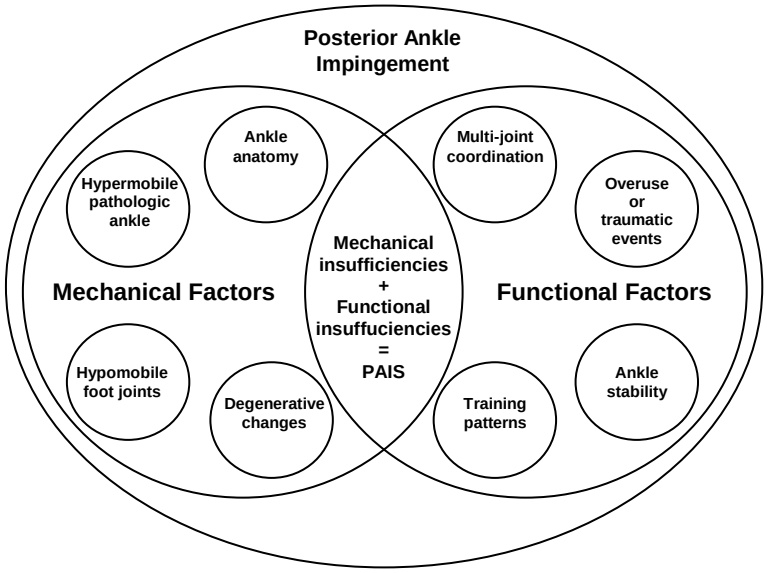


**Figure 2.** PAIS mechanical and functional factors

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# Chapter 3

# Manuscript 2

# Pathomechanics of Posterior Ankle Impingement Syndrome in Pre-Professional Female Ballet Dancers – A Descriptive, Exploratory, Case-Control Study

## Abstract

Pain of the posterior compartment of ankle in female ballet dancers can result from many causes and may represent a diagnostic challenge. Posterior ankle impingement syndrome (PAIS) refers to a group of pathologic entities that result from repetitive or acute forced plantar flexion of the foot and ankle, especially in the *en pointe* and full *demi-pointe* positions (Bauman, Gallagher & Hamilton, 1996; Hamilton, Geppert &Thompson, 1996; Robinson & White, 2002; Howse, 2004; Peace, Hillier, Hulme & Healy, 2004; Maquirriain, 2005; Kadel, 2006; Motta-Valencia, 2006; van Dijk, 2006; Kennedy, Hodgkins, Colombier, Guyette & Hamilton, 2007; Hamilton, 2008; Abisseti, Ometi, Pascale & De Bartolomeu, 2009; Russell, Kruse, Koutedakis, McEawn & Wyon, 2010; Russel, Shave, Yoshioka, Kruse, Koutedakis & Wyon 2010). *Purpose*. To compare ankle plantar flexion kinetics through, muscle activity, ankle stiffness and postural sway in pre-professional female ballet dancers with and without PAIS, while performing full *pointe* and *demi-pointe* movements, concerning the differences between movements and between groups. *Study design*. Exploratory, comparative, case-control. *Materials and Methods*. We considered eight pre-professional female ballet dancers from Escola de Dança do Conservatório Nacional (EDCN), aged 14-22 years (mean 16,8$\pm$2,8), height range from 154 to 177,5 cm (mean 165,5$\pm$8,5), weight range from 46,5 to 61Kg (mean 52,3$\pm$5,3). For surface electromyography (EMG) it was used standard silver/silver chlorides (Ag/AgCl), disposable pregelled electrodes, with an EMG system. Ankle kinematics was assessed using a twin axis goniometer, ankle stiffness through a triaxial accelerometer. Postural sway was measured with a pressure plate system. *Results*. A pattern was identified in muscle activity within the PAIS group on the double leg demi-pointe (DLDP) movement, that also proven to be the most stiff movement at the ankle. PAIS group subjects also showed less postural sway variations than controls being the double leg positions the ones with greater postural sway variation. *Discussion*. A clear pattern was observed in muscle activity in the ankle position that presented less accelerometer signal variation for all participants and the one where the ankle joint was stiffer, this pattern may be explained through the fact that movement is the most frequently performed within the dance context being more likely for a pattern to settle. PAIS subjects revealed greater stiffness at ankle joint than controls, which may indicate that for PAIS subjects, the more stiff the ankle position is, more strongly the ankle joint is locked increasing the compression. Postural sway showed much less variation in the single leg positions than in the double leg positions for all participants. *Conclusion*. Based on the study outcomes the position where PAIS is more likely

to occur is the single led demi-pointe position. However and despite of the differences found between groups, for drawing a PAIS biomechanical profile, further study is needed with a larger sample to consider representative outcomes.

***Key Words*:** posterior ankle impingement syndrome; female ballet dancers; pathomechanics; ankle injury.

## Resumo

O síndrome do conflito posterior do tornozelo é uma lesão frequente na prática de ballet clássico atingindo maioritariamente as bailarinas devido ao uso abusivo da flexão plantar extrema do tornozelo ao efectuar as posições de ponta e meia-ponta (Bauman, Gallagher & Hamilton, 1996; Hamilton , Geppert & Thompson, 1996; Robinson & White, 2002; Howse, 2004; Paz, Hillier Hulme, & Healy, 2004; Maquirriain, 2005; Kadel, 2006; Motta-Valencia, 2006; van Dijk, 2006; Kennedy, Hodgkins, Colombier , Guyette & Hamilton, 2007; Hamilton, 2008; Abisseti, Ometi, Pascale & De Bartolomeu, 2009; Russell, Kruse, Koutedakis, McEawn & Wyon, 2010; Russel, Shave, Yoshioka, Kruse, Koutedakis & Wyon 2010). *Objectivo*. Avaliar o movimento de flexão plantar do tornozelo ao executar as posições de ponta e meia-ponta, considerando a actividade muscular, a oscilação postural e a rigidez da articulação. A avaliação foi realizada em sujeitos com recorrência da lesão e em sujeitos sem historial de lesão, comparando os resultados entre sujeitos e entre as posições efectuadas. *Desenho do estudo*. Caso-controlo, exploratório, descritivo. *Materiais e Métodos*. Consideramos oito bailarinas pré-profissional da Escola de Dança do Conservatório Nacional (EDCN), com idades entre 14 e 22 anos (16,8 +2,8), altura entre 154 e 177,5 cm (165,5 +8,5), peso entre 46,5 e 61 kg (52,3 +5,3). A actividade muscular foi avaliada com um sistema de electromiografia (EMG). A referência cinemática do movimento do tornozelo foi avaliada através de um electrogoniometro e a rigidez da articulação na flexão plantar foi avaliada com acelerómetro triaxial. A oscilação postural foi medida com uma placa de pressões. *Resultados*. Foi identificado um padrão na actividade muscular nos sujeitos com conflito posterior do tornozelo, verificado no movimento de meia-ponta efectuado com as duas pernas. A mesma posição foi igualmente aquela onde os sujeitos mostraram maior oscilação postural e onde a articulação do tornozelo se mostrou mais rígida na flexão plantar mantida, facto verificado em ambos os grupos mas com destaque para os sujeitos com conflito posterior que apresentaram maior rigidez na articulação comparados com os respectivos controlos. *Discussão*. Um claro padrão foi observado na actividade muscular na posição do tornozelo que apresentou menor variação de sinal do acelerómetro para todos os participantes, possivelmente devido ao facto de que o movimento de meia-ponta bilateral é um dos mais frequentemente executados no contexto da dança sendo por isso mais provável que um padrão se desenvolva neste movimento do que noutro menos executado e mais instável. Os sujeitos com conflito posterior revelaram maior rigidez na articulação do tornozelo na flexão plantar mantida comparados com os controlos, o que pode indicar que para estes, quanto mais rígida é a posição do

tornozelo, mais fortemente a articulação do tornozelo está bloqueado nessa posição aumentando a compressão. A oscilação postural apresentou bastante menos variação nas posições executadas numa só perna em todos os participantes, devido à transferência do centro de força directamente para cima da base de apoio, facto que não se verifica nas posições bilaterais onde o centro de força é repartido pelas duas pernas e não centrado apenas numa. *Conclusão*. Com base nos resultados do estudo, nas posições avaliadas aquela onde o conflito posterior do tornozelo é mais provável de ocorrer é nas posições executadas em meia-ponta com destaque para a meia-ponta executada unilateralmente. No entanto e apesar das diferenças encontradas entre os grupos, são necessários estudos com amostras maiores considerar os resultados representativos.

***Palavras-chave:*** síndrome do conflito posterior do tornozelo; mecânica patológica; lesão do tornozelo em bailarinas.

## 3.1. Introduction

Posterior ankle impingement syndrome (PAIS) refers to a group of pathologic entities that result from repetitive or acute forced plantar flexion of the ankle into extreme ranges of motion, and is a clinical situation common among ballet dancers, especially females, due to the abusive use of plantar flexed ankle while performing *pointe* and *demi-pointe* positions (Hamilton, Geppert &Thompson, 1996; Robinson & White, 2002; Howse, 2004; Peace, Hillier, Hulme & Healy, 2004; Maquirriain, 2005; Kadel, 2006; Motta-Valencia, 2006; van Dijk, 2006; Kennedy, Hodgkins, Colombier, Guyette & Hamilton, 2007; Hamilton, 2008; Abisseti, Ometi, Pascale & De Bartolomeu, 2009; Russell, Kruse, Koutedakis, McEawn & Wyon, 2010a; Russel, Shave, Yoshioka, Kruse, Koutedakis & Wyon 2010b). The repetitive event most of the time is characterized by altered kinetics in muscle and joint function that may predispose for PAIS to settle through ankle instability and/or decreased space between tibia and calcaneus, compressing the soft tissues or bony structures sometimes found in the posterior ankle anatomy, so it´s of utmost importance in PAIS assessment, to understand the current and previous history of injury, request clinic oriented exams, check ankle stability and range of motion as well as dance technical errors, since in most cases the injury arises from technical failures (Bauman, Gallagher & Hamilton, 1996; Howse, 2004; Batson, 2007; Hamilton, 2008; Abisseti et al., 2009; Russell et al., 2010a; Russell et al., 2010b). The differential diagnosis and the confirmation of clinical co-existing conditions are also crucial. A proper diagnosis can avoid surgery and less time off the inactivity through early intervention and proper functional rehabilitation may prevent PAIS recurrence (Abisseti et al., 2009; Russell, et al., 2010b).

Pain in the posterior ankle of female ballet dancers can result from many causes and may represent a diagnostic challenge and the best available evidence suggests that the proper ankle plantar flexion mechanics, required in order to obtain aesthetical alignment, especially in female ballerinas, depends on functional aspects of ankle stability and foot mechanics, as well as favorable anatomic conditions (Bauman, Gallagher & Hamilton, 1996; Bureau, Cardinal, Hobden & Aubin, 2000; Carmont, Patrick & Cassar-Pullicino, 2006; Kennedy, Hodgkins, Colombier, Guyette & Hamilton, 2007; Hamilton, 2008; Russell et al., 2010a; Russel et al., 2010b), and being the ankle such a key joint in ballet, and since most studies indicate that the repetitive movement of weight bearing forced plantar flexion of the foot and ankle in closed kinetic chain, in the *en pointe* and full *demi-pointe* positions, is the most likely causing factor for PAIS to arise (Marotta, Micheli, 1992; Hamilton et al., 1996; Bureau,

Cardinal, Hobden & Aubin, 2000; Hillier et al., 2004; Peace et al., 2004; Motta-Valencia, 2006; Kadel, 2006; van Dijk, 2006; Kennedy et al., 2007; Hamilton, 2008; Abisseti et al., 2009; Russell et al., 2010a; Russell et al., 2010b), there must be a biomechanical explanation to answer why some ballet dancers are more prone to this injury than others with identical dance training. Once again, the answer might be on how the movement is performed.

According to a recent review of literature made by Krasnow, Wilderming, Stecyk, Wyon & Koutedakis (2011), biomechanical researches in dance date back to early 1960s, being that only in the 1970s, pioneer researchers, first introduced measurement tools and research methodologies that were the forerunners of the current equipment and approaches used today, aiming to study how dancers performed dance movements. Understanding the movement is in fact the goal of biomechanics in dance science research, by observing both kinematic and kinetic aspects of a dancer´s movement (Wilson & Kwon, 2008).

Between establishing baselines for dance performance, propose new insights related to motor strategies, dance teaching and dance training, the focusing on anatomical and/or biomechanical factors like precursors or correlate to injury, was also subject of interest among researchers (Massó et al., 2004; Kadel, Donaldson-Fletcher, Segal, & Orendurf, 2006; Ahonen, 2008; Koutedakis, Owolabi & Apostolos, 2008; Wilson & Kwon, 2008; Russell et al., 2008; Russell et al., 2010a; Krasnow et al., 2011), playing their analysis an important role in issues like skill enhancement, and injury prevention.

The *relevé*, is one of the more studied dance actions, since it´s part of any dancer's repertoire (Wilson & Kwon, 2008; Krasnow et al., 2011) when a dancer plantar flex the ankle and foot, rising to *demi-pointe* or higher achieving the full *pointe* position. Ankle motion in dance or other activity depends on how forces are applied to the levers of the skeleton (Russel et al., 2008; Ahonen, 2008; Clippinger, 2007). In mechanics there are three types of levers that produce motion: type 1; type 2; type 3, all these three types of levers can be seen about the ankle, depending on the motion performed and whether or not the lower extremity is weightbearing (Ahonen, 2008). This *relevé* action can be describe as a second-class lever, once the load to be lifted or the resistance of the lever, is represented by the body weight exerted through the ankle talocrural joint and is situated between the *fulcrum*, here represented by the metatarsophalangeal joints of the foot, and the applied force exerted by the ankle plantar flexor muscles of the lower leg (Floyd & Thompson, 2004; Clippinger, 2007; Wilson & Kown, 2008; Ahonen, 2008; Russel et al., 2008; Kapandji, 2011). Understanding the muscle activity in these movements, as a component of motor control, involved in the

strategies that dancers use in muscle recruitment for performing such specific movements, as well as postural sway through movement and ankle stability, can be assessed by electromyography analysis (EMG) in synchrony with motion capture techniques and force platforms, and may provide useful information on how to increase effectiveness and minimize the risk for injury during dance practice (Wilson & Kwon, 2008; Koutedakis, Owolabi & Apostolos, 2008; Krasnow et al., 2011).

In the review made by Wilson & Kown (2008), they stated that the individual muscle firing patterns of muscle recruitment showed by studies involving EMG analysis, often demonstrate variability between dancers performing the same action, this evidence lead us to consider the possibility of having differences in these muscle firing patterns on individuals with the same type of recurrent injury, especially when these result from overuse, like PAIS. It is also know that muscle imbalance is a major contributor for many injuries to arise, especially in the lower extremity, and that the foot and the ankle account with 34% to 62% of the injury incidence rate, being that previous injury and dance discipline, are both correlate with the increased risk of injury recurrence (Macintyre & Joy, 2000; Bronner, Ojofeitimi & Rose, 2003; Weisler, Hunter, Martin, Curl & Hoen, 1996). However, in what concerns to PAIS, no studies were found correlating biomechanics and clinics.

Because PAIS is one of the most misdiagnosed ankle injuries among ballet dancers which may lead to restrictions in technical progression, or even to career end, it´s urgent to design studies with targeted research objectives, to be able to act preventively, being necessary to direct new research protocols for the injury free periods, since most of the available papers on case studies, report to the acute phase of injury describing the clinical findings and treatment procedures (Marotta & Micheli, 1992; Hamilton et al., 1996; Bureau et al., 2000; Peace et al., 2004; Abisseti et al., 2009; Russell et al., 2010a; Russel et al., 2010b), which does not allow to determine accurately a predictive pre-injury profile.

### 3.1.1. Study Purpose

The purpose of this study was to evaluate, compare and describe ankle plantar flexion in pre-professional female ballet dancers with and without PAIS, while performing full *pointe* and full *demi-pointe* movements, concerning the differences between movements and between groups.

The aims of the study were:

1. To assess muscle activity while performing double and single leg *en pointe* and full *demi-pointe*.
2. To assess ankle stiffness depicted through the ankle vibration while standing in maximum plantar flexion in *en pointe* and full *demi-pointe* positions performed double and single leg.
3. To assess postural sway while standing in maximum plantar flexion in *en pointe* and full *demi-pointe* positions performed double and single leg.
4. To compare the muscle activation firing sequence between groups for the performed movements.

For that, two hypotheses were proposed:

**H.1** Muscle activity will be different between subjects of the PAIS group and Control group.

**H.2** There will be differences in ankle stability and postural sway between subjects within the PAIS group and controls, while standing in double and single leg *en pointe* and double and single leg full *demi-pointe*.

This is a descriptive, exploratory, case-control study.

## 3.2. Methods

### 3.2.1. Participants

They were considered 116 dancers, all students of the *Escola de Dança do Conservatório Nacional* (EDCN), aged from 9 to 21 years old. The EDCN is the most prestigious dance school in Portugal with academic studies integrated. In the current year, EDCN counted with a total of 169 students, 116 girls (69%) and 53 boys (31%) spread over a training program of eight years, divided into three skill levels: beginner, intermediate and advanced. Students in the advanced level attend to the $6^{th}$, $7^{th}$ and $8^{th}$ years of the training program and have a weekly schedule of 20 to 26.5 hours, of which 4 to 5 hours are of academic teaching and 15 to 20.5 hours are of dance training. The workload demands of the dance training program, depends on the skill level in which students attend to, having the first three years corresponding to the beginner level, significantly less hours of dance training over the last years.

The study sample included a total of eight female dancers aged between 14 to 21 years old, from intermediate and advanced levels classes of EDCN, divided into two groups, with four dancers forming the case group with PAIS (*PAIS group*), and other four dancers as the respective controls (*Control group*). The recruitment of the study sample was done in two phases following the previously established inclusion and exclusion criteria.

a) General inclusion criteria for both groups

1. Attending EDCN for minimum period of at least three years followed, including the current year.
2. All dancers must have a dance performance evaluation in classical ballet disciplines equal or superior to 3 on an evaluation scale from 0 to 5.

b) Inclusion criteria for *PAIS group*

1. Having PAIS, resulting from the ballet practice, and which has conditioned or compelled the dancers to stop the activity for a minimum period of 24 hours.
2. Having reported more than one PAIS episode or symptoms.

c) Inclusion criteria for *Control group*

1. None of the dancers may have suffered ever from PAIS during their dance practice.
2. Need to have similar body structure than the respective PAIS subject, in wath concerns to height, weight and body mass index (BMI)
3. Having the same preferential stance leg than the respective PAIS subject.
4. Attending to the same skill level or higher, but never inferior, than the respective PAIS subject.

d) Exclusion criteria for both groups

1. All subjects that at the time of data collection have an active injury or some other limitation that does not enable to proceed accurately to data collection.

### 3.2.2. Subjects' Selection

The subjects' recruitment for the study was made in two phases on EDCN. In the first phase of the recruitment process, EDCN clinical database was examined, from

September 2010 to May 2011, for identifying PAIS cases. After scanning the clinical database, six cases were identified, five of whom reporting recurrent episodes, being such the ones selected for the *PAIS group* by fitting the inclusion criteria. Once formed the *PAIS group*, subjects were weighed, height measured and the preferential stance leg was determined (by pushing the subject forward from the back). The second phase of the recruitment process was the application of the criteria to the rest of the school female students, for select the *Control group*, based on the *PAIS group* characteristics.

By the time of the data collection, one of the participants from the *PAIS group* had an acute recurrence of the injury and was excluded, being the respective subject from the *Control group* also excluded.

The study sample featured eight pré-professional female ballet dancers (n=8), being that six subjects were currently at the advanced level and the remaining two subjects in the intermediate level, age range from 14 to 22 years old (mean 16,8$\pm$2,8), height range from 154 to 177,5 cm (mean 165,5$\pm$8,5), weight range from 46,5 to 61Kg (mean 52,3$\pm$5,3), years of ballet practice range from 5 to 10 years (mean 165,5$\pm$8,5), pointe shoes practice range from 3 to 8 years (mean 6,5$\pm$1,9) and dance hours per week range from 8,5 to 21 hours (mean 17,6$\pm$5,3). Table 1 shows the sample general features and also the PAIS and control group features. All subjects were healthy and free of active injury at the time of study.

### 3.2.3. Instruments and Data Collection Protocol

The participants performed all the tests in the movement laboratory Physiotherapy Department of *Escola Superior de Saúde do Alcoitão* (ESSA). The data collection procedures were done individually for each subject on different days depending on subjects´ availability. For the protocol procedures they were asked to wear their ballet clothes or shorts, to make possible the placement of the instruments on the lower leg and ankle. When participants arrived to ESSA, it was filled an identification sheet[1] for each participant, concerning the conduct of the protocol. Participants were also instructed on the movements that they needed to perform, that consisted in four dance movements: supported double leg *en pointe* (DLP)

[1] The identification sheet contains data previously collected during the selection process (i.e. age, weight, height, group to which the subject belongs, preferential stance leg, ankle with recurrent PAIS), and reference charts for the biomechanical assessment. The identification sheet is displayed on appendix B.

and *demi-pointe* (DLDP) performed in 1st position[2] ; supported single leg *en pointe* (SLP) and *demi-pointe* (SLDP) performed in 6th position[3]. Each subject performed three trials for each one of the four dance movements (Massó et al., 2004; Kadel, Donaldson-Fletcher, Segal, & Orendurf, 2006; Krasnow et al., 2011), always holding the plantar flexed ankle in the end position, for a three second period, before lowering the ankle back to normal positioning.

**Table 1.** Sample general features

| | Sample | | |
|---|---|---|---|
| | Subjects n=8<br>mean±sd | *PAIS group* n=4<br>mean±sd | *Control group* n=4<br>mean±sd |
| Age<br>(yrs old) | 16,8±2,8 | 17±3,4 | 16,7±2,5 |
| Heigth<br>(cm) | 165,5±8,5 | 165,5±8,8 | 165,5±9,6 |
| Weigth<br>(kg) | 52,3±5,3 | 52,2±5,6 | 52,3±5,8 |
| Ballet practice<br>(years) | 7,8±1,7 | 7,7±1,5 | 8±2,1 |
| Pointe shoes<br>(years) | 6,5±1,9 | 6,2±1,5 | 6,7±2,5 |
| Dance<br>hours/week | 17,6±5,3 | 17,3±5,2 | 17,8±6,2 |

For the subjects of the *PAIS group*, the assessed lower limb was the one where the injury usually occurs and for the subjects of the *Control group*, the assessed lower limb was the same that the respective subject from the *PAIS group*. For the movements performed *en pointe*, the subjects wore their own pointe shoes. The *demi-pointe* movements were performed with the subjects barefooted.

For measuring muscle activity, it was used surface EMG analysis, through standard silver/silver chloride (Ag/AgCl), disposable pregelled electrodes, from Multi Bio Sensors (MBS) and surface EMG amplifiers from *Biovision*. Ankle motion was measured using a twin axis goniometer from *Biomectrics* for ankle angular variation during movement, and a triaxial accelerometer (PLUX) was used for measuring the ankle vibration during movement. Postural

[2] 1st position - hips are externally rotated and adducted with the heels in contact with each other. The knees are aligned over the feet (Gilbert, Gross and Klug, 1998).

[3] 6st position - feet and legs stand in parallel (Gilbert, Gross and Klug, 1998).

sway was measured with a pressure plate system, (Footscan®3D plate by RSscan). All the instruments were plugged to a *Biovision* inputbox in a total of ten channels (Table 2). The trigger communication used for synchronize all the channels was the TTL signal from the pressure plate, corresponding to channel 1. The acquisition software for monitoring and recording all sampled signals was *DaisyLab*.

**Table 2.** Channels description

| Channel | Signal Description | Acronym |
|---|---|---|
| 1 | Trigger – FootScan pressure plate | TTL |
| 2 | Accelerometer anterior/posterior axis – X | ACC X |
| 3 | Accelerometer vertical axis –Y | ACC Y |
| 4 | Accelerometer transversal axis – Z | ACC Z |
| 5 | Goniometer flexion/extension | GON 1 |
| 6 | Goniometer inversion/eversion | GON 2 |
| 7 | Peroneus Longus muscle and ground electrode signal | EMG 1 |
| 8 | Medial Gastrocnemius muscle | EMG 2 |
| 9 | Lateral Gastrocnemius muscle | EMG 3 |
| 10 | Soleus muscle | EMG 4 |

Surface EMG electrodes placement was done following the recomendations made by Hermens (1999) and Cram & Criswell (2010). The subjects´ skin on the location sites of placement of the surface EMG electrodes, was shaved, rubbed with abrasive paper and cleaned up with a gauze pad with alcohol. When the skin surface was dry, the electrodes were placed in pairs, 2cm apart and parallel to the muscle fibers on the muscle bellies of the assessed muscles as described on Table 3. The ground electrode (reference electrode), was placed on tibia´s anterior tuberosity.

Between the electrodes application on skin and the EMG amplifiers connection for signal recording, it was given a time period of five minutes in order to reduce the skin impedance (Correia & Mil-Homens , 2004; Cram & Criswell, 2010). Surface EMG signal were recorded at a sample frequency of 1000Hz and filtered at a cut-off frequency of: high pass 10Hz and low pass 500Hz Butterworths 2$^{nd}$ level (Hodges & Bui, 1996; Merlleti, 1999).

The electrogoniometer was placed on the posterior aspect of the ankle, as in the instructions manual of the equipment, and calibrated for each subject before trial with a manual goniometer, respectively for plantar flexion/extension and ankle inversion/eversion.

**Table 3.** Muscle electrodes placement location

| Muscles | Electrode location site |
|---|---|
| Peroneus Longus muscle | ¼ on the line between the tip of the head of the fibula to the tip of the lateral malleolus |
| Medial Gastrocnemius muscle | Distal from the knee and 2cm medial to midline |
| Lateral Gastrocnemius muscle | Distal from the knee and 2cm lateral to midline |
| Soleus muscle | inferior and lateral aspects of the leg, below the belly of gastrocnemius |

The triaxial accelerometer was placed on the medial portion of the assessed ankle, posteriorly to the medial malleolus, positioned according to the axis orientation in the respective normal anatomic position.

Postural sway was measured with a footscan®3D plate by RSscan, recorded at sample frequency of 100 Hz, and calibrated according to the equipment instructions manual.

After the instruments placement and settings, the subjects´ performed all the requested movement's protocol over the pressure plate, Figure 1, starting by the double leg positions.

### 3.2.4. Data Analysis

The collected data was processed offline using Python and Eclipse as an integrated development environment (van Rossum, 2003) with the numpy package (Oliphant, 2006).

In order to accomplish our research goals and test our hypothesis, we chose to extract the following variables from the collected data:

- Ankle plantar flexion movement onset time.
- The end time when maximum plantar flexion is reached, corresponding to the end of the rising phase to achieve the *en pointe* and *demi-pointe* positions.

Once determined the time related variables, the following parameters were studied for each of the three trials of all the performed movements:

- The muscle activity onset time´s for each assessed muscle at the beginning of the plantar flexion movement.
- Ankle stiffness traduced by accelerometer signal for vertical, antero-posterior and transversal variations in ankle with maximum plantar flexion during a three seconds *plateau*.
- Postural sway with ankle in maximum plantar flexion during a three seconds *plateau*.

The first parameter to be processed from the collected data was the onset time´s of ankle plantar flexion motion and the end times of the corresponding rising phase. Times were obtained through the kinematic reference withdrawn from the goniometer signals, since all the other parameters will be determined according to the phases of the ankle motion. The onset time´s will gave us the time references for determine the corresponding muscle activity at that time, and the end time of the ankle plantar flexion rising phase gives us the time frame of the beginning of the three seconds plateau, from which shall be assessed ankle stiffness and postural sway.

The signals from the goniometer correspond to the ankle´s angle variation. It´s therefore expected that at the beginning of the plantar flexion movement will occur, an angular variation.

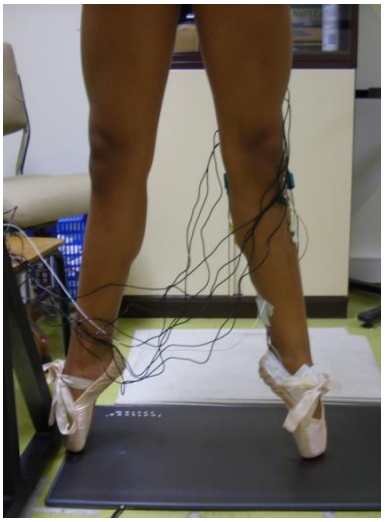
Thus, the ankle plantar flexion start times, was obtained through the goniometer GON 1 signal, when the signal starts to ascent and the end times, acquired at the peak angle of GON 1 signal. Figure 3 exemplifies the procedure.

The muscle activity data concerning the start times of muscle activation, were taken directly from the moment in which the EMG signals denote evidence of muscle contraction, considering the onset time of the ankle movement given by the GON 1 signal, being that all signals were centered at y-axis zero, rectified and smoothed with a moving average window of 10 samples, to get the EMG signal's envelope. The mean and standard deviation error were computed for the rest period of the EMG signal and a threshold was defined. After, were found the indices for which the signal values were higher than the defined threshold, accepting the first value encountered as the initial instant of muscular activity after validating it for sporadic activations by checking if the end of the activation was at least 100ms after the start of the activation.

The ankle stiffness in maximum plantar flexion was obtained through the analysis of the signal variations from the three axes of the accelerometer, on the three seconds time

*plateau* withdrawn from instant when the GON 1 signal indicated the end of the rising phase of the ankle maximum plantar flexion. At this instants of the ACC X, ACC Y and ACC Z signals, it was calculated the average, and standard deviation relative to the average. And it was considered that, minor the standard deviation, means that more stiff will be the ankle at the *plateau* of maximum plantar flexion, since that the standard deviation indicates that the withdrawal average does not have great data variation.

Supported double leg demi-pointe in 1st position



Supported double leg full pointe in 1st position

Supported single leg demi-pointe in 6st position

Supported single leg full pointe in 6st position

**Figure 1.** Movement protocol

Also was calculated the slope of the linear regression line and the respective inherent error. The slope, if close to zero, will indicate that the linear regression line is with a horizontal orientation, and therefore the *plateau* of maximum plantar flexion is centered on the average of the obtained value. When the slope of the linear regression line, is different from zero, could have a positive or negative value. When positive, indicates an increase on the ankle acceleration, and when negative shows the opposite.

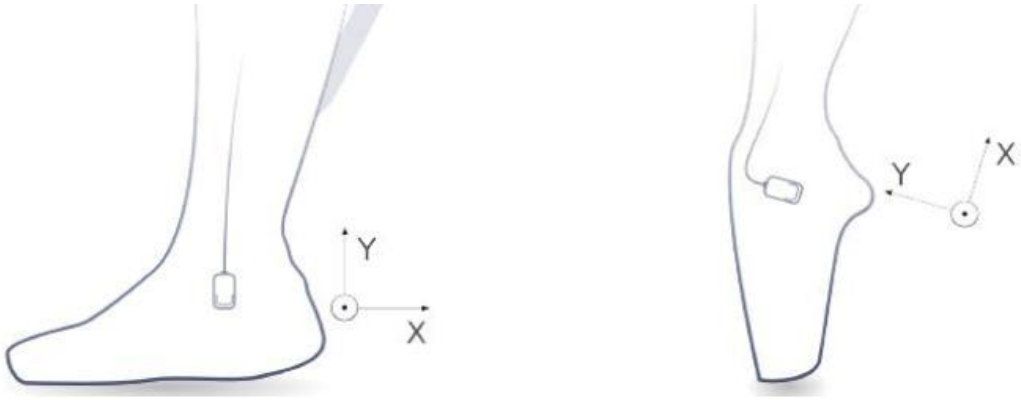



**Figure 2.** Accelerometer áxis switch during plantar flexion movement

Subject´s postural sway in ankle maximum plantar flexion during the three seconds time *plateau* was obtained by calculating the center of force (COF) travelled distance during that time. The reference times for this procedure were obtained through the GON 1 signal concerning the ankle plantar flexion movement phases indicates the beginning of the three *plateau* at the end of the movement rising phase.

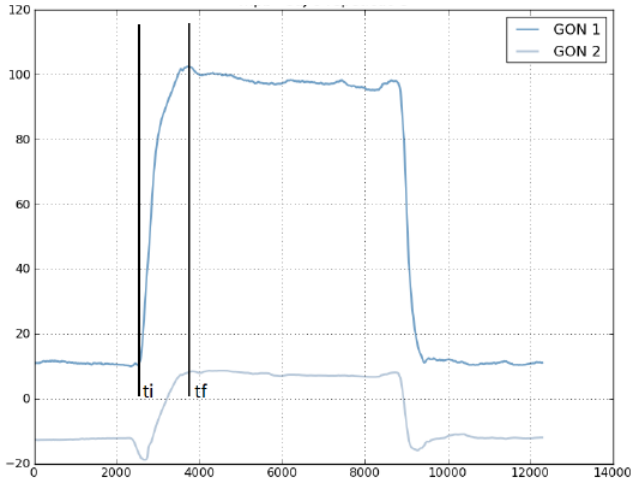



**Figure 3.** Example of signal obtained through GON 1 flexion/extension angle; ti, inicial time; tf, final time

## 3.3. Results

The data presented in the result tables, refers to the average values obtained after processing the data collected from the three trials by each subject performed per movement[2].

In the analysis of muscle activity data concerning the activation time when the movement starts, we found that in the DLDP movement, Table 1, there´s a pattern tendency verified in the PAIS group subject´s, where three out of four demonstrated the same muscle activation sequence: EMG 2, *medial gastrocnemius muscle* followed by EMG 4, *soleus muscle*, EMG 1, *peroneus longus muscle* ending the sequence with EMG 3, *lateral gastrocnemius muscle*.

**Table 4.1** Mean onset time´s (ms) concerning muscle activity in 1st position DLDP

| Group | Subjects | EMG AS | Mean onset time (ms) | | | | |
|---|---|---|---|---|---|---|---|
| | | | EMG 1 (PL) | EMG 2 (MG) | EMG 3 (LG) | EMG 4 (S) | GON 1 |
| Pais | 1 | 2;4;1;3 | 1229 | 1161 | 1427 | 1196 | 1527 |
| | 2 | 4;2;3;1 | 1625 | 1411 | 1573 | 1356 | 1399 |
| | 3 | 2;4;1;3 | 1537 | 1466 | 1574 | 1521 | 1756 |
| | 4 | 2;4;1;3 | 2499 | 2370 | 2582 | 2487 | 2397 |
| Control | 1 | 2;1;3;4 | 2026 | 1952 | 2233 | 2255 | 2351 |
| | 2 | 1;2;3;4 | 1268 | 1308 | 1348 | 1380 | 1525 |
| | 3 | 1;3;2;4 | 949 | 974 | 965 | 1008 | 1096 |
| | 4 | 2;1;3;4 | 1844 | 1636 | 1856 | 1890 | 1969 |

EMG AS, EMG Activation Sequence; PL, Peroneus Longus; MG, Medial Gastrocnemius; LG, Lateral Gastrocnemius; S, Soleus

Subjects from the control group shown muscle activation sequences different from the ones verified in the PAIS group. Only two out of four had the same muscle activation sequence: EMG 2, *medial gastrocnemius muscle*; EMG 1, *peroneus longus muscle*; EMG 3, *lateral gastrocnemius muscle*; EMG 4, *soleus muscle*. For all the subjects of the control group *soleus muscle* EMG 4, was the last muscle to be activated in the beginning of the DLDP plantar flexion movement.

We also found in the SLP movement, Table 4.4, similar activation sequences on muscle activity within the PAIS group, where it was possible to verify that all the four subjects activate first the *medial gastrocnemius muscle* EMG 2, and three of them subsequently activated the *peroneus longus muscle* EMG 1, finishing the activation sequence

with EMG 4, the *soleus muscle*. Still in the PAIS group, they were verified in two of the four subjects the same muscle activation sequence: EMG 2; EMG 1; EMG 3; EMG 4. Subjects within the Control group shown different muscle activation sequences that the ones verified in the PAIS group, and also different between them.

**Table 4.2** Mean onset time´s (ms) concerning muscle activity in 1st position DLP

| | | | Mean onset time (ms) | | | | |
|---|---|---|---|---|---|---|---|
| Group | Subjects | EMG AS | EMG 1 (PL) | EMG 2 (MG) | EMG 3 (LG) | EMG 4 (S) | GON 1 |
| Pais | 1 | 1&2;4;3 | 965 | 965 | 1113 | 973 | 1353 |
| | 2 | 2;4;1;3 | 1694 | 1653 | 1816 | 1677 | 1644 |
| | 3 | 2;1;3;4 | 1477 | 1455 | 1517 | 1550 | 1643 |
| | 4 | 2;3;1;4 | 1501 | 1421 | 1483 | 1525 | 1458 |
| Control | 1 | 1;4;2;3 | 1084 | 1420 | 1518 | 1288 | 1838 |
| | 2 | 2;3;4;1 | 1037 | 997 | 991 | 1036 | 1305 |
| | 3 | 1;3;4;2 | 726 | 967 | 873 | 879 | 1092 |
| | 4 | 2;1;3;4 | 1305 | 1118 | 1329 | 1375 | 1514 |

EMG AS, EMG Activation Sequence; PL, Peroneus Longus; MG, Medial Gastrocnemius; LG, Lateral Gastrocnemius; S, Soleus

**Table 4.3** Mean onset time´s (ms) concerning muscle activity in 6st position SLDP

| | | | Mean onset time (ms) | | | | |
|---|---|---|---|---|---|---|---|
| Group | Subjects | EMG AS | EMG 1 (PL) | EMG 2 (MG) | EMG 3 (LG) | EMG 4 (S) | GON 1 |
| Pais | 1 | 2;4;3;1 | 1480 | 996 | 1545 | 1544 | 1657 |
| | 2 | 4;2;1;3 | 1574 | 1514 | 1648 | 1364 | 1884 |
| | 3 | 2;3;4;1 | 1668 | 1386 | 1525 | 1558 | 1830 |
| | 4 | 4;1;2;3 | 1808 | 2042 | 2098 | 1667 | 2337 |
| Control | 1 | 1;4;3;2 | 1594 | 1678 | 1665 | 1625 | 1838 |
| | 2 | 2;3;4;1 | 1317 | 1129 | 1278 | 1294 | 1470 |
| | 3 | 1;4;2;3 | 1041 | 1074 | 1078 | 1050 | 989 |
| | 4 | 3;1;2;4 | 1574 | 1587 | 1566 | 1615 | 1816 |

EMG AS, EMG Activation Sequence; PL, Peroneus Longus; MG, Medial Gastrocnemius; LG, Lateral Gastrocnemius; S, Soleus

For the DLP and SLDP movements, respectively Tables 4.2 and 4.3, the muscle activation sequences were more random, and weren´t observed any patterns or similarities between groups or between subjects within the same group.

**Table 4.4** Mean onset time´s (ms) concerning muscle activity in 6st position SLP

| Group | Subjects | EMG AS | Mean onset time (ms) | | | | |
|---|---|---|---|---|---|---|---|
| | | | EMG 1 (PL) | EMG 2 (MG) | EMG 3 (LG) | EMG 4 (S) | GON 1 |
| Pais | 1 | 2;1;3;4 | 899 | 893 | 911 | 996 | 1438 |
| | 2 | 2;1;4;3 | 1627 | 1623 | 1812 | 1726 | 2196 |
| | 3 | 2;3;1;4 | 1470 | 1193 | 1311 | 1512 | 1621 |
| | 4 | 2;1;3;4 | 1663 | 1350 | 1761 | 1940 | 2204 |
| Control | 1 | 1;4;2;3 | 1073 | 1486 | 1494 | 1078 | 1746 |
| | 2 | 3;2;4;1 | 1291 | 1211 | 1142 | 1255 | 1408 |
| | 3 | 1;4;3;2 | 1029 | 1194 | 1108 | 1107 | 1382 |
| | 4 | 3;2;1;4 | 1286 | 1069 | 1008 | 1300 | 1465 |

EMG AS, EMG Activation Sequence; PL, Peroneus Longus; MG, Medial Gastrocnemius; LG, Lateral Gastrocnemius; S, Soleus

Summarizing these results, concerning our first study hypothesis, a clear evidence of muscle activation pattern was found in the PAIS group on the DLDP movement, when compared with controls, and on the SLP movement, also was found within the PAIS group, similarities on the muscle activation sequences, different from controls. Therefore based on our qualitative assessment of the results, the study's first hypothesis was partially accepted.

**Table 5.1** ACC axes linear regression for ankle vibration in the 3 seconds *plateau* on 1st position DLDP

| Group | Subjects | ACC X | | | | ACC Y | | | | ACC Z | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Sd | Slope | *r* | Mean | Sd | Slope | *R* | Mean | sd | slope | *r* |
| Pais | 1 | -3,1448 | 0,0013 | 0,00000 | 0,02 | -2,7546 | 0,0012 | 0,00000 | -0,05 | -2,8265 | 0,0020 | 0,00000 | 0,68 |
| | 2 | -2,8448 | 0,0016 | 0,00000 | -0,50 | -2,7363 | 0,0010 | 0,00000 | 0,51 | -2,7997 | 0,0018 | 0,00000 | 0,04 |
| | 3 | -3,1133 | 0,0014 | 0,00000 | 0,51 | -2,7466 | 0,0011 | 0,00000 | 0,02 | -2,7851 | 0,0022 | 0,00000 | 0,75 |
| | 4 | -2,8781 | 0,0035 | 0,00000 | -0,49 | -2,7348 | 0,0022 | 0,00000 | 0,24 | -2,7599 | 0,0036 | 0,00000 | 0,03 |
| Control | 1 | -3,0882 | 0,0019 | 0,00000 | 0,20 | -2,7501 | 0,0029 | 0,00000 | -0,50 | -2,7437 | 0,0054 | 0,00001 | 0,85 |
| | 2 | -2,8277 | 0,0035 | 0,00000 | -0,75 | -2,7391 | 0,0020 | 0,00000 | 0,65 | -2,8243 | 0,0015 | 0,00000 | 0,43 |
| | 3 | -3,0781 | 0,0027 | 0,00000 | 0,50 | -2,7356 | 0,0015 | 0,00000 | 0,71 | -2,7707 | 0,0020 | 0,00000 | -0,45 |
| | 4 | -2,8217 | 0,0013 | 0,00000 | -0,38 | -2,7546 | 0,0010 | 0,00000 | 0,31 | -2,7723 | 0,0012 | 0,00000 | 0,16 |

The ankle stiffness, through the analysis of the results obtained from the accelerometer data at the end of the rising phase during a three seconds *plateau*, we found differences between movements and between groups through *sd* comparison. For all the

participants, the DLDP movement, Table 5.1, was the one where most stiffness was observed, presenting less signal variation within the accelerometer axes, followed by the SLDP movement, Table 5.3. The SLP movement, Table 5.4, was where we observed more signal variation within the accelerometer axis when comparing the data from all the four performed movements.

**Table 5.2** ACC axes linear regression for ankle vibration in the 3 seconds *plateau* on 1st position DLP

| | | ACC X | | | | ACC Y | | | | ACC Z | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Group | Subjects | Mean | Sd | Slope | *r* | Mean | Sd | Slope | *r* | Mean | sd | slope | *R* |
| Pais | 1 | -3,0456 | 0,0035 | 0,00000 | 0,65 | -2,7180 | 0,0013 | 0,00000 | -0,20 | -2,8013 | 0,0038 | 0,00000 | 0,89 |
| | 2 | -2,8554 | 0,0037 | 0,00000 | -0,60 | -2,7341 | 0,0021 | 0,00000 | 0,47 | -2,7925 | 0,0021 | 0,00000 | -0,26 |
| | 3 | -3,1260 | 0,0035 | 0,00000 | 0,61 | -2,7555 | 0,0034 | 0,00000 | 0,44 | -2,7776 | 0,0035 | 0,00000 | -0,06 |
| | 4 | -2,8571 | 0,0034 | 0,00000 | -0,64 | -2,7404 | 0,0017 | 0,00000 | 0,39 | -2,7645 | 0,0032 | 0,00000 | -0,19 |
| Control | 1 | -3,0922 | 0,0028 | 0,00000 | 0,39 | -2,7608 | 0,0026 | 0,00000 | 0,18 | -2,7250 | 0,0034 | 0,00000 | 0,17 |
| | 2 | -2,8294 | 0,0072 | -0,00001 | -0,88 | -2,7360 | 0,0037 | 0,00000 | 0,83 | -2,8437 | 0,0024 | 0,00000 | 0,36 |
| | 3 | -3,0985 | 0,0060 | 0,00001 | 0,79 | -2,7472 | 0,0039 | 0,00000 | 0,63 | -2,7605 | 0,0029 | 0,00000 | -0,12 |
| | 4 | -2,8098 | 0,0026 | 0,00000 | -0,90 | -2,7577 | 0,0015 | 0,00000 | 0,81 | -2,7862 | 0,0016 | 0,00000 | 0,78 |

**Table 5.3** ACC axes linear regression for ankle vibration in the 3 seconds *plateau* on 6st position SLDP

| | | ACC X | | | | ACC Y | | | | ACC Z | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Group | Subjects | Mean | Sd | Slope | *r* | mean | Sd | Slope | *r* | Mean | sd | slope | *R* |
| Pais | 1 | -3,1827 | 0,0019 | 0,00000 | -0,37 | -2,7912 | 0,0024 | 0,00000 | -0,26 | -2,7892 | 0,0018 | 0,00000 | -0,20 |
| | 2 | -2,8210 | 0,0027 | 0,00000 | -0,66 | -2,7628 | 0,0022 | 0,00000 | 0,52 | -2,7544 | 0,0015 | 0,00000 | 0,10 |
| | 3 | -3,1310 | 0,0021 | 0,00000 | 0,42 | -2,7653 | 0,0019 | 0,00000 | 0,22 | -2,7594 | 0,0017 | 0,00000 | 0,16 |
| | 4 | -2,7879 | 0,0024 | 0,00000 | -0,10 | -2,8032 | 0,0015 | 0,00000 | 0,56 | -2,7196 | 0,0025 | 0,00000 | -0,10 |
| Control | 1 | -3,1280 | 0,0058 | 0,00001 | 0,70 | -2,7766 | 0,0040 | 0,00000 | 0,53 | -2,7314 | 0,0039 | 0,00000 | 0,40 |
| | 2 | -2,8111 | 0,0027 | 0,00000 | -0,03 | -2,7563 | 0,0025 | 0,00000 | -0,24 | -2,7874 | 0,0027 | 0,00000 | 0,82 |
| | 3 | -3,1119 | 0,0021 | 0,00000 | 0,28 | -2,7654 | 0,0030 | 0,00000 | 0,47 | -2,7345 | 0,0044 | 0,00000 | -0,39 |
| | 4 | -2,7948 | 0,0017 | 0,00000 | 0,30 | -2,7817 | 0,0017 | 0,00000 | -0,08 | -2,7491 | 0,0010 | 0,00000 | 0,00 |

Between groups we also found differences concerning the accelerometer axis signal variations. In the ACC X antero-posterior axis, three out of four from the PAIS group, shown less signal variation in the DLDP and SLDP movements, respectively Tables 5.1., and 5.3., when compared to controls. In the ACC Y vertical axis, PAIS group subjects shown less

signal variation than controls, in the SLDP and SLP movements, and three out of four subjects from PAIS group had shown also less signal variation than controls for the DLDP and DLP movements. For the ACC Y vertical axis, three subjects within the PAIS group showed more signal variation than controls in the SDLP movement, and for the DLDP and SLDP the opposite was observed.

Another interesting finding was that the accelerometer axis that presented less signal variation and therefore more stiffness was the ACC Y vertical axis, observed in three out of four PAIS group subjects on the DLDP movement, Table 5.1, when compared with the other movements and with controls. The ACC X antero-posterior axis, in the Control group subjects, on the SSLP movement, Table 5.4, was the one showing less signal variation, indicating less ankle vibration.

The results regarding postural sway, displayed in Table 6, demonstrated that for all participants from both groups, the movements where it was detected greater postural sway during a three seconds *plateau* at the end of the rising phase of the ankle plantar flexion movement were the double leg movements: DLDP and DLP.

**Table 5.4** ACC axes linear regression for ankle vibration in the 3 seconds *plateau* on 6$^{st}$ position SLP

| | | ACC X | | | | ACC Y | | | | ACC Z | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Group | Subjects | Mean | Sd | Slope | *r* | mean | Sd | Slope | *r* | Mean | sd | slope | *r* |
| Pais | 1 | -3,0749 | 0,0104 | 0,00001 | 0,60 | -2,7427 | 0,0037 | 0,00000 | 0,38 | -2,7490 | 0,0044 | 0,00000 | 0,66 |
| | 2 | -2,8149 | 0,0054 | 0,00000 | -0,65 | -2,7688 | 0,0028 | 0,00000 | 0,41 | -2,7494 | 0,0033 | 0,00000 | 0,80 |
| | 3 | -3,1174 | 0,0060 | 0,00000 | 0,65 | -2,7741 | 0,0045 | 0,00000 | 0,41 | -2,7250 | 0,0026 | 0,00000 | 0,38 |
| | 4 | -2,7862 | 0,0034 | 0,00000 | -0,53 | -2,7889 | 0,0019 | 0,00000 | 0,44 | -2,7448 | 0,0018 | 0,00000 | 0,43 |
| Control | 1 | -3,1432 | 0,0043 | 0,00000 | 0,63 | -2,8126 | 0,0049 | 0,00000 | 0,24 | -2,6915 | 0,0036 | 0,00000 | 0,39 |
| | 2 | -2,8027 | 0,0116 | -0,00001 | -0,66 | -2,7583 | 0,0080 | 0,00001 | 0,59 | -2,7982 | 0,0066 | 0,00000 | 0,55 |
| | 3 | -3,1347 | 0,0111 | 0,00000 | 0,37 | -2,7826 | 0,0119 | 0,00000 | 0,29 | -2,7292 | 0,0031 | 0,00000 | 0,40 |
| | 4 | -2,7680 | 0,0031 | 0,00000 | -0,77 | -2,8032 | 0,0021 | 0,00000 | 0,62 | -2,7491 | 0,0014 | 0,00000 | 0,64 |

Between groups, subjects from the PAIS group in general had shown less postural sway variation than controls while holding the ankle in maximum plantar flexion during the three seconds *plateau* for the four performed movements.

On the SLDP movement, all subjects from PAIS group had less postural sway than controls. For the DLP and SLP movements, three of the four subjects within the PAIS group

had shown less postural sway than controls, but for the DLDP movement, three subjects of the PAIS group, had greater postural sway, comparing to controls.

Since the presented values correspond to the average of the results obtained from the three trials per movement[4] that each subject performed, in some subjects, when comparing the trials results one by one, sometimes we found some discrepancies in one of three results, like in subject 2 from Control group, which can be attributed to a greater imbalance that happened only in performing that movement, this fact increased the presented average value.

**Table 6** Postural sway, 3 seconds *plateau*, mean COF travelled distance (mm)

| | | 3 seconds *plateau*, mean COG travelled distance (mm) | | | |
|---|---|---|---|---|---|
| Group | Subjects | DLDP | DLP | SLDP | SLP |
| Pais | 1 | 20,594 | 3,627 | 2,847 | 6,629 |
| | 2 | 26,291 | 72,741 | 1,672 | 4,289 |
| | 3 | 20,15 | 16,701 | 2,104 | 4,605 |
| | 4 | 26,647 | 2,373 | 1,822 | 2,790 |
| Control | 1 | 23,158 | 2,297 | 3,687 | 5,725 |
| | 2 | 27,974 | 96,628 | 3,111 | 7,785 |
| | 3 | 25,985 | 2,684 | 2,316 | 11,556 |
| | 4 | 14,211 | 29,249 | 4,664 | 3,485 |

COG, Center of Gravity; DLDP, Double Leg Demi-Pointe; DLP, Double Leg Pointe, SLDP, Single Leg Demi Pointe; SLP, Single Leg Pointe

Our second hypothesis was proved, by the existing differences found between PAIS group subjects and Control group subjects, with regard to postural sway assessed through the pressure plate.

## 3.4. Discussion

Considering our research goals that were to assess, explore and describe ankle kinetics regarding muscle activity firing sequences, ankle stability and postural sway, in pre-professional female ballet dancers with and without PAIS, given the differences between them, we observed some interesting findings.

A clear pattern was observed in muscle activity concerning the muscle firing sequence on three out of four subjects from PAIS group, while performing the DLDP

[4] Displayed on appendix 7

movement. This pattern may be explained through the fact that from all the performed movements, the DLDP movement is the most frequently performed within the dance context and according to the accelerometer data, was the one where the ankle proved to be more stiff, therefore, is more likely for a pattern to settle on a more rigid and repetitive movement than on a more flexible and less repetitive movement. Data also showed that the greater the flexibility observed in the ankle, more randomness was observed in the muscle activation firing sequence. According to previous studies, the muscle recruitment patterns reflect individually the dancer's motor strategy for performing movement (Batson, 2007; Wilson & Kwon, 2008). Those individual patterns often show variability between dancers performing the same action (Wilson & Kwon, 2008). Chatfield (2003), underlines the importance of understanding the dancer's performance patterns, once that even on a highly skilled dancer there aren't two performances exactly the same, for that he stated that the observation of multiple trials for the same individual over time, generates a more accurate information regarding the neuromuscular activity illustrating the irregularities and consistencies in movement performance. In our study, despite of each subject only have performed three trials per movement, a pattern was found in one of the movements, fact that we believe to demonstrate that there is evidence in the muscle recruitment activity for subjects with PAIS, that isn't observed in controls, which may be associated to injury and ankle stiffness.

Pointe shoes may also affect the way how muscles trigger their activation sequence, because they surely affect the way how ankle behaves in terms of flexibility, through the type of pointe shoe combined to the type of foot, once that pointe shoes are design to meet more aesthetic than functional requirements (Massó, 2004; Wilson & Kown, 2008; Shah, 2009). Some female ballet dancers reduce injury recurrence by changing the pointe shoes type, but no studies were found correlating pointe shoes and muscle activity being a theme for further research. Another strategy that ballet dancers may develop for minimizing the effects of posterior impingement by delaying the soft tissues or bony structures compression between the tibia and calcaneus, is to privilege ankle plantar flexion through the secondary movers muscles instead of the primary movers by changing the muscle activation onset. This can be achieved if the dancer uses the deep muscles of the lower leg, as opposed to the gastrocnemius muscles, when performing *en pointe* and *demi-pointe* positions, once these muscles act in the mid and forefoot due to their distal insertions (Abisseti et al., 2009). If the dancer performs *relevé* using the deep muscles of the lower leg, such as the *tibialis posterior* (TP), *flexor digitorum longus* (FDL), *flexor hallucis longus* (FHL) and the peroneals, the talus

may be shifted forward during plantar flexion of the ankle, delaying the impingement on the posterior tibia. If the gastrocnemius muscles, as opposed to the deep muscles, are used, the calcaneus is lifted and the soft tissues and/or bony structures located in the posterior ankle will be compressed between the tibia and the calcaneus (Ahonen, 2008; Abisseti et al., 2009).

The limitation in assessing the muscle activity from the deeper lower leg muscles does not allow us to draw an accurate profile of the muscle activation, enabling to differentiate between primary and secondary flexors and their firing sequences (Kennedy et al., 2007; Abisseti et al., 2009; Russel et al., 2010b).

The ankle stiffness traduced through the ankle directional vibration, observed in both groups revealed that the less flexible movements for the ankle were the ones performed in the *demi-pointe* position, DLDP and SLDP, Tables 5.1 and 5.3, respectively. The differences between groups were more evident in positions of greater stiffness, particularly at the SLP position, Table 5.4, which may indicate that for PAIS subjects, the stiffer the ankle position is more joint compression may be driven to the posterior ankle.

Another interesting finding was the differences found by comparing the results of the ankle vibration and postural sway in subjects performing the same movement. We found that the movement where subjects showed less vibration, DLDP, Table 5.1., was the movement where subjects from both groups also showed greater postural sway, Table 6.

This can be seen as a compensatory attempt for the ballet dancers to keep balance through the desired alignment within the dance technique, once locked the ankle joint, is likely to occur compensation mechanism on the upper segments of the body to keep the dance technique desired alignment revealing greater postural sway when the hip ROM or the postural control aren't effective for responding to ankle stiffness (Wilson & Kown, 2008; Krasnow et al., 2011).

The postural sway verified on the single leg movements, Table 6, shown much less variation of the COF than the double leg positions, and that variation also was lower for the PAIS group subjects in the SLDP position. These lower postural sway variations in the single leg movements may be explained by the fact that on these positions the body weight is shifted to the supporting ankle, allowing that the COF can stay more centered within the BOS.

This indicates that for the single leg movements the fact of PAIS subjects have lower COF variation through the ankle joint may increase the compression of the joint, especially in the SLDP position where all the PAIS group subjects showed the lowest scores of postural sway (Table 6).

### 3.4.1. Limitations

The major limitation of the research was the inability to collect data with surface EMG from the deeper muscles of the lower leg that play a fundamental role in the ankle and foot extreme plantar flexion mechanics.

Another limitation of the research was the small number of subjects which turns harder to identify patterns and also impossible to obtain representative outcomes from the studied parameters.

## 3.5. Conclusions

Within our study purpose that was to compare and describe ankle plantar flexion kinetics, ankle stiffness and postural sway in pre-professional female ballet dancers with and without PAIS, while performing full *pointe* and full *demi-pointe* movements, we concluded that the differences observed through the research outcomes between PAIS group subjects and Control group subjects, may indicated that probably there´s a biomechanical behavior which may create patterns that when undetectable lead to injury by overuse.

Through the obtained results we found that within the tested positions, PAIS is more likely to occur in the single leg demi-pointe SLDP position, once that at this position the ankle show less directional vibration after the DLDP position that was the stiffer position for the ankle in maximum plantar flexion, and where the COF is more centered within the BOS through the ankle joint, increasing the compression when the ankle is in full plantar flexion.

However these findings still need further investigation using a larger study sample to consider representative outcomes, and the inclusion of another variables also need to be investigated within this context, such as the dance training type, the foot morphology and functional anatomy, once that these variables have influence on muscle response, ankle stability and postural sway.

Biomechanical understanding of common ballet movements like *pointe* and *demi-pointe* among many others, are necessary for developing effective training strategies, as well for the prevention and treatment of injuries among dancers.

Dance has often been described as both an artistic and athletic pursuit and the biomechanical analysis applied to dance science, helps to identify elements of the dancer

physical skill, but also may contribute to an understanding of the artistry of dance, specifically, concerning deeper knowledge on the dancer's body in terms of mechanical motion and adaptation to the dance practice, which we believe to be the key for preventing injury and develop a skilled performance of movement.

### 3.5.1. Future Directions

Ankle stability and postural sway through multi-joint coordination is part of the dancer's daily struggle to accomplish the aesthetical and functional demands of a skilled performance movement. Recurrent Injury biomechanics correlating kinetics and movement coordination and balance, still need targeted investigation in fields such as the muscle activity concerning the muscular response to the dance training type.

Issues like muscle activity can be influenced through training and through technique, having a direct impact on coordination and balance, this may play an important role on injury prevention, especially to avoid fallen into overuse.

The relationship between foot intrinsic muscles and ankle plantar flexors, and the way how that interaction may affect ankle joint motion and stability in *en pointe* and *demi-pointe* movements, should be considered a theme of future research

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# Chapter 4

# Overall Discussion and Conclusion

## 4.1. Discussion

The dance medicine literature is still young and heterogeneous, limiting the ability to draw consistent conclusions specific to injury yet, the best available evidence agrees that the proper ankle plantar flexion mechanics, required in order to obtain aesthetical alignment, especially in female ballerinas, depends on functional aspects of motor control as well as favorable anatomic conditions. The importance of dance technique in the execution of a specific dance movement, must consider aspects such as dynamic alignment through multi-joint coordination under an effective motor control, in order to accomplish a skilled performance and keep the dancer injury free ((Kennedy et al., 2007; Batson, 2007; Hamilton, 2008; Abisseti et al., 2009). PAIS as a result of the abusive use of the extreme plantar flexion movement, may cause kinetic patterns responsible for the injury recurrence.

Those kinetic patterns may be cause or consequence or both, of undesirable or unskilled motor control that will be noted in the ballet dancer posture (Hamilton, 1990; Howse, 2004; Batson, 2007; Kennedy et al., 2007; Krasnow et al., 2011).

Female ballet dancers spend much of their time *en pointe* or *demi-pointe,* which are positions with a small base of support (BOS) by most standards. As a result, a high level of center-of-gravity (COG) training is required to provide a stable equilibrium in the kinetic chain (Bauman et al., 1996; Kennedy et al., 2007; Ahonen, 2008). In our experimental study [5], the postural sway measured in subjects with and without PAIS, through the centre of pressure (COF) travelled distance over the BOS, allowed us to observe that the single leg movements, shown much less variation of the COF than the double leg positions, and that variation was lower for the PAIS group subjects. This indicates that for the single leg movements PAIS subjects by having a lower COF variation through the ankle joint may increase the compression of the joint.

Returning to the motor control issue, when an injury occurs on the ankle, the proprioceptive retraining is one of the most important considerations in the rehabilitation, considering that mechanoreceptor reflexes in the joint are affected when injury occurs (Hertel, 2002). Normal reflex coordination of muscle tone in posture and movement may also become impaired when injury occurs to the joint capsule. This impairment may be retrained with exercises directed at working the different joints of the foot and ankle to allow for positional understanding and awareness for each joint (Hertel, 2002; Batson, 2007).

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Like evidence found in a rehabilitation protocol suggested by Abisseti and colleagues, (2009) the ability to overcome an unstable equilibrium is best achieved by dynamic functional exercises that consider bony alignment, neural input, endurance, strength, and technique requirements, once that muscle activity is the mean by which the motor control operates. Previous studies state that the muscle recruitment patterns reflect individually the dancer's motor strategy for performing movement (Batson, 2007; Wilson & Kwon, 2008), and the understanding of those patterns with their irregularities and consistencies, allows to feature the movement performance (Chatfield, 2003; Wilson & Kwon, 2008).

Abissetti et al., (2009) found that some ballet dancers reduce injury recurrence by using the deeper muscles of the lower leg, as opposed to the gastrocnemius muscles, when performing *en pointe* and *demi-pointe* positions, once these muscles have their action driven to the mid and forefoot due to their distal insertions (Abisseti et al., 2009). If the dancer performs *relevé* using the deep muscles of the lower leg, such as the *tibialis posterior* (TP), *flexor digitorum longus* (FDL), *flexor hallucis longus* (FHL) and the peroneals, the talus may be shifted forward during plantar flexion of the ankle, delaying the impingement on the posterior tibia. If the gastrocnemius muscles, as opposed to the deep muscles, are used, the calcaneus is lifted and the soft tissues and/or bony structures located in the posterior ankle will be compressed between the tibia and the calcaneus (Abisseti, 2009).

On our experimental protocol, we observed patterns in muscle activity concerning the muscle firing sequence on three out of four subjects from PAIS group, while performing the DLDP movement. This finding may support the fact that in PAIS the muscle activity is an important aspect of the injury mechanics and should be taken into account. However further investigation is needed to obtain representative results.

In what concerns to ankle stiffness here depicted through ankle joint vibration while standing in maximum plantar flexion, measured with the triaxial accelerometer, we found that PAIS group subjects revealed more stiffness on all the tested positions when compared to controls and within positions the ones where the ankle proven to be stiffer were the ones performed in *demi-pointe*, DLDP and SLDP. Interestingly and with regard to ankle impingement, we found by cross-checking the data from the accelerometer and the pressure plate, that the position where the ballet dancer is more at risk of PAIS, was the SLDP, once this position was where PAIS group subjects demonstrated less postural sway variation and less directional vibration on the accelerometer signal after the DLDP position, what may increase the compression of the posterior compartment of the ankle.

Unfortunately no studies were found within the dance context regarding ankle stiffness and accelerometry.

## 4.2. Conclusion

In light of the proposed objectives for this study, which were to feature PAIS Pathomechanics and to assess ankle joint kinetics in subjects with this type of injury while performing the two ballet movements most often associated to this injury, the outcomes allowed us to realize that PAIS, within the context of overuse injuries resulting from dance practice, once installed may develop kinetic patterns that will influence motion, limiting the ability of the dancer's for compensate from movement own imbalances in order to keep a proper dynamic alignment through multi-joint coordination when changing from one movement to another, resulting in the injury recurrence.

We have concluded that for our subjects the position where PAIS is more likely to develop, was the single leg *demi-pointe* SLDP, where the ankle show less directional vibration after the DLDP position that was the stiffer position for the ankle in maximum plantar flexion, and where the COF is more centered into the BOS through the ankle joint, increasing the compression when the ankle is in full plantar flexion.

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# Glossary

## The Classical Ballet Positions

The technique of ballet is based on the five positions of the feet from which the steps and movements of ballet start, finish or pass through (Micheli, Gillespie and Walaszek, 1984). These five basic positions are characterized by turnout from the hips (Micheli, Gillespie and Walaszek, 1984).

## First position

The hips are externally rotated and adducted with the heels in contact with each other. The knees are aligned over the feet (Gilbert, Gross and Klug, 1998).

## Second position

This position is similar to first position except that the heels are a pelvis-width apart due to hip abduction (Gilbert, Gross and Klug, 1998).

## Third position

This position the thigh and legs contact each other. The hips are externally rotated and adducted. The knees are aligned over the feet. The heel of the front foot lies in front of the middle of the longitudinal arch of the back foot (Gilbert, Gross and Klug, 1998).

## Fourth position

The hips are externally rotated and adducted, with the knees aligned over the feet. There is flexion at the hip joint of the forward leg and extension at the hip joint of the back leg thus allowing the feet to be apart. The front legs heel lies directly in front of the first metatarsal head of the back foot, while the heel of the back leg is directly behind the front legs fifth metatarsal (Gilbert, Gross and Klug, 1998).

## Fifth position

This is exactly the same as fourth position excepting that the thighs and legs are in contact (Gilbert, Gross and Klug, 1998).

**Sixth position**

Feet and legs stand in parallel (Gilbert, Gross and Klug, 1998).

**Demi-pointe**

To balance on the plantar aspect of the toes with a fully flexed metacarpophalangeal joint (Micheli, Gillespie, Walaszek, 1984).

**En pointe**

The position of the foot in the pointe shoe, in which the heel is raised, the ankle and midfoot are fully plantar flexed and the dancer stands on top of her toes, principally the first and second digits (Khan et al., 1995).~

**Plié**

The movement whereby the dancer slowly bends the knees in line with the fully turned out feet (Khan et al., 1995).

**Relévé**

Rising movement of the body that starts from a demiplie, and requires a slight snatch so that it is more dynamic than a rise (Khan et al., 1995).

**Rolling**

A term used to describe the ankle when the foot is flat on the floor. The technical fault seen is excessive pronation resulting from forcing turnout (Khan et al., 1995).

**Sickling**

The term used to describe the ankle when the dancer is in the demi-pointe or en pointe position. Sickling in refers to when excess bodyweight is taken on the lateral portion of the foot. Sickling out is when excess body weight is taken on the medial portion of the foot (Khan et al., 1995).

# Appendix

# Appendix 1: Informed Consent

UNIVERSIDADE LUSÓFONA
I Faculdade de Educação Física e Desporto

Exmº. Sr./Sra.
Encarregado de Educação/Pai/Mãe

A Faculdade de Educação Física e Desporto/Centro de Estudos de Exercício e Saúde da Universidade Lusófona de Humanidades e Tecnologias, vem por este meio solicitar que V. Exa. se digne autorizar a recolha de dados do seu educando/filho(a), referentes a avaliação biomecânica da articulação do tornozelo com o objectivo de contribuir para a caracterização da lesão: *Síndrome do Conflito Posterior do Tornozelo*. Este projecto está a ser desenvolvido no âmbito do Mestrado em Exercício e Saúde, da Faculdade de Educação Física e Desporto, da Universidade Lusófona de Humanidades e Tecnologias. Qualquer informação adicional deverá ser solicitada para o telefone nº 965053523.

Agradecendo desde já a colaboração

Dra. Raquel Barreto Madeira
(Professora auxiliar convidada da Faculdade de Educação Física e Desporto, ULHT)

Lisboa, 23 de Novembro de 2010

Av. do Campo Grande, 376
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Telefone. 21 751 55 00
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email: informacoes@ ulusofona.pt
www.ulusofona.pt

# Termo de Autorização

Eu, _____ Encarregado de Educação de _____ autorizo que o(a) meu(minha) filho (a)/educando(a) realize testes para a avaliação biomecânica da articulação do tornozelo.

Fui informado que dos resultados apurados me seria fornecido um relatório individualizado.

Autorizo que os dados sejam utilizados exclusivamente para fins científicos e pedagógicos, omitindo-se, em qualquer circunstância, a identificação do(a) meu(minha) educando(a).

Lisboa,___ de ___ de 2010

_____

UNIVERSIDADE LUSÓFONA
I Faculdade de Educação Física e Desporto

Exmº. Sr.
Director do Conselho Executivo
Da Escola de Dança do Conservatório Nacional
Rua João Pereira da Rosa
Lisboa

A Faculdade de Educação Física e Desporto/Centro de Estudos de Exercício e Saúde da Universidade Lusófona de Humanidades e Tecnologias, vem por este meio solicitar que V. Exa. se digne autorizar a recolha de dados dos alunos desse estabelecimento de ensino, referentes a avaliação biomecânica do tornozelo, com o objectivo de contribuir para a caracterização da lesão: *Síndrome do Conflito Posterior do Tornozelo*. Este projecto está a ser desenvolvido no âmbito do Mestrado em Exercício e Saúde, da Faculdade de Educação Física e Desporto, da Universidade Lusófona de Humanidades e Tecnologias. Qualquer informação adicional deverá ser solicitada para o telefone nº 965053523.

Sem mais nenhum assunto de momento e agradecendo desde já a atenção dispensada, aguarda-se deferimento,

Dra. Raquel Barreto Madeira

Lisboa, 23 de Novembro de 2010

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# Appendix 2: Lab ID Sheet

**Name** _____ **Subject ____**
**Age** ____ **Weight** _____ Kg **Height** _____ cm

**Dominant Leg** ☐ left ☐ right

**Assessed Leg** ☐ left ☐ right

***PAIS ankle** ☐ left ☐ right
*(only subjects with injury)

**Group**
***PAIS** ☐
**Control** ☐

Electrogoniometer calibration

| Plantar Flexion (PF) | Inversion (Inv) |
|---|---|
| *x* _____mv *y* _____ º<br>*x* _____mv *y* _____ º | *x* _____mv *y* _____ º<br>x _____mv *y* _____ º |

**Trials per movement reference check list**

| **DLDP (*1st position*)** | **DLP (*1st position*)** | **SLDP (*6st position*)** | **SLP (*6st position*)** |
|---|---|---|---|
| ☐ DLDP_1 | ☐ DLP_1 | ☐ SLDP_1 | ☐ SLP_1 |
| ☐ DLDP_2 | ☐ DLP_2 | ☐ SLDP_2 | ☐ SLP_2 |
| ☐ DLDP_3 | ☐ DLP_3 | ☐ SLDP_3 | ☐ SLP_3 |

**Date __/__/____**

# Appendix 3: Subject´s Features

Data set from PAIS dancers group

| Subject | Age | H(cm) | W(Kg) | Dance practice (yrs) | Pointe shoes practice (yrs) | Dance level attendance | Classical ballet average grade | Dynamic dominant leg | Ankle with PAIS | Dance hours/week |
|---|---|---|---|---|---|---|---|---|---|---|
| Marya Y. | 16 | 177,5 | 59 | 9 | 7 | Advanced | 4 | Right | Left | 20 |
| Raquel F. | 16 | 157,5 | 54,5 | 9 | 7 | Advanced | 3 | Right | Right | 20 |
| Marta P. | 14 | 166,5 | 49 | 7 | 4 | Intermediate | 4 | Right | Left | 9,5 |
| Joana G. | 22 | 160,5 | 46,5 | 6 | 7 | Advanced | 3 | Right | Right | 20 |

Data set from control group

| Subject | Age | H(cm) | W(Kg) | Dance practice (yrs) | Pointe shoes practice (yrs) | Dance level attendance | Classical ballet average grade | Dynamic dominant leg | Dance hours/week |
|---|---|---|---|---|---|---|---|---|---|
| Catarina C. | 18 | 177 | 61 | 8 | 8 | Advanced | 4 | Right | 21 |
| Cátia L. | 18 | 154 | 49 | 9 | 8 | Advanced | 3 | Right | 21 |
| Maria M. | 13 | 168 | 48,5 | 5 | 3 | Intermediate | 3 | Right | 8,5 |
| Inês P. | 18 | 163 | 51 | 10 | 8 | Advanced | 4 | Right | 21 |

# Appendix 4: GON 1 movement times

**Table A.1.1** GON 1, 1st position DLDP movement times (ms)

| Group | Subject | Trial | GON 1 | | |
|---|---|---|---|---|---|
| | | | Start | End | diff |
| PAIS | 1 | 1 | 1332 | 3036 | 1704 |
| | | 2 | 1652 | 3431 | 1779 |
| | | 3 | 1596 | 3261 | 1665 |
| | | mean | 1527 | 3243 | 1716 |
| | 2 | 1 | 1578 | 3243 | 1665 |
| | | 2 | 1256 | 3438 | 2182 |
| | | 3 | 1363 | 3392 | 2029 |
| | | mean | 1399 | 3358 | 1959 |
| | 3 | 1 | 1934 | 2833 | 899 |
| | | 2 | 1624 | 2389 | 765 |
| | | 3 | 1709 | 2762 | 1053 |
| | | mean | 1756 | 2661 | 906 |
| | 4 | 1 | 2877 | 4963 | 2086 |
| | | 2 | 2764 | 4256 | 1492 |
| | | 3 | 1549 | 3577 | 2028 |
| | | mean | 2397 | 4265 | 1869 |
| CONTROL | 1 | 1 | 2659 | 5128 | 2469 |
| | | 2 | 2428 | 4131 | 1703 |
| | | 3 | 1967 | 4206 | 2239 |
| | | mean | 2351 | 4488 | 2137 |
| | 2 | 1 | 1638 | 2753 | 1115 |
| | | 2 | 1325 | 2785 | 1460 |
| | | 3 | 1613 | 2778 | 1165 |
| | | mean | 1525 | 2772 | 1247 |
| | 3 | 1 | 1363 | 2478 | 1115 |
| | | 2 | 858 | 2063 | 1205 |
| | | 3 | 1068 | 2216 | 1148 |
| | | mean | 1096 | 2252 | 1156 |
| | 4 | 1 | 2077 | 3389 | 1312 |
| | | 2 | 1678 | 3100 | 1422 |
| | | 3 | 2151 | 3127 | 976 |
| | | mean | 1969 | 3205 | 1237 |

**Table A.1.2** GON 1, 1st position DLP movement times (ms)

| Group | Subject | Trial | GON 1 | | |
|---|---|---|---|---|---|
| | | | Start | End | diff |
| PAIS | 1 | 1 | 1445 | 3091 | 1646 |
| | | 2 | 1478 | 2856 | 1378 |
| | | 3 | 1135 | 2456 | 1321 |
| | | mean | 1353 | 2801 | 1448 |
| | 2 | 1 | 1972 | 3713 | 1741 |
| | | 2 | 2003 | 3687 | 1684 |
| | | 3 | 958 | 2699 | 1741 |
| | | mean | 1644 | 3366 | 1722 |
| | 3 | 1 | 1756 | 2751 | 995 |
| | | 2 | 1525 | 2272 | 747 |
| | | 3 | 1647 | 2298 | 651 |
| | | mean | 1643 | 2440 | 798 |
| | 4 | 1 | 1080 | 4696 | 3616 |
| | | 2 | 1772 | 3648 | 1876 |
| | | 3 | 1521 | 2879 | 1358 |
| | | mean | 1458 | 3741 | 2283 |
| CONTROL | 1 | 1 | 1631 | 3009 | 1378 |
| | | 2 | 1861 | 2970 | 1109 |
| | | 3 | 2023 | 3269 | 1246 |
| | | mean | 1838 | 3083 | 1244 |
| | 2 | 1 | 1384 | 2155 | 771 |
| | | 2 | 1329 | 1985 | 656 |
| | | 3 | 1201 | 1910 | 709 |
| | | mean | 1305 | 2017 | 712 |
| | 3 | 1 | 1141 | 2194 | 1053 |
| | | 2 | 827 | 2123 | 1296 |
| | | 3 | 1307 | 2475 | 1168 |
| | | mean | 1092 | 2264 | 1172 |
| | 4 | 1 | 1826 | 2909 | 1083 |
| | | 2 | 1469 | 2667 | 1198 |
| | | 3 | 1247 | 2472 | 1225 |
| | | mean | 1514 | 2683 | 1169 |

**Table A.1.3** GON 1, 6st position SLDP movement times (ms)

| Group | Subject | Trial | GON 1 | | |
|---|---|---|---|---|---|
| | | | Start | End | diff |
| PAIS | 1 | 1 | 1622 | 2942 | 1320 |
| | | 2 | 1468 | 3018 | 1550 |
| | | 3 | 1882 | 3240 | 1358 |
| | | mean | 1657 | 3067 | 1409 |
| | 2 | 1 | 2050 | 3811 | 1761 |
| | | 2 | 1484 | 3072 | 1588 |
| | | 3 | 2117 | 3626 | 1509 |
| | | mean | 1884 | 3503 | 1619 |
| | 3 | 1 | 1668 | 2988 | 1320 |
| | | 2 | 2022 | 3324 | 1302 |
| | | 3 | 1799 | 2947 | 1148 |
| | | mean | 1830 | 3086 | 1257 |
| | 4 | 1 | 2530 | 4865 | 2335 |
| | | 2 | 2616 | 3688 | 1072 |
| | | 3 | 1865 | 3167 | 1302 |
| | | mean | 2337 | 3907 | 1570 |
| CONTROL | 1 | 1 | 1712 | 3760 | 2048 |
| | | 2 | 1836 | 3591 | 1755 |
| | | 3 | 1966 | 3622 | 1656 |
| | | mean | 1838 | 3658 | 1820 |
| | 2 | 1 | 1703 | 2671 | 968 |
| | | 2 | 1341 | 2292 | 951 |
| | | 3 | 1365 | 2234 | 869 |
| | | mean | 1470 | 2399 | 929 |
| | 3 | 1 | 411 | 1712 | 1301 |
| | | 2 | 1407 | 2403 | 996 |
| | | 3 | 1150 | 2374 | 1224 |
| | | mean | 989 | 2163 | 1174 |
| | 4 | 1 | 2065 | 2888 | 823 |
| | | 2 | 1696 | 2730 | 1034 |
| | | 3 | 1687 | 2701 | 1014 |
| | | mean | 1816 | 2773 | 957 |

**Table A.1.4** GON 1, 6st position SLP movement times (ms)

| Group | Subject | Trial | GON 1 | | |
|---|---|---|---|---|---|
| | | | Start | End | diff |
| PAIS | 1 | 1 | 1082 | 2077 | 995 |
| | | 2 | 1891 | 3287 | 1396 |
| | | 3 | 1341 | 2470 | 1129 |
| | | mean | 1438 | 2611 | 1173 |
| | 2 | 1 | 1727 | 3545 | 1818 |
| | | 2 | 2633 | 3792 | 1159 |
| | | 3 | 2227 | 3433 | 1206 |
| | | mean | 2196 | 3590 | 1394 |
| | 3 | 1 | 1471 | 2179 | 708 |
| | | 2 | 1722 | 2487 | 765 |
| | | 3 | 1669 | 2530 | 861 |
| | | mean | 1621 | 2399 | 778 |
| | 4 | 1 | 1747 | 2781 | 1034 |
| | | 2 | 2636 | 3784 | 1148 |
| | | 3 | 2229 | 3990 | 1761 |
| | | mean | 2204 | 3518 | 1314 |
| CONTROL | 1 | 1 | 1674 | 2478 | 804 |
| | | 2 | 1844 | 2782 | 938 |
| | | 3 | 1719 | 2676 | 957 |
| | | mean | 1746 | 2645 | 900 |
| | 2 | 1 | 1674 | 2248 | 574 |
| | | 2 | 1308 | 1863 | 555 |
| | | 3 | 1242 | 1799 | 557 |
| | | mean | 1408 | 1970 | 562 |
| | 3 | 1 | 1255 | 1848 | 593 |
| | | 2 | 1534 | 2299 | 765 |
| | | 3 | 1358 | 2046 | 688 |
| | | mean | 1382 | 2064 | 682 |
| | 4 | 1 | 1522 | 2517 | 995 |
| | | 2 | 1582 | 2583 | 1001 |
| | | 3 | 1291 | 2075 | 784 |
| | | mean | 1465 | 2392 | 927 |

# Appendix 5: Muscle activity onsets considering GON 1 start time

**Table A.2.1** 1st position DLDP movement, muscle onset time (ms)

| Group | Subject | Trial | EMG1 | EMG2 | EMG3 | EMG4 | GON 1 start time |
|---|---|---|---|---|---|---|---|
| PAIS | 1 | 1 | 990 | 982 | 1356 | 988 | 1332 |
| | | 2 | 1364 | 1280 | 1608 | 1300 | 1652 |
| | | 3 | 1333 | 1221 | 1318 | 1299 | 1596 |
| | | mean | 1229 | 1161 | 1427 | 1196 | 1527 |
| | 2 | 1 | 1802 | 1501 | 1607 | 1444 | 1578 |
| | | 2 | 1388 | 1256 | 1409 | 1198 | 1256 |
| | | 3 | 1685 | 1475 | 1702 | 1427 | 1363 |
| | | mean | 1625 | 1411 | 1573 | 1356 | 1399 |
| | 3 | 1 | 1720 | 1585 | 1745 | 1659 | 1934 |
| | | 2 | 1432 | 1343 | 1442 | 1443 | 1624 |
| | | 3 | 1460 | 1470 | 1535 | 1461 | 1709 |
| | | mean | 1537 | 1466 | 1574 | 1521 | 1756 |
| | 4 | 1 | 2762 | 2449 | 2820 | 2686 | 2877 |
| | | 2 | 2624 | 2572 | 2715 | 2630 | 2764 |
| | | 3 | 2112 | 2090 | 2211 | 2144 | 1549 |
| | | mean | 2499 | 2370 | 2582 | 2487 | 2397 |
| CONTROL | 1 | 1 | 2193 | 2059 | 2714 | 2774 | 2659 |
| | | 2 | 2312 | 2079 | 2230 | 2330 | 2428 |
| | | 3 | 1573 | 1718 | 1756 | 1661 | 1967 |
| | | mean | 2026 | 1952 | 2233 | 2255 | 2351 |
| | 2 | 1 | 1452 | 1375 | 1439 | 1416 | 1638 |
| | | 2 | 920 | 1100 | 1151 | 1233 | 1325 |
| | | 3 | 1433 | 1449 | 1454 | 1491 | 1613 |
| | | mean | 1268 | 1308 | 1348 | 1380 | 1525 |
| | 3 | 1 | 1204 | 1208 | 1242 | 1272 | 1363 |
| | | 2 | 774 | 758 | 755 | 804 | 858 |
| | | 3 | 868 | 956 | 897 | 947 | 1068 |
| | | mean | 949 | 974 | 965 | 1008 | 1096 |
| | 4 | 1 | 2074 | 1748 | 1808 | 2096 | 2077 |
| | | 2 | 1490 | 1361 | 1685 | 1579 | 1678 |
| | | 3 | 1967 | 1798 | 2074 | 1994 | 2151 |
| | | mean | 1844 | 1636 | 1856 | 1890 | 1969 |

**Table A.2.2** 1st position DLP movement, muscle onset time (ms)

| Group | Subject | Trial | EMG1 | EMG2 | EMG3 | EMG4 | GON 1 start time |
|---|---|---|---|---|---|---|---|
| PAIS | 1 | 1 | 1057 | 977 | 1106 | 1041 | 1445 |
| | | 2 | 1047 | 1069 | 1283 | 1124 | 1478 |
| | | 3 | 791 | 848 | 951 | 753 | 1135 |
| | | mean | 965 | 965 | 1113 | 973 | 1353 |
| | 2 | 1 | 1631 | 1661 | 1736 | 1608 | 1972 |
| | | 2 | 1872 | 1853 | 2115 | 1939 | 2003 |
| | | 3 | 1579 | 1445 | 1598 | 1483 | 958 |
| | | mean | 1694 | 1653 | 1816 | 1677 | 1644 |
| | 3 | 1 | 1668 | 1649 | 1718 | 1792 | 1756 |
| | | 2 | 1295 | 1262 | 1321 | 1383 | 1525 |
| | | 3 | 1469 | 1453 | 1513 | 1474 | 1647 |
| | | mean | 1477 | 1455 | 1517 | 1550 | 1643 |
| | 4 | 1 | 1401 | 1323 | 1382 | 1458 | 1080 |
| | | 2 | 1596 | 1581 | 1593 | 1616 | 1772 |
| | | 3 | 1507 | 1359 | 1474 | 1502 | 1521 |
| | | mean | 1501 | 1421 | 1483 | 1525 | 1458 |
| CONTROL | 1 | 1 | 631 | 993 | 1026 | 673 | 1631 |
| | | 2 | 1229 | 1537 | 1790 | 1728 | 1861 |
| | | 3 | 1392 | 1729 | 1739 | 1462 | 2023 |
| | | mean | 1084 | 1420 | 1518 | 1288 | 1838 |
| | 2 | 1 | 1014 | 929 | 946 | 1010 | 1384 |
| | | 2 | 1489 | 1521 | 1540 | 1546 | 1329 |
| | | 3 | 607 | 540 | 488 | 553 | 1201 |
| | | mean | 1037 | 997 | 991 | 1036 | 1305 |
| | 3 | 1 | 135 | 273 | 229 | 230 | 1141 |
| | | 2 | 854 | 1100 | 1068 | 1079 | 827 |
| | | 3 | 1188 | 1528 | 1323 | 1328 | 1307 |
| | | mean | 726 | 967 | 873 | 879 | 1092 |
| | 4 | 1 | 1509 | 1321 | 1606 | 1550 | 1826 |
| | | 2 | 1247 | 1047 | 1211 | 1326 | 1469 |
| | | 3 | 1159 | 985 | 1169 | 1249 | 1247 |
| | | mean | 1305 | 1118 | 1329 | 1375 | 1514 |

**Table A.2.3** 6st position SLDP movement, muscle onset time (ms)

| Group | Subject | Trial | EMG1 | EMG2 | EMG3 | EMG4 | GON 1 start time |
|---|---|---|---|---|---|---|---|
| PAIS | 1 | 1 | 1502 | 1483 | 1388 | 1483 | 1622 |
| | | 2 | 1268 | 1230 | 1421 | 1325 | 1468 |
| | | 3 | 1671 | 274 | 1827 | 1824 | 1882 |
| | | mean | 1480 | 996 | 1545 | 1544 | 1657 |
| | 2 | 1 | 1921 | 1830 | 2092 | 1598 | 2050 |
| | | 2 | 1354 | 1349 | 1434 | 1295 | 1484 |
| | | 3 | 1448 | 1364 | 1418 | 1198 | 2117 |
| | | mean | 1574 | 1514 | 1648 | 1364 | 1884 |
| | 3 | 1 | 1408 | 1157 | 1316 | 1240 | 1668 |
| | | 2 | 1951 | 1602 | 1812 | 1993 | 2022 |
| | | 3 | 1646 | 1398 | 1447 | 1440 | 1799 |
| | | mean | 1668 | 1386 | 1525 | 1558 | 1830 |
| | 4 | 1 | 1012 | 2069 | 2094 | 1080 | 2530 |
| | | 2 | 2538 | 2538 | 2557 | 2079 | 2616 |
| | | 3 | 1875 | 1520 | 1644 | 1843 | 1865 |
| | | mean | 1808 | 2042 | 2098 | 1667 | 2337 |
| CONTROL | 1 | 1 | 2028 | 1810 | 1926 | 1990 | 1712 |
| | | 2 | 1256 | 1336 | 1407 | 1309 | 1836 |
| | | 3 | 1498 | 1888 | 1662 | 1576 | 1966 |
| | | mean | 1594 | 1678 | 1665 | 1625 | 1838 |
| | 2 | 1 | 1681 | 1270 | 1544 | 1567 | 1703 |
| | | 2 | 722 | 509 | 663 | 775 | 1341 |
| | | 3 | 1549 | 1608 | 1626 | 1540 | 1365 |
| | | mean | 1317 | 1129 | 1278 | 1294 | 1470 |
| | 3 | 1 | 1057 | 1009 | 1029 | 1010 | 411 |
| | | 2 | 1015 | 1191 | 1154 | 1114 | 1407 |
| | | 3 | 1052 | 1023 | 1051 | 1026 | 1150 |
| | | mean | 1041 | 1074 | 1078 | 1050 | 989 |
| | 4 | 1 | 1976 | 1919 | 1938 | 2036 | 2065 |
| | | 2 | 1404 | 1495 | 1436 | 1523 | 1696 |
| | | 3 | 1343 | 1346 | 1324 | 1286 | 1687 |
| | | mean | 1574 | 1587 | 1566 | 1615 | 1816 |

**Table A.2.4** 1st position SLP movement, muscle onset time (ms)

| Group | Subject | Trial | EMG1 | EMG2 | EMG3 | EMG4 | GON 1 start time |
|---|---|---|---|---|---|---|---|
| PAIS | 1 | 1 | 833 | 2736 | 19 | 2870 | 1082 |
| | | 2 | 1470 | 1606 | 1604 | 1819 | 1891 |
| | | 3 | 1226 | 1073 | 1130 | 1168 | 1341 |
| | | mean | 899 | 893 | 911 | 996 | 1438 |
| | 2 | 1 | 1019 | 1233 | 1477 | 1282 | 1727 |
| | | 2 | 1923 | 1714 | 2075 | 2071 | 2633 |
| | | 3 | 1940 | 1921 | 1883 | 1825 | 2227 |
| | | mean | 1627 | 1623 | 1812 | 1726 | 2196 |
| | 3 | 1 | 1361 | 973 | 1123 | 1524 | 1471 |
| | | 2 | 1743 | 1224 | 1335 | 1726 | 1722 |
| | | 3 | 1305 | 1382 | 1475 | 1286 | 1669 |
| | | mean | 1470 | 1193 | 1311 | 1512 | 1621 |
| | 4 | 1 | 1284 | 1250 | 1319 | 1457 | 1747 |
| | | 2 | 2042 | 1407 | 2368 | 2371 | 2636 |
| | | 3 | 1662 | 1392 | 1596 | 1992 | 2229 |
| | | mean | 1663 | 1350 | 1761 | 1940 | 2204 |
| CONTROL | 1 | 1 | 280 | 1379 | 1395 | 359 | 1674 |
| | | 2 | 1481 | 1607 | 1629 | 1500 | 1844 |
| | | 3 | 1458 | 1471 | 1457 | 1375 | 1719 |
| | | mean | 1073 | 1486 | 1494 | 1078 | 1746 |
| | 2 | 1 | 1561 | 1370 | 1297 | 1502 | 1674 |
| | | 2 | 1195 | 1199 | 1125 | 1198 | 1308 |
| | | 3 | 1118 | 1064 | 1005 | 1066 | 1242 |
| | | mean | 1291 | 1211 | 1142 | 1255 | 1408 |
| | 3 | 1 | 834 | 1157 | 965 | 976 | 1255 |
| | | 2 | 1203 | 1177 | 1152 | 1199 | 1534 |
| | | 3 | 1051 | 1248 | 1206 | 1147 | 1358 |
| | | mean | 1029 | 1194 | 1108 | 1107 | 1382 |
| | 4 | 1 | 1350 | 1082 | 924 | 1385 | 1522 |
| | | 2 | 1465 | 1140 | 1155 | 1467 | 1582 |
| | | 3 | 1044 | 985 | 946 | 1049 | 1291 |
| | | mean | 1286 | 1069 | 1008 | 1300 | 1465 |

# Appendix 6: Ankle stability through ACC axes linear regression

**Table A.3.2** 1st position DLDP, ACC three seconds *plateau* stability (linear regression)

| Subject (Group) | Trial | ACC X | | | | ACC Y | | | | ACC Z | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mean | sd | slope | *r* | mean | sd | slope | *r* | mean | sd | slope | *r* |
| 1 (PAIS) | 1 | -3,1428 | 0,0012 | 0,00000 | 0,91 | -2,7536 | 0,0007 | 0,00000 | 0,74 | -2,8256 | 0,0016 | 0,00000 | 0,39 |
| | 2 | -3,1467 | 0,0010 | 0,00000 | -0,38 | -2,7558 | 0,0010 | 0,00000 | -0,49 | -2,8271 | 0,0023 | 0,00000 | 0,83 |
| | 3 | -3,1448 | 0,0017 | 0,00000 | -0,48 | -2,7544 | 0,0019 | 0,00000 | -0,40 | -2,8268 | 0,0020 | 0,00000 | 0,81 |
| | mean | -3,1448 | 0,0013 | 0,00000 | 0,02 | -2,7546 | 0,0012 | 0,00000 | -0,05 | -2,8265 | 0,0020 | 0,00000 | 0,68 |
| 2 (PAIS) | 1 | -2,8409 | 0,0014 | 0,00000 | -0,58 | -2,7370 | 0,0010 | 0,00000 | 0,32 | -2,8042 | 0,0016 | 0,00000 | 0,52 |
| | 2 | -2,8456 | 0,0018 | 0,00000 | -0,16 | -2,7361 | 0,0013 | 0,00000 | 0,50 | -2,7994 | 0,0024 | 0,00000 | -0,79 |
| | 3 | -2,8478 | 0,0017 | 0,00000 | -0,75 | -2,7360 | 0,0007 | 0,00000 | 0,72 | -2,7956 | 0,0015 | 0,00000 | 0,40 |
| | mean | -2,8448 | 0,0016 | 0,00000 | -0,50 | -2,7363 | 0,0010 | 0,00000 | 0,51 | -2,7997 | 0,0018 | 0,00000 | 0,04 |
| 3 (PAIS) | 1 | -3,1119 | 0,0009 | 0,00000 | 0,70 | -2,7463 | 0,0011 | 0,00000 | -0,17 | -2,7841 | 0,0025 | 0,00000 | 0,84 |
| | 2 | -3,1137 | 0,0019 | 0,00000 | 0,89 | -2,7475 | 0,0010 | 0,00000 | 0,65 | -2,7825 | 0,0018 | 0,00000 | 0,50 |
| | 3 | -3,1144 | 0,0013 | 0,00000 | -0,06 | -2,7461 | 0,0012 | 0,00000 | -0,41 | -2,7887 | 0,0024 | 0,00000 | 0,90 |
| | mean | -3,1133 | 0,0014 | 0,00000 | 0,51 | -2,7466 | 0,0011 | 0,00000 | 0,02 | -2,7851 | 0,0022 | 0,00000 | 0,75 |
| 4 (PAIS) | 1 | -2,8732 | 0,0020 | 0,00000 | 0,17 | -2,7328 | 0,0016 | 0,00000 | -0,46 | -2,7700 | 0,0029 | 0,00000 | 0,70 |
| | 2 | -2,8799 | 0,0050 | -0,00001 | -0,98 | -2,7358 | 0,0028 | 0,00000 | 0,79 | -2,7556 | 0,0047 | 0,00000 | -0,39 |
| | 3 | -2,8812 | 0,0034 | 0,00000 | -0,65 | -2,7359 | 0,0023 | 0,00000 | 0,39 | -2,7540 | 0,0033 | 0,00000 | -0,23 |
| | mean | -2,8781 | 0,0035 | 0,00000 | -0,49 | -2,7348 | 0,0022 | 0,00000 | 0,24 | -2,7599 | 0,0036 | 0,00000 | 0,03 |
| 1 (Control) | 1 | -3,0904 | 0,0018 | 0,00000 | 0,95 | -2,7475 | 0,0009 | 0,00000 | -0,06 | -2,7514 | 0,0024 | 0,00000 | 0,78 |
| | 2 | -3,0884 | 0,0018 | 0,00000 | -0,36 | -2,7534 | 0,0048 | -0,00001 | -0,81 | -2,7369 | 0,0087 | 0,00001 | 0,89 |
| | 3 | -3,0857 | 0,0021 | 0,00000 | 0,02 | -2,7494 | 0,0029 | 0,00000 | -0,64 | -2,7427 | 0,0051 | 0,00001 | 0,86 |
| | mean | -3,0882 | 0,0019 | 0,00000 | 0,20 | -2,7501 | 0,0029 | 0,00000 | -0,50 | -2,7437 | 0,0054 | 0,00001 | 0,85 |
| 2 (Control) | 1 | -2,8354 | 0,0037 | 0,00000 | -0,79 | -2,7360 | 0,0022 | 0,00000 | 0,66 | -2,8214 | 0,0016 | 0,00000 | 0,29 |
| | 2 | -2,8246 | 0,0042 | 0,00000 | -0,73 | -2,7402 | 0,0024 | 0,00000 | 0,66 | -2,8267 | 0,0022 | 0,00000 | 0,94 |
| | 3 | -2,8232 | 0,0027 | 0,00000 | -0,72 | -2,7411 | 0,0015 | 0,00000 | 0,63 | -2,8249 | 0,0009 | 0,00000 | 0,08 |
| | mean | -2,8277 | 0,0035 | 0,00000 | -0,75 | -2,7391 | 0,0020 | 0,00000 | 0,65 | -2,8243 | 0,0015 | 0,00000 | 0,43 |
| 3 (Control) | 1 | -3,0748 | 0,0020 | 0,00000 | 0,50 | -2,7353 | 0,0013 | 0,00000 | 0,94 | -2,7678 | 0,0029 | 0,00000 | -0,81 |
| | 2 | -3,0804 | 0,0016 | 0,00000 | 0,04 | -2,7358 | 0,0011 | 0,00000 | 0,33 | -2,7731 | 0,0018 | 0,00000 | -0,09 |
| | 3 | -3,0789 | 0,0044 | 0,00001 | 0,95 | -2,7355 | 0,0021 | 0,00000 | 0,87 | -2,7711 | 0,0014 | 0,00000 | -0,44 |
| | mean | -3,0781 | 0,0027 | 0,00000 | 0,50 | -2,7356 | 0,0015 | 0,00000 | 0,71 | -2,7707 | 0,0020 | 0,00000 | -0,45 |
| 4 (Control) | 1 | -2,8237 | 0,0016 | 0,00000 | -0,30 | -2,7533 | 0,0014 | 0,00000 | -0,05 | -2,7728 | 0,0013 | 0,00000 | 0,77 |
| | 2 | -2,8222 | 0,0012 | 0,00000 | -0,81 | -2,7546 | 0,0010 | 0,00000 | 0,81 | -2,7717 | 0,0009 | 0,00000 | -0,49 |
| | 3 | -2,8192 | 0,0010 | 0,00000 | -0,03 | -2,7560 | 0,0007 | 0,00000 | 0,17 | -2,7723 | 0,0015 | 0,00000 | 0,20 |
| | mean | -2,8217 | 0,0013 | 0,00000 | -0,38 | -2,7546 | 0,0010 | 0,00000 | 0,31 | -2,7723 | 0,0012 | 0,00000 | 0,16 |

**Table A.3.2** 1st position DLP, ACC three seconds *plateau* stability (linear regression)

| Subject (Group) | Trial | ACC X | | | | ACC Y | | | | ACC Z | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mean | sd | slope | *r* | mean | sd | slope | *r* | mean | sd | slope | *r* |
| 1 (PAIS) | 1 | -3,0479 | 0,0019 | 0,00000 | 0,96 | -2,7185 | 0,0003 | 0,00000 | -0,53 | -2,7999 | 0,0033 | 0,00000 | 0,97 |
| | 2 | -3,0436 | 0,0052 | 0,00001 | 0,89 | -2,7170 | 0,0010 | 0,00000 | 0,47 | -2,8030 | 0,0038 | 0,00000 | 0,88 |
| | 3 | -3,0452 | 0,0033 | 0,00000 | 0,09 | -2,7185 | 0,0026 | 0,00000 | -0,54 | -2,8009 | 0,0044 | 0,00000 | 0,81 |
| | mean | -3,0456 | 0,0035 | 0,00000 | 0,65 | -2,7180 | 0,0013 | 0,00000 | -0,20 | -2,8013 | 0,0038 | 0,00000 | 0,89 |
| 2 (PAIS) | 1 | -2,8505 | 0,0034 | 0,00000 | -0,45 | -2,7354 | 0,0016 | 0,00000 | 0,18 | -2,7949 | 0,0013 | 0,00000 | 0,42 |
| | 2 | -2,8596 | 0,0046 | 0,00000 | -0,60 | -2,7309 | 0,0026 | 0,00000 | 0,52 | -2,7987 | 0,0025 | 0,00000 | -0,45 |
| | 3 | -2,8561 | 0,0030 | 0,00000 | -0,74 | -2,7361 | 0,0019 | 0,00000 | 0,69 | -2,7838 | 0,0025 | 0,00000 | -0,75 |
| | mean | -2,8554 | 0,0037 | 0,00000 | -0,60 | -2,7341 | 0,0021 | 0,00000 | 0,47 | -2,7925 | 0,0021 | 0,00000 | -0,26 |
| 3 (PAIS) | 1 | -3,1316 | 0,0026 | 0,00000 | 0,71 | -2,7583 | 0,0024 | 0,00000 | 0,51 | -2,7758 | 0,0023 | 0,00000 | -0,14 |
| | 2 | -3,1234 | 0,0028 | 0,00000 | 0,26 | -2,7543 | 0,0038 | 0,00000 | 0,19 | -2,7778 | 0,0049 | 0,00000 | -0,25 |
| | 3 | -3,1228 | 0,0051 | 0,00001 | 0,86 | -2,7540 | 0,0039 | 0,00000 | 0,64 | -2,7790 | 0,0035 | 0,00000 | 0,22 |
| | mean | -3,1260 | 0,0035 | 0,00000 | 0,61 | -2,7555 | 0,0034 | 0,00000 | 0,44 | -2,7776 | 0,0035 | 0,00000 | -0,06 |
| 4 (PAIS) | 1 | -2,8669 | 0,0048 | -0,00001 | -0,87 | -2,7376 | 0,0017 | 0,00000 | -0,07 | -2,7614 | 0,0063 | 0,00001 | 0,75 |
| | 2 | -2,8512 | 0,0022 | 0,00000 | -0,68 | -2,7423 | 0,0012 | 0,00000 | 0,79 | -2,7653 | 0,0013 | 0,00000 | -0,75 |
| | 3 | -2,8531 | 0,0031 | 0,00000 | -0,37 | -2,7412 | 0,0021 | 0,00000 | 0,45 | -2,7666 | 0,0020 | 0,00000 | -0,56 |
| | mean | -2,8571 | 0,0034 | 0,00000 | -0,64 | -2,7404 | 0,0017 | 0,00000 | 0,39 | -2,7645 | 0,0032 | 0,00000 | -0,19 |
| 1 (Control) | 1 | -3,0940 | 0,0037 | 0,00000 | 0,91 | -2,7631 | 0,0024 | 0,00000 | 0,25 | -2,7216 | 0,0031 | 0,00000 | 0,61 |
| | 2 | -3,0939 | 0,0023 | 0,00000 | 0,55 | -2,7585 | 0,0028 | 0,00000 | 0,09 | -2,7309 | 0,0034 | 0,00000 | 0,21 |
| | 3 | -3,0887 | 0,0023 | 0,00000 | -0,30 | -2,7607 | 0,0025 | 0,00000 | 0,20 | -2,7224 | 0,0038 | 0,00000 | -0,31 |
| | mean | -3,0922 | 0,0028 | 0,00000 | 0,39 | -2,7608 | 0,0026 | 0,00000 | 0,18 | -2,7250 | 0,0034 | 0,00000 | 0,17 |
| 2 (Control) | 1 | -2,8267 | 0,0052 | -0,00001 | -0,82 | -2,7371 | 0,0028 | 0,00000 | 0,76 | -2,8423 | 0,0031 | 0,00000 | 0,52 |
| | 2 | -2,8322 | 0,0097 | -0,00001 | -0,96 | -2,7348 | 0,0049 | 0,00001 | 0,92 | -2,8452 | 0,0021 | 0,00000 | 0,25 |
| | 3 | -2,8294 | 0,0066 | -0,00001 | -0,85 | -2,7360 | 0,0035 | 0,00000 | 0,82 | -2,8437 | 0,0021 | 0,00000 | 0,31 |
| | mean | -2,8294 | 0,0072 | -0,00001 | -0,88 | -2,7360 | 0,0037 | 0,00000 | 0,83 | -2,8437 | 0,0024 | 0,00000 | 0,36 |
| 3 (Control) | 1 | -3,0991 | 0,0076 | 0,00001 | 0,97 | -2,7507 | 0,0049 | 0,00001 | 0,85 | -2,7527 | 0,0022 | 0,00000 | -0,42 |
| | 2 | -3,0949 | 0,0050 | 0,00000 | 0,62 | -2,7439 | 0,0031 | 0,00000 | 0,54 | -2,7646 | 0,0016 | 0,00000 | -0,02 |
| | 3 | -3,1016 | 0,0053 | 0,00001 | 0,79 | -2,7472 | 0,0039 | 0,00000 | 0,52 | -2,7642 | 0,0049 | 0,00000 | 0,09 |
| | mean | -3,0985 | 0,0060 | 0,00001 | 0,79 | -2,7472 | 0,0039 | 0,00000 | 0,63 | -2,7605 | 0,0029 | 0,00000 | -0,12 |
| 4 (Control) | 1 | -2,8064 | 0,0027 | 0,00000 | -0,93 | -2,7598 | 0,0016 | 0,00000 | 0,91 | -2,7866 | 0,0014 | 0,00000 | 0,57 |
| | 2 | -2,8091 | 0,0028 | 0,00000 | -0,94 | -2,7583 | 0,0017 | 0,00000 | 0,86 | -2,7854 | 0,0017 | 0,00000 | 0,94 |
| | 3 | -2,8140 | 0,0022 | 0,00000 | -0,83 | -2,7550 | 0,0011 | 0,00000 | 0,65 | -2,7868 | 0,0017 | 0,00000 | 0,84 |
| | mean | -2,8098 | 0,0026 | 0,00000 | -0,90 | -2,7577 | 0,0015 | 0,00000 | 0,81 | -2,7862 | 0,0016 | 0,00000 | 0,78 |

**Table A.3.3** 6st position SLDP, ACC three seconds *plateau* stability (linear regression)

| Subject (Group) | Trial | ACC X | | | | ACC Y | | | | ACC Z | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mean | sd | slope | *r* | mean | sd | slope | *r* | mean | sd | slope | *r* |
| 1 (PAIS) | 1 | -3,1865 | 0,0021 | 0,00000 | -0,77 | -2,7943 | 0,0026 | 0,00000 | -0,43 | -2,7901 | 0,0021 | 0,00000 | -0,65 |
| | 2 | -3,1795 | 0,0013 | 0,00000 | 0,58 | -2,7878 | 0,0017 | 0,00000 | 0,52 | -2,7908 | 0,0011 | 0,00000 | -0,77 |
| | 3 | -3,1822 | 0,0022 | 0,00000 | -0,91 | -2,7914 | 0,0028 | 0,00000 | -0,86 | -2,7866 | 0,0023 | 0,00000 | 0,82 |
| | mean | -3,1827 | 0,0019 | 0,00000 | -0,37 | -2,7912 | 0,0024 | 0,00000 | -0,26 | -2,7892 | 0,0018 | 0,00000 | -0,20 |
| 2 (PAIS) | 1 | -2,8211 | 0,0024 | 0,00000 | -0,92 | -2,7637 | 0,0023 | 0,00000 | 0,89 | -2,7519 | 0,0020 | 0,00000 | -0,90 |
| | 2 | -2,8189 | 0,0030 | 0,00000 | -0,31 | -2,7625 | 0,0023 | 0,00000 | 0,31 | -2,7583 | 0,0011 | 0,00000 | 0,59 |
| | 3 | -2,8229 | 0,0026 | 0,00000 | -0,74 | -2,7622 | 0,0021 | 0,00000 | 0,38 | -2,7530 | 0,0014 | 0,00000 | 0,61 |
| | mean | -2,8210 | 0,0027 | 0,00000 | -0,66 | -2,7628 | 0,0022 | 0,00000 | 0,52 | -2,7544 | 0,0015 | 0,00000 | 0,10 |
| 3 (PAIS) | 1 | -3,1336 | 0,0019 | 0,00000 | 0,53 | -2,7658 | 0,0017 | 0,00000 | 0,46 | -2,7621 | 0,0016 | 0,00000 | -0,18 |
| | 2 | -3,1273 | 0,0017 | 0,00000 | -0,07 | -2,7636 | 0,0016 | 0,00000 | -0,48 | -2,7580 | 0,0023 | 0,00000 | 0,70 |
| | 3 | -3,1322 | 0,0027 | 0,00000 | 0,81 | -2,7664 | 0,0023 | 0,00000 | 0,69 | -2,7582 | 0,0012 | 0,00000 | -0,04 |
| | mean | -3,1310 | 0,0021 | 0,00000 | 0,42 | -2,7653 | 0,0019 | 0,00000 | 0,22 | -2,7594 | 0,0017 | 0,00000 | 0,16 |
| 4 (PAIS) | 1 | -2,7634 | 0,0025 | 0,00000 | 0,69 | -2,8154 | 0,0013 | 0,00000 | 0,90 | -2,7312 | 0,0049 | -0,00001 | -0,91 |
| | 2 | -2,8048 | 0,0031 | 0,00000 | -0,33 | -2,7962 | 0,0017 | 0,00000 | 0,44 | -2,7090 | 0,0016 | 0,00000 | -0,06 |
| | 3 | -2,7954 | 0,0015 | 0,00000 | -0,67 | -2,7980 | 0,0015 | 0,00000 | 0,33 | -2,7187 | 0,0011 | 0,00000 | 0,66 |
| | mean | -2,7879 | 0,0024 | 0,00000 | -0,10 | -2,8032 | 0,0015 | 0,00000 | 0,56 | -2,7196 | 0,0025 | 0,00000 | -0,10 |
| 1 (Control) | 1 | -3,1238 | 0,0050 | 0,00000 | 0,27 | -2,7719 | 0,0039 | 0,00000 | 0,10 | -2,7353 | 0,0024 | 0,00000 | 0,40 |
| | 2 | -3,1319 | 0,0085 | 0,00001 | 0,89 | -2,7790 | 0,0060 | 0,00001 | 0,78 | -2,7317 | 0,0064 | 0,00000 | 0,12 |
| | 3 | -3,1281 | 0,0039 | 0,00000 | 0,96 | -2,7789 | 0,0021 | 0,00000 | 0,71 | -2,7273 | 0,0028 | 0,00000 | 0,67 |
| | mean | -3,1280 | 0,0058 | 0,00001 | 0,70 | -2,7766 | 0,0040 | 0,00000 | 0,53 | -2,7314 | 0,0039 | 0,00000 | 0,40 |
| 2 (Control) | 1 | -2,8185 | 0,0035 | 0,00000 | 0,17 | -2,7514 | 0,0028 | 0,00000 | -0,33 | -2,7890 | 0,0020 | 0,00000 | 0,77 |
| | 2 | -2,8082 | 0,0021 | 0,00000 | -0,32 | -2,7581 | 0,0020 | 0,00000 | -0,11 | -2,7869 | 0,0022 | 0,00000 | 0,84 |
| | 3 | -2,8067 | 0,0026 | 0,00000 | 0,06 | -2,7596 | 0,0027 | 0,00000 | -0,27 | -2,7863 | 0,0039 | 0,00000 | 0,85 |
| | mean | -2,8111 | 0,0027 | 0,00000 | -0,03 | -2,7563 | 0,0025 | 0,00000 | -0,24 | -2,7874 | 0,0027 | 0,00000 | 0,82 |
| 3 (Control) | 1 | -3,1144 | 0,0026 | 0,00000 | 0,58 | -2,7691 | 0,0035 | 0,00000 | 0,79 | -2,7296 | 0,0058 | 0,00000 | -0,55 |
| | 2 | -3,1143 | 0,0021 | 0,00000 | -0,18 | -2,7629 | 0,0033 | 0,00000 | 0,46 | -2,7421 | 0,0051 | 0,00000 | -0,63 |
| | 3 | -3,1070 | 0,0015 | 0,00000 | 0,45 | -2,7642 | 0,0023 | 0,00000 | 0,15 | -2,7319 | 0,0024 | 0,00000 | 0,01 |
| | mean | -3,1119 | 0,0021 | 0,00000 | 0,28 | -2,7654 | 0,0030 | 0,00000 | 0,47 | -2,7345 | 0,0044 | 0,00000 | -0,39 |
| 4 (Control) | 1 | -2,7950 | 0,0014 | 0,00000 | 0,52 | -2,7810 | 0,0015 | 0,00000 | -0,16 | -2,7500 | 0,0013 | 0,00000 | -0,09 |
| | 2 | -2,7937 | 0,0008 | 0,00000 | -0,31 | -2,7827 | 0,0011 | 0,00000 | 0,36 | -2,7487 | 0,0009 | 0,00000 | -0,03 |
| | 3 | -2,7958 | 0,0029 | 0,00000 | 0,70 | -2,7813 | 0,0023 | 0,00000 | -0,45 | -2,7487 | 0,0010 | 0,00000 | 0,12 |
| | mean | -2,7948 | 0,0017 | 0,00000 | 0,30 | -2,7817 | 0,0017 | 0,00000 | -0,08 | -2,7491 | 0,0010 | 0,00000 | 0,00 |

**Table A.3.4** 6st position SLP, ACC three seconds *plateau* stability (linear regression)

| Subject (Group) | Trial | ACC X | | | | ACC Y | | | | ACC Z | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mean | sd | slope | *r* | mean | sd | slope | *r* | mean | sd | slope | *r* |
| 1 (PAIS) | 1 | -3,0751 | 0,0084 | 0,00000 | 0,45 | -2,7423 | 0,0032 | 0,00000 | 0,11 | -2,7498 | 0,0040 | 0,00000 | 0,76 |
| | 2 | -3,0716 | 0,0105 | 0,00001 | 0,65 | -2,7418 | 0,0033 | 0,00000 | 0,44 | -2,7483 | 0,0047 | 0,00000 | 0,71 |
| | 3 | -3,0780 | 0,0124 | 0,00001 | 0,70 | -2,7439 | 0,0046 | 0,00000 | 0,59 | -2,7490 | 0,0044 | 0,00000 | 0,52 |
| | mean | -3,0749 | 0,0104 | 0,00001 | 0,60 | -2,7427 | 0,0037 | 0,00000 | 0,38 | -2,7490 | 0,0044 | 0,00000 | 0,66 |
| 2 (PAIS) | 1 | -2,8103 | 0,0048 | 0,00000 | -0,70 | -2,7711 | 0,0024 | 0,00000 | 0,46 | -2,7504 | 0,0032 | 0,00000 | 0,86 |
| | 2 | -2,8192 | 0,0054 | 0,00000 | -0,69 | -2,7668 | 0,0025 | 0,00000 | 0,59 | -2,7484 | 0,0035 | 0,00000 | 0,64 |
| | 3 | -2,8153 | 0,0060 | 0,00000 | -0,54 | -2,7685 | 0,0036 | 0,00000 | 0,19 | -2,7496 | 0,0032 | 0,00000 | 0,89 |
| | mean | -2,8149 | 0,0054 | 0,00000 | -0,65 | -2,7688 | 0,0028 | 0,00000 | 0,41 | -2,7494 | 0,0033 | 0,00000 | 0,80 |
| 3 (PAIS) | 1 | -3,1130 | 0,0064 | 0,00001 | 0,72 | -2,7742 | 0,0041 | 0,00000 | 0,33 | -2,7202 | 0,0036 | 0,00000 | 0,75 |
| | 2 | -3,1263 | 0,0049 | 0,00000 | 0,52 | -2,7775 | 0,0043 | 0,00000 | 0,33 | -2,7282 | 0,0019 | 0,00000 | 0,39 |
| | 3 | -3,1129 | 0,0068 | 0,00001 | 0,69 | -2,7706 | 0,0051 | 0,00000 | 0,56 | -2,7266 | 0,0024 | 0,00000 | -0,01 |
| | mean | -3,1174 | 0,0060 | 0,00000 | 0,65 | -2,7741 | 0,0045 | 0,00000 | 0,41 | -2,7250 | 0,0026 | 0,00000 | 0,38 |
| 4 (PAIS) | 1 | -2,7808 | 0,0035 | 0,00000 | -0,84 | -2,7943 | 0,0017 | 0,00000 | 0,59 | -2,7417 | 0,0027 | 0,00000 | 0,92 |
| | 2 | -2,7776 | 0,0032 | 0,00000 | -0,46 | -2,7940 | 0,0023 | 0,00000 | 0,48 | -2,7473 | 0,0011 | 0,00000 | 0,09 |
| | 3 | -2,8001 | 0,0034 | 0,00000 | -0,28 | -2,7783 | 0,0018 | 0,00000 | 0,24 | -2,7453 | 0,0017 | 0,00000 | 0,28 |
| | mean | -2,7862 | 0,0034 | 0,00000 | -0,53 | -2,7889 | 0,0019 | 0,00000 | 0,44 | -2,7448 | 0,0018 | 0,00000 | 0,43 |
| 1 (Control) | 1 | -3,1400 | 0,0039 | 0,00000 | 0,58 | -2,8129 | 0,0047 | 0,00000 | 0,17 | -2,6881 | 0,0030 | 0,00000 | 0,42 |
| | 2 | -3,1424 | 0,0033 | 0,00000 | 0,58 | -2,8134 | 0,0038 | 0,00000 | 0,25 | -2,6896 | 0,0038 | 0,00000 | 0,25 |
| | 3 | -3,1471 | 0,0056 | 0,00001 | 0,73 | -2,8116 | 0,0062 | 0,00000 | 0,29 | -2,6969 | 0,0041 | 0,00000 | 0,49 |
| | mean | -3,1432 | 0,0043 | 0,00000 | 0,63 | -2,8126 | 0,0049 | 0,00000 | 0,24 | -2,6915 | 0,0036 | 0,00000 | 0,39 |
| 2 (Control) | 1 | -2,8095 | 0,0118 | -0,00001 | -0,67 | -2,7552 | 0,0082 | 0,00001 | 0,61 | -2,7947 | 0,0089 | 0,00000 | 0,40 |
| | 2 | -2,7941 | 0,0130 | -0,00001 | -0,74 | -2,7630 | 0,0093 | 0,00001 | 0,66 | -2,8015 | 0,0069 | 0,00001 | 0,67 |
| | 3 | -2,8046 | 0,0099 | -0,00001 | -0,58 | -2,7568 | 0,0064 | 0,00000 | 0,50 | -2,7984 | 0,0042 | 0,00000 | 0,58 |
| | mean | -2,8027 | 0,0116 | -0,00001 | -0,66 | -2,7583 | 0,0080 | 0,00001 | 0,59 | -2,7982 | 0,0066 | 0,00000 | 0,55 |
| 3 (Control) | 1 | -3,1322 | 0,0099 | 0,00001 | 0,51 | -2,7834 | 0,0101 | 0,00000 | 0,32 | -2,7244 | 0,0036 | 0,00000 | 0,75 |
| | 2 | -3,1324 | 0,0116 | 0,00001 | 0,36 | -2,7796 | 0,0127 | 0,00001 | 0,35 | -2,7321 | 0,0039 | 0,00000 | -0,18 |
| | 3 | -3,1396 | 0,0116 | 0,00000 | 0,24 | -2,7848 | 0,0130 | 0,00000 | 0,22 | -2,7311 | 0,0020 | 0,00000 | 0,63 |
| | mean | -3,1347 | 0,0111 | 0,00000 | 0,37 | -2,7826 | 0,0119 | 0,00000 | 0,29 | -2,7292 | 0,0031 | 0,00000 | 0,40 |
| 4 (Control) | 1 | -2,7653 | 0,0027 | 0,00000 | -0,75 | -2,8054 | 0,0023 | 0,00000 | 0,67 | -2,7490 | 0,0007 | 0,00000 | 0,27 |
| | 2 | -2,7682 | 0,0029 | 0,00000 | -0,86 | -2,8027 | 0,0018 | 0,00000 | 0,78 | -2,7493 | 0,0013 | 0,00000 | 0,81 |
| | 3 | -2,7704 | 0,0039 | 0,00000 | -0,69 | -2,8014 | 0,0023 | 0,00000 | 0,43 | -2,7490 | 0,0022 | 0,00000 | 0,86 |
| | mean | -2,7680 | 0,0031 | 0,00000 | -0,77 | -2,8032 | 0,0021 | 0,00000 | 0,62 | -2,7491 | 0,0014 | 0,00000 | 0,64 |

# Appendix 7: Postural Sway

**Table A.4** Postural sway variation (mm)

| Group | Subjects | Trials | Protocol positions | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | DLDP | Gon 1 | DLP | Gon 1 | SLDP | Gon 1 | SLP | Gon 1 |
| PAIS | 1 | 1 | 18,364 | 3036 | 3,52 | 3091 | 3,601 | 2942 | 6,16 | 2077 |
| | | 2 | 18,459 | 3431 | 3,759 | 2856 | 1,748 | 3018 | 6 | 3287 |
| | | 3 | 24,96 | 3261 | 3,602 | 2456 | 3,193 | 3240 | 7,913 | 2470 |
| | | Mean | 20,594 | 3243 | 3,627 | 2801 | 2,847 | 3067 | 6,629 | 2611 |
| | 2 | 1 | 30,428 | 3243 | 82,853 | 3713 | 1,287 | 3811 | 2,306 | 3545 |
| | | 2 | 24,39 | 3438 | 54,644 | 3687 | 2,053 | 3072 | 5,662 | 3792 |
| | | 3 | 24,055 | 3392 | 80,728 | 2699 | 1,678 | 3626 | 4,899 | 3433 |
| | | Mean | 26,291 | 3358 | 72,741 | 3366 | 1,672 | 3503 | 4,289 | 3590 |
| | 3 | 1 | 19,341 | 2833 | 2,892 | 2751 | 4,232 | 2988 | 5,899 | 2179 |
| | | 2 | 26,691 | 2389 | 38,156 | 2272 | 0,364 | 3324 | 4,854 | 2487 |
| | | 3 | 14,418 | 2762 | 9,056 | 2298 | 1,718 | 2947 | 3,062 | 2530 |
| | | Mean | 20,15 | 2661 | 16,701 | 2440 | 2,104 | 3086 | 4,605 | 2399 |
| | 4 | 1 | 10,165 | 4963 | 1,886 | 4696 | 3,512 | 4865 | 4,222 | 2781 |
| | | 2 | 42 | 4256 | 3,226 | 3648 | 0,501 | 3688 | 1,983 | 3784 |
| | | 3 | 27,899 | 3577 | 2,009 | 2879 | 1,453 | 3167 | 2,167 | 3990 |
| | | Mean | 26,647 | 4265 | 2,373 | 3741 | 1,822 | 3907 | 2,790 | 3518 |
| CONTROL | 1 | 1 | 12,805 | 5128 | 2,091 | 3009 | 4,186 | 3760 | 4,848 | 2478 |
| | | 2 | 34,212 | 4131 | 2,001 | 2970 | 3,753 | 3591 | 2,589 | 2782 |
| | | 3 | 22,459 | 4206 | 2,799 | 3269 | 3,124 | 3622 | 9,739 | 2676 |
| | | Mean | 23,158 | 4488 | 2,297 | 3083 | 3,687 | 3658 | 5,725 | 2645 |
| | 2 | 1 | 24,658 | 2753 | 3,62 | 2155 | 3,198 | 2671 | 13,374 | 2248 |
| | | 2 | 34,719 | 2785 | 2,848 | 1985 | 2,049 | 2292 | 4,462 | 1863 |
| | | 3 | 24,546 | 2778 | 283,417 | 1910 | 4,088 | 2234 | 5,519 | 1799 |
| | | Mean | 27,974 | 2772 | 96,628 | 2017 | 3,111 | 2399 | 7,785 | 1970 |
| | 3 | 1 | 17,652 | 2478 | 3,879 | 2194 | 1,815 | 1712 | 29,08 | 1848 |
| | | 2 | 43,473 | 2063 | 1,767 | 2123 | 2,324 | 2403 | 3,437 | 2299 |
| | | 3 | 16,832 | 2216 | 2,407 | 2475 | 2,81 | 2374 | 2,151 | 2046 |
| | | Mean | 25,985 | 2252 | 2,684 | 2264 | 2,316 | 2163 | 11,556 | 2064 |
| | 4 | 1 | 13,342 | 3389 | 35,639 | 2909 | 6,559 | 2888 | 4,535 | 2517 |
| | | 2 | 13,058 | 3100 | 46,565 | 2667 | 3,786 | 2730 | 3,486 | 2583 |
| | | 3 | 16,235 | 3127 | 5,544 | 2472 | 3,648 | 2701 | 2,435 | 2075 |
| | | Mean | 14,211 | 3205 | 29,249 | 2683 | 4,664 | 2773 | 3,485 | 2392 |