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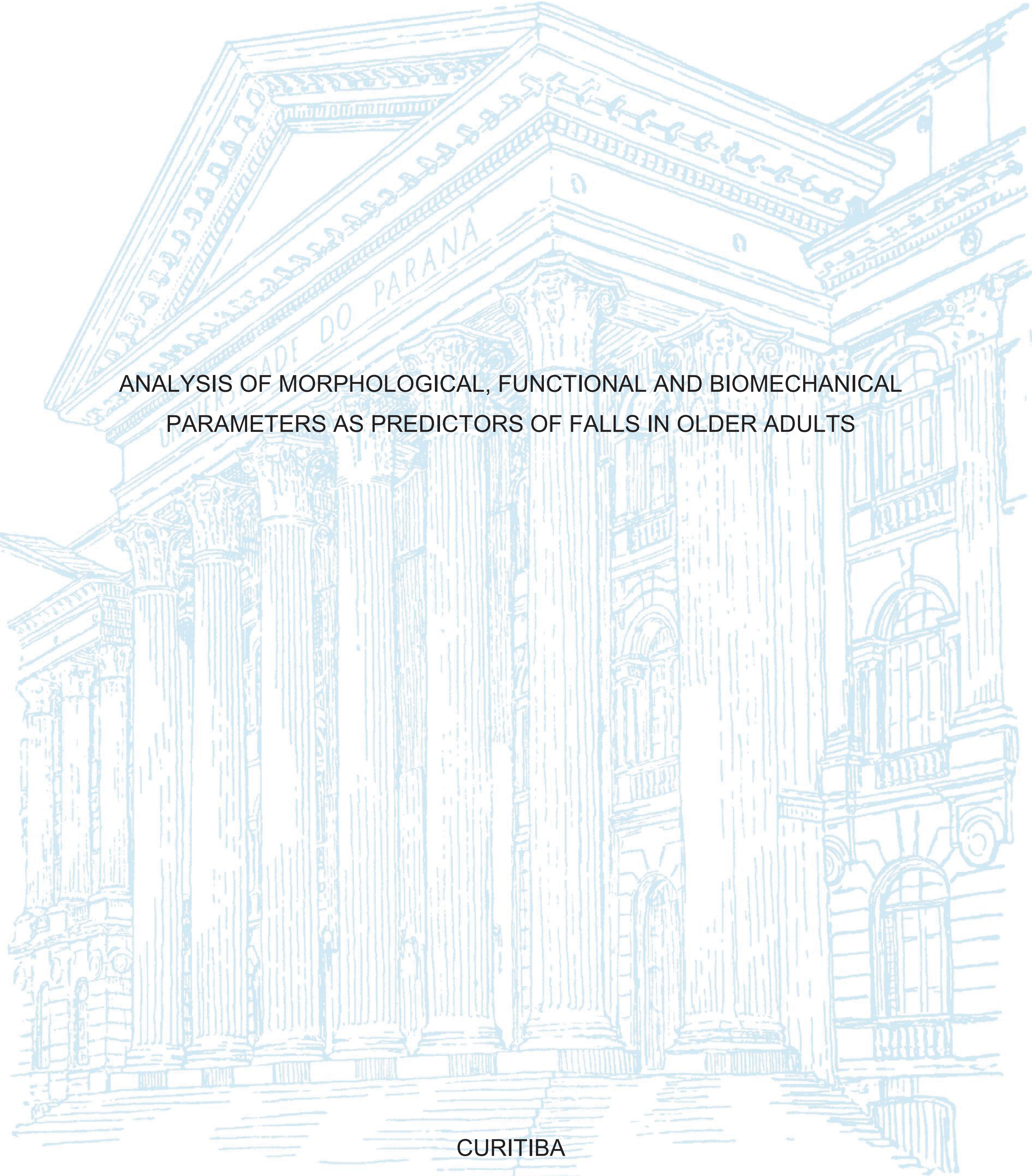

ANALYSIS OF MORPHOLOGICAL, FUNCTIONAL AND BIOMECHANICAL PARAMETERS AS PREDICTORS OF FALLS IN OLDER ADULTS

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ANALYSIS OF MORPHOLOGICAL, FUNCTIONAL AND BIOMECHANICAL PARAMETERS AS PREDICTORS OF FALLS IN OLDER ADULTS

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Orientador: Prof. Dr. André Luiz Félix Rodacki

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APPROVAL MINUTE

The Examining Board is designated by the Collegiate of the Graduate Program of the Federal University of Paran in Physical Education where invited to argue the dissertation of Master of Sciences by **JOICE KATIANE MENDES BECK**, entitled: **"ANALYSIS OF MORPHOLOGICAL, FUNCTIONAL AND BIOMECHANICAL PARAMETERS AS PREDICTORS OF FALLS IN OLDER ADULTS"**, under the supervision of Dr. ANDRE LUIZ FELIX RODACKI, which and after assessment of the candidate and the work, the Examining Board decided for the APPROVAL in the present rite.

The granting of the title of Master of Sciences is contingent upon the fulfillment of all the requirements indicated by the Examining Board and terms determined int the regulation of the Graduate Program.

Curitiba, february 11th, 2020.

Rodacki

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RESUMO

O processo de envelhecimento reduz a rigidez do tendão, aumenta a gordura intramuscular e reduz a força muscular. O primeiro estudo deste trabalho comparou a rigidez do tendão do tríceps sural e a gordura intramuscular de idosos em relação ao histórico de quedas e ao nível de atividade física. Trinta e um participantes foram alocados em dois grupos de acordo com o histórico de quedas (caidores e não caidores) e em dois grupos de acordo com o número de minutos de atividade fisica por semana (ativo e não ativo). Não foram encontradas diferenças entre os grupos de acordo com o histórico de quedas. O grupo não ativo apresentou maior infiltração de gordura que o grupo ativo, enquanto o grupo ativo apresentou maior rigidez com TS do que o grupo não ativo. O segundo estudo comparou a rigidez do tendão do tríceps sural e a gordura intramuscular dos idosos e relacionou esses parâmetros à potência da articulação do tornozelo e à capacidade reativa entre os que caem e os que não caem (de acordo com um tropeço induzida controlada por laboratório). Foram avaliadas a contração voluntária isométrica, a rigidez do tendão de Aquiles e a infiltração de gordura. No segundo estudo, a rigidez e a potência do tornozelo foram capazes de prever quedas em idosos em 6% e 37%, respectivamente. Concluindo, houve relação entre rigidez do tendão, infiltração de gordura do tríceps sural e atividade física, a rigidez do tendão de Aquiles a potência articular de tornozelo mostraram serem um preditor de quedas nos idosos.

Palavras-chave: idosos, quedas, infiltração de gordura e rigidez do tendão de Aquiles.

ABSTRACT

The first study of this work compared the stiffness of the sural triceps tendon (TS) and the intramuscular fat of older adults in relation to the history of falls and the level of physical activity. Thirty-one participants were allocated into four groups according to: 1) the fall history (fallers and non-fallers) and 2) the number of minutes of activity per week (active and non-active). No differences were found between the groups according to the history of falls for fat infiltration and Achilles tendon stiffness. The non-active group showed greater fat infiltration and less TS stiffness than the active group. The second study compared the TS stiffness tendon and the intramuscular fat of the older adults and related to ankle joint power and reactive capacity between fallers and non-fallers (according to a laboratory-controlled induced trip). The Isometric voluntary contraction, the Achilles tendon stiffness and fat infiltration were assessed. In the second study, the stiffness and the ankle power were able to predict falls in older adults by 6% and 37%, respectively. In conclusion, there was a relationship between tendon stiffness, triceps sural fat infiltration and physical activity, ST stiffness and ankle power to be a predictor of falls in the older adults.

Key words: older adults, falls, fat infiltration and Achilles tendon stiffness.

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DISSERTATION STRUCTURE

This dissertation was structured in five chapters. The first was devoted to general introduction, which contains the contextualization and justification that guide this study. The Chapter II contains the general objectives and hypotheses. Chapter III presents the literature review on the main aspects related to physical, functional and muscular characteristics and changes inherent to the aging process. In order to answer objectives and test the generated hypotheses, the dissertation was divided into two experimental studies. The first study (chapter IV) was designed to identify differences in morphological parameters of triceps sural between fallers and non-fallers and between physically active and non-active individuals. The latest study (chapter V) aimed to analyze the difference in the stiffness of the Achilles tendon and the muscular fat infiltration between fallers and non-fallers, according to an induced stumble test. In the same chapter we will address the correlation between fat infiltrates and tendon stiffness with variables of muscle function and reaction capacity.

1 INTRODUCTION

The rate of falls in individuals aged over 65 years is around 27% (FASANO et al., 2012) and approximately one out of three older adults experience a fall once a year. Despite the fact that most falls are multifactorial, the interaction between the environmental risks (i.e., extrinsic factors - uneven surfaces, slippery floors, low illumination, etc.) and the inherent limitations of the aging process (i.e., intrinsic factors – fat infiltration, reduced tendon stiffness, poor balance, etc.), play an important role in the gait and are a complex phenomenon (LORD et al., 2007).

The number of age-related falls has been associated with the degeneration of several systems (e.g., vestibular, sensory, motor) that influence the postural control and turn older adults more prone to falls (HORAK, 2006). Thus, the integrity of the postural control system is fundamental to maintain and recover balance during a disturbance (e.g., stumbling) (LIN & WOOLLACOTT, 2005). Hence, the ability to perceive a disturbance, organize an adequate response and timely recruit the appropriate muscles is fundamental to restore balance and avoid a fall (LIN & WOOLLACOTT, 2005).

Reduced strength and power of the dorsi and plantar flexor muscles have been described as potential factors for stumbling and falls in older adults (SKELTON et al., 2002). Indeed, large torques around the ankle are required to reestablish balance when the center of mass exceeds the limits of stability during a disturbance (LAROCHE et al., 2010; MELZER et al., 2007). Moreover, changes in neural coordination and muscle control reduce the muscle-tendon unit stiffness, especially around the ankle (PIJNAPPELS et al., 2008), and may play a role while restoring balance.

It has been well documented that the muscle-tendon units of older adults are about 15% more complacent than their younger counterparts (VIIDIK, 1979). This difference is related to changes in several structures of the muscle-tendon unit (i.e., increased cross-linking of non-reducible collagen, increased elastin, collagen type V (KJAER, 2004; TUITE et al., 2007; VIIDIK, 1979) and reduced ability to transmit forces to the joints (DAVIES et al., 2009; MORSE et al., 2005). Thus, in addition to the reduced ability of the muscles to produce force and power, a low muscle-tendon unit stiffness may cause low torque generation rates and also delayed sensorial information with respect to changes in muscle length. It may take longer to produce appropriate responses, which causes difficulties to reestablish balance and ultimately diminish the chances to avoid a fall (PIJNAPPELS et al., 2008).

The triceps sural muscle quality group may represent an additional issue, as aged muscles are prone to present large amounts of infiltrated fat that decrease the muscular ability to produce force and power (FUJIWARA et al., 1982; MORSE et al., 2005; NADEAU et al., 1999). This occurs first in fast-twitch muscles (EVANS & LEXELL, 1995; LEE et al., 2006), such as the gastrocnemius (FUJIWARA et al., 2010), which plays a central role while producing large amounts of power around the ankle when recovering from a trip.

So far, most studies have used simple and inexpensive tests, in which a single or a set of variables are selected to represent the main fall-related parameters. These studies have assessed muscle strength and power (BENTO et al., 2010; MORELAND et al., 2004), dynamic balance (MELZER et al., 2007), gait-related variables (CHIBA et al., 2005), functionality (SHUMWAY-COOK et al., 2000), anthropometry (HIMES & REYNOLDS, 2012), muscle morphology (FUJIWARA et al., 2010) and tendinous morphology (MAGNUSSON et al., 2008). However, only some of these parameters were previously associated with the prediction of falls. A more comprehensive analysis of the influence of each variable and its associations is necessary to better understand the risk of falls.

Finally, there are important methodological limitations related to how fallers from non-fallers were identified. Retrospective studies are more prone to errors due to memory problems, which are aggravated by age-related cognitive changes (GREENE et al., 2014; ROSENBLATT; GRABINER, 2012). Retrospective studies also fail to account for several changes after a fall event and differences in the control of dynamic balance during walking between older adults with and without a fall history.

Some studies (BOHRER et al., 2018; MADIGAN et al., 2014; PAVOL et al., 2001; PIJNAPPELS et al., 2008)(MADIGAN et al., 2014; PAVOL et al., 2001; PIJNAPPELS et al., 2008) have induced a trip under controlled laboratory conditions, which is an interesting opportunity to impose real-world disturbance conditions (i.e., during a trip). Although a stumbling condition has been mimicked under controlled conditions, most experiments were performed with the aid of a treadmill, which may not replicate real-world conditions. In addition, only a reduced number of fall-related parameters were assessed. Therefore, this study was designed to compare the contribution of a number of variables, including morphological aspects (intramuscular fat and stiffness), ankle power and reactive capacity in older fallers and non-fallers with historical of falls and induced trip at laboratory.

2 AIMS

2.1.1 General Aim

To determine and to compare the morphological, functional and biomechanical parameters between faller and non-faller older adults.

2.1.2 Specific Aims and Hypotheses:

a) To determine and to compare the gastrocnemius echo intensity and Achilles tendon stiffness between faller and non-faller older adults.

   H_1 - Older adults with fall history have higher gastrocnemius echo intensity than older adults without fall history;

   H_2 - Older adults with fall history have smaller Achilles tendon stiffness than seniors without fall history.

b) To determine and to compare the gastrocnemius echo intensity and Achilles tendon stiffness between active and non-active physically older adults.

   H_3 - Active older adults have higher Achilles tendon stiffness than non-active counterparts.

   H_4 - Active older adults have smaller gastrocnemius echo intensity than non-active counterparts.

c) To determine and to compare the gastrocnemius echo intensity, Achilles tendon stiffness and plantar flexor power between faller and non-faller older adults from the laboratory induced trip.

   H_5 - Older adults with fall history have smaller Achilles tendon stiffness than those not prone to falls;

   H_6 - Older adults with fall history have smaller plantar flexor power than those prone to falls;

   H_7 - Older adults with fall history have higher gastrocnemius echo intensity than those prone to falls;

3 REVIEW OF THE LITERATURE

This review of the literature was performed to substantiate the problem and support the study method, organized into four topics. The first one refers to the prevalence of falls due to the aging process in order to allow the understanding of the impacts of falls among the older adults. Among the known impacts, there is a reduction in functional capacity, which implies greater difficulty in carrying out activities of daily living and has a strong relation with a higher risk of falls in the older adults, which is addressed in the second topic. Moreover, the reduction of muscle function parameters in the old adults, such as the strength and power of the distal musculature, is strongly associated with the increasing number of falls in this population, as observed in topic three. The fourth topic deals with the postural control system, which is responsible for integrating the information generated by the sensory and neuromuscular systems, in order to produce a motor response that is adequate to the demands of the environment.

3.1 AGING AND FALLS

Falls constitute a common event among the older adults and represent a global public health problem (SHORR et al., 2008). It is estimated that, by 2025, a 300% increase in the older adults population will occur, which will have a major impact on the country's economy and health system (SIQUEIRA et al., 2011). The prevalence of falls is directly associated with age, sedentary lifestyle, self-perceived poor health, and chronic use of medications (SIQUEIRA et al., 2011).

Falls occur as a result of a complex interaction of risk factors, which can be classified as biological, behavioral, environmental and socioeconomic (WHO, 2010). Biological factors refer to individual’s characteristics. Behavioral risk factors (sedentary, smoking, alcohol and environmental) carpets, furniture, steps are considered modifiable. Socioeconomic factors refer to the influence of the social condition and economic status on individuals in the society. The combination of biological, environmental and behavioral factors increases the risk of falls (WHO, 2010).

Falls are a common event in the older adults, and it is considered that a healthy individual aged 65 years or older who has never fallen has a 27% risk of falling (FASANO et al., 2012). The factors can lead to numerous disabling diseases, extensive hospitalizations and death. For this reason they represent a significant cost and public health problem. The costs can be either direct, which includes medical consultations, hospital, home nursing care, outpatient, rehabilitation, diagnostic tests, medication, home care, home modifications, equipment and institutional care, as well as indirect, such as morbidity and mortality (LORD et al., 2007; MASUD & MORRIS, 2001).

Falls can result in activity restriction such as performing their ADL's (actives of daily life) and fear of falling, reduced quality of life and independence (PERRACINI & RAMOS, 2002). Even falls that do not result in physical injury can result in "post-fall syndrome," a loss of confidence and hesitation, with consequent loss of mobility and independence (LORD et al., 2007).

Although, environmental factors are not the main cause of most falls, the interaction between a hazardous environment (extrinsic factor) and the limitations of physical abilities such as vision, impairment of muscle strength and balance (intrinsic factors) inherent in aging seem to play an important role in falls (LORD et al., 2007) . Thus, the occurrence of falls is strongly related to exposure, they occur mainly during the activities of daily living (LORD et al., 2007; PIJNAPPELS et al., 2008), especially during walking. Understanding the mechanisms involved in falls is a way of trying to prevent this event in the elderly. Therefore, selecting the best fall identification mechanism and the variables involved must be studied.

3.2 FUNCTIONAL CAPACITY AND FALLS

Aging is a natural process inherent in humans and can be considered as the reduction of adaptability to the environment and functionality that may result in difficulties in carrying out the activities of daily living (SPIRDUSO et al., 1995).

Functional capacity can be defined as the individual's ability to perform daily activities independently and it is possible to categorize these activities in two types: Activities of Daily Living (ADL), those essential for survival and hygiene, and Instrumental Activities of Daily Living (IADL), those essential for life in society, such as performing household chores, shopping and taking buses alone (FRIED et al., 2004).

Due to increased life expectancy, the ability to engage in an active and independent lifestyle depends greatly on how the older adult's fitness level will be maintained. Therefore, a functional aptitude is required that encompasses the physical capacity required to perform daily activities safely and independently, without excessive fatigue (RIKLI & JONES, 2013). Thus, physical activity is required to sustain/maintain strength, endurance, flexibility, mobility (GURALNIK et al., 1996; RIKLI & JONES, 2013), and power (MISZKO et al., 2003) in order to perform activities of daily living and instrumental activities (AIDLs) (GURALNIK et al., 1996; RIKLI & JONES, 2013),.

Daily tasks (such as getting up from a sitting position, keeping upright on foot and walking) are considered as motor skills. In addition to increasing the risk of falling, motor performance deficits can reduce independence and life quality. As with any other skill, the functional tasks’ performance can be improved through training (LORD et al., 2007).

The functionality can be evaluated indirectly, through self-report questionnaires or directly, through performance tests. These are based on objective results from validated tests, from reference values or from the individual perception of the difficulties or specific changes in the execution of the task (FRIED et al., 2004; VON BONSDORFF & RANTANEN, 2011). In that sense, numerous tests and batteries were developed, but in this study only one was addressed: the Timed up and go (TUG) because this test has a high degree of reliability (BISCHOFF et al., 2003).

3.3 MUSCULAR FUNCTION AND AGING

It is well known that a significant decline in neuromuscular function and performance occur with increasing age. This decline is characterized by an inevitable reduction of muscle mass, which is associated with loss of strength, known as sarcopenia, (DOHERTY, 2003; FRONTERA et al., 2000). Longitudinal studies concluded that the rate of muscle mass reduction after sixty years range from 1.0 to 1.5% per year (DELMONIACO et al., 2009; FRONTERA et al., 2000).

Sarcopenia encompasses the changes from the central and peripheral nervous system, altered hormonal status, inflammatory effects, altered caloric intake and protein (DOHERTY, 2003), and the intrinsic properties of muscle fibers (FRONTERA et al., 2000). Thus, sarcopenia is hypothesized to be associated with metabolic, physiological and functional deficiencies and the inability to perform functional tasks in the older adults (DEY et al., 2009; DOHERTY, 2003).

In functional terms, the rate of torque development is a very important parameter in muscle mechanics, because rapid movements usually involve muscle contractions within 50-200 ms, which is considerably less than the time that muscle takes to reach maximum strength (~ 350ms) (AAGAARD et al., 2002). Therefore, high rates of torque development play an important role in the ability to perform fast and strong movements (BENTO et al., 2010). Low rates of torque development in older adults are also found to result in increased risk of falls as well as the ability to promptly respond to unexpected disturbances (AAGAARD et al., 2002),. The reduction of the rate of development of torque with aging can be attributed to quantitative factors (loss of muscle mass) and qualitative factors, such as the decreased motor units firing rates, type II fiber atrophy, fiber pennation angle and reduced muscle-tendon unit stiffness (AAGAARD et al., 2002).

It has been shown that individuals with reduced muscle strength of the lower limbs are unable to support the body after the reaction with a step in recovering from an induced stumbling and present a greater chance to experience a fall (PAVOL et al., 2001). The slow reactions of older adults to postural disturbances demonstrate the need for increments of strength and power as a strategy to increase the chances of a successful recovery while tripping (THELEN et al., 1997; VAN DEN BOGERT. et al., 2012).

Fallers exhibit minor strength and rate of torque development of plantar and dorsiflexors compared to non-fallers. These specific muscle groups are associated with falls for two reasons: they are necessary for gait and are fundamental to maintaining balance after a postural disturbance (LAROCHE et al., 2010). Thus, it is suggested that strength and velocity of dorsi and plantiflexor movement, and power should be considered as potential contributory factors for falls in older adults (LAROCHE et al., 2010; SUZUKI et al., 2001)'.

The control of the musculoskeletal system, in other words, coordination (timing and technique), involves essentially a certain amount of stimulus for each muscle as a function of time (BOBBERT & SOEST, 1994). Additionally, it has been proposed that peak muscle power or maximal ability to perform muscle work per unit of time is more critical than strength variable with respect to the relationship between muscle damage, functional limitation and subsequent disabilities (SUZUKI et al., 2001).

3.4 POSTURAL CONTROL AND AGING

Postural control is considered a complex motor task that results from the interaction of multiple sensory-motor processes aimed to provide orientation and postural balance (MELZER et al., 2007). The postural orientation involves the active control of body alignment and tone in relation to gravity, support surface, visual environment and internal references. In addition, it is based on the interpretation of convergent sensory information of somatosensory, vestibular and visual systems (HORAK, 2006). The postural balance also involves the coordination of sensory-motor strategies to stabilize center of mass (CM) and its changes or adjustments after perturbations define how the balance is maintained

In general, six important resources or subcomponents are necessary for postural control: biomechanical constraints, movement strategies, sensory strategies, spatial orientation, dynamic control and cognitive processes (HORAK, 2006). Regarding the biomechanical constraints, the support base, represented by the feet, is the most important factor to be considered. Thus, any limitation related to size, strength, pain or control of the feet can affect the balance (HORAK, 2006).

Another limiting and important factor to be considered in the control of balance refers to the maintenance of the CM within the support base in static and dynamic situations, and when this relationship is not maintained, the system will be unbalanced and/or unstable. For this purpose, the Central Nervous System (CNS) has an internal representation of the stability cone used to determine the limits of movement. In other words, how far one can move from front to back and from side to side without losing balance (HORAK, 2006). In addition, individuals more prone to falls have small stability limits (HORAK, 2006).

In dynamic situations such as walking or changes of posture, unlike quasi-static position, the CM is not within the support base, which generates greater postural oscillations and greater instability. Depending on the degrees of freedom of the joints of the body there is always a greater displacement in the anteroposterior direction, but there are also lateral displacements. Older individuals with increased susceptibility to falls tend to present CM excursions in the lateral direction larger than normal counterparts (HORAK, 2006).

Stability recovery requires motion strategies to control CM within the support basis. The ankle strategy occurs with minimal disturbance of balance. On the other hand, the hip strategy is used in response to moderate instabilities and relies on high levels of strength and power and mobility around the hip. However, when CM exceeds stability limits, the step strategy is used, in which the individual takes a step forward to regain balance. The latter strategy is the one most commonly used by older people who are prone to falls risk (HORAK, 2006). Although, the causes of falls are varied and complex, the ability to respond effectively to disturbances of balance is critical (MAKI et al., 2008). To maintain balance, the ability to detect postural disturbances (internal or external) and generate appropriate responses is required. However, this ability decreases with age and can lead to imbalances and increased risk of falls (LIN & WOOLLACOTT, 2005).

Although, motion strategies are automatic and triggered within 100ms after perceiving an external disturbance, individuals may have influence on the strategy selected and the magnitude of response based on intention, experience and expectation. In addition, postural strategies anticipatory to voluntary movement also help maintain stability by compensating for destabilization by the movement of the arms (HORAK, 2006).

Postural control plays a key role in the ability to maintain balance during various activities of daily living especially those that include independent standing and gait elements (MELZER et al., 2007). In maintaining balance when considered important in the daily tasks, and functional independence, the ability to respond rapidly to external stimuli or disturbances is fundamental, meaning reactive postural control. This is a fundamental aspect of balance control, which is usually assessed from the evaluation of the individual's response to disturbances caused in controlled situations.

In summary, the increase in balance disorders and the number of falls with increasing age does not occur due to the aging of the balance system, but rather because of the greater probability of deficiencies occurring in the physiological systems underlying the equilibrium task (LIN & WOOLLACOTT, 2005). There are a range of physiological factors that may be involved in these age-related changes, including decreased nerve conduction velocity, increased sensory thresholds, increased central processing time, increased stiffness of passive tissues, increased active muscle stiffness due to coactivation or the initial postural set, increasing dependence of vision for postural control and reduction of muscle strength and torque generation capacity (MELZER & ODDSSON, 2004).

Freitas Júnior and colleagues (FREITAS JÚNIOR & BARELA, 2006) speculate that the main causes of falls are the structural and functional changes that occur in the sensorial and motor systems as a function of the aging process. Regarding the deficiencies that affect the postural control system, they are related to the longer time to detect and integrate the most relevant sensory information, to select the best response for a given situation, and to require more time to generate motor actions necessary to maintain balance and orientation postural. When the postural control system fails in any of these steps, imbalances and, often, falls can occur (FREITAS JÚNIOR & BARELA, 2006).

Thus, recovery of balance and fall prevention should be based on an effective evaluation of the various systems underlying postural control. In terms of evaluation of postural control, different approaches and methodologies are available in the literature, being possible to perform evaluations from typical pressure center measurements through instrumentation to test that do not require the use of instruments, such as functional tests, in which usually runs execution time. In this study, we chose to evaluate the dynamic balance, since in this evaluation approach, additional demands of proprioception, range of motion and strength are required, along with the ability to remain standing (GRIBBLE & HERTEL, 2003). In addition, dynamic balance is required in performing normal daily activities such as walking, running, and climbing stairs (KINZEY & ARMSTRONG, 1998). Two tests are generally used: the Timed-up and go test and the Step Test.

3.5 MORPHOLOGICAL ASPECTS AND AGING

Age-related changes in muscle "quality" contribute to changes in skeletal muscle quantity and to the loss of muscle function in old age. The aging of human skeletal muscle has a reduced proportion of glycolytic type II muscle fibers (LARSSON, 1983) and a decrease in the contractile capacity of the muscle fiber (LARSSON et al., 1997).

In aging process, there is an increase in the accumulation of adipose tissue around the muscle concomitant with a reduced cross-sectional area of the muscle (BAUMGARTNER et al., 1995; BORKAN et al., 1983). This regional parameter of body composition has been associated with reduced capacity of oxidative enzymes (SIMONEAU et al., 1995) and insulin resistance (GOODPASTER et al., 1997) in muscle. Muscle-wasting diseases, such as Duchenne muscular dystrophy, are also characterized by reductions in muscle mass and muscle attenuation, coinciding with impaired muscle function (ZHAO et al., 2009).

The low amount of muscle mass is associated with poor functional performance and self-reported disability (STERNFELD et al., 2002; VISSER et al., 2005). In addition, there is a change in muscle composition (BORKAN et al., 1983; OVEREND et al., 1992b) with increased fat infiltration. There is significant association among amount of fat infiltration in muscle, muscle strength and mobility performance (GOODPASTER et al., 2001; VISSER et al., 2005). The increasing infiltration of fat into the muscle with aging may be important if not central aspect of sarcopenia (VISSER et al., 2005).

However, the actual functional outcome of architectural alterations will also depend on tendon stiffness, because the force developed by the contractile component is not only affected by muscle architecture but also by the mechanical properties of the tendinous structures in series with the contractile component (NARICI & MAGANARIS, 2006). It is known that older tendons are approximately 15% more compliant (MAGANARIS & PAUL, 2002) and the cross sectional area is 22% bigger than younger tendons (MAGNUSSON et al., 2008). This difference occurs due to changes in tendon composition.

Studies show that with aging, there is an increase in non-reducible collagen crosslinking; reduction of collagen fibril crimp angle; increased elastin; reduction of extracellular water content and mucopolysaccharide; and increased type V collagen (KJAER, 2004; TUITE et al., 2007). This combination of factors has two clear implications: primarily for a number of serial sarcomeres in a fiber, an older tendon stretches more in muscle contraction, making the sarcomere shorten more (CUTTS, 1988; HERZOG et al., 1991). Thus, there is a reduction in contractile force due to overlapping of filaments is smaller (NARICI & MAGANARIS, 2006). Furthermore, a more compliant tendon requires a longer time to be stretched (WILKIE, 1949), i.e., the oldest tendons have a reduced ability to transmit contractile force to bones and muscles (DAVIES et al., 2009; NARICI et al., 1996).

Identify parameters that can influence the transmission of forces, especially in distal structures can help develop effective training programs for the prevention of falls (BOHRER et al., 2018). Epro and colleagues (EPRO et al., 2018) carried out a study with induced stumbling on the treadmill in older adults and found that 30% variability of the support base and 21% of stability margin may be related to variance of sural triceps strength and tendon stiffness. It is suggested in the study, based on the electromyographic signal of the triceps sural during stumbling, that the greater force of this musculature and stiffness of the Achilles tendon in the stronger group can facilitate the generation of greater magnitudes and rates of plantiflexion, creating a placement more effective recovery limb after stumbling. However, the studies did not directly analyze the articular moments during the stumbling, failing to bring the exact magnitudes of plantiflexion that may be influenced by the quality of the triceps sural and the Achilles tendon.

4 MORPHOLOGICAL PROPERTIES OF TRICEPS SURAL RELATED TO PHYSICAL ACTIVITY AND FALL HISTORY IN OLDER WOMEN

4.1 INTRODUCTION

Aging has been related to a significant decline in neuromuscular function, reduced muscle mass and strength, and diminished general performance (LORD et.al., 2007). These declines are present in the early phases of the senescence, even in well-conditioned older adults (DOHERTY, 2003). Changes in central and peripheral nervous system innervation (DELMONIACO et al., 2009), inflammatory effects (DOHERTY, 2003) and intrinsic properties of muscle joints and tendons (FRONTERA et.al. 2000) have been pointed out as the main underlying mechanisms responsible for the reduced muscle mass and strength. Muscle mass reduction – also referred to as sarcopenia (CHOU et al., 2012) – impacts on daily activities, loss of mobility, independence, and increased risk of falls in older adults (PERRACINI & RAMOS, 2002).

Strength and power reduction of the ankle extensors and flexors muscles are potential risk factors for falls (SKELTON et al., 2002) due to the large torques required to reestablish balance when the center of mass exceeds the stability limits (LAROCHE et al., 2010). The ability of the ankle muscles to generate rapid force (TSCHOPP et al., 2011) is essential to recover balance after a trip (PAVOL et al., 2001) and also plays a vital role to maintain balance in a quiet standing posture (VAN DEN BOGERT. et al., 2002).

The aging process does not affect only the ability of the muscles to produce force but also reduces the tendon stiffness, especially the triceps sural (TS) muscle-tendon unit (PIJNAPPELS et al. , 2008). It is well known that older tendons are approximately 15% more complacent than their younger counterparts due to increased cross-linking of non-reducible collagen, increased elastin, collagen type V, among others (KJAER, 2004; TUITE et al., 2007). Thus, less rigid tendons have diminished capacity to transmit contractile force to bones and muscles (DAVIES et al., 2009; NARICI et al., 1996). Therefore, low stiffness may cause low torque generation rate and delayed sensorial information regarding the changes in muscle length. Delays in the afferent feedback may difficult balance recovery and increase the chances of falling (PIJNAPPELS et al. , 2008). The quality of the TS muscles may also play a role in the stiffness regulation (FUJIWARA et al., 1982; NADEAU et al., 1999) as they are prone to fat infiltration. Infiltrated fat reduces the contractile fibers and decreases strength (MORSE et al., 2005), especially in the fast-twitching fibers of the gastrocnemius (EVANS & LEXEL, 1995; FUJIWARA et al., 2010).

In order to minimize the effects of sarcopenia, some studies have tested the effects of several physical activities on the tendon stiffness (FERRI et al., 2003; FRONTERA et al. 2000; SUETTA et al., 2004). For example, Epro and colleagues (EPRO et al., 2018) carried out a 14 weeks training program of resistance exercises and observed a 22% increase in the stiffness of the TS tendon. It is likely that more active older adults, with a higher physical activity profile, have greater tendon stiffness than their less active counterparts. So far, no studies have analyzed the TS tendon stiffness and the infiltrated fat muscle content concerning physical activity level and fall history.

This study aimed to compare the TS muscle-tendon unit stiffness and the infiltrated fat muscle content of older women regarding their fall history and physical activity level. It was hypothesized that older women with fall history present lower TS tendon stiffness than their counterparts without fall history. It was also hypothesized that older women with low physical activity level present larger amounts of infiltrated fat in the TS than physically active older adults.

4.2 MATERIALS AND METHODS

4.2.1 Participants

Thirty-one older women (67.0 ± 3.0 years; 71.0 ± 14.0 kg; 1.58 ± 0.1 m) living independently in the community were invited via telephone and agreed to participate. Although the contact to participate in the study included men and women during the recruitment phase, only women volunteered. All participants signed a consent form approved by the Ethics Committee of the University. Participants with previous TS rupture, TS pain or injury (e.g., tendinopathy) within the last five years, peripheral neuropathies and any other musculoskeletal impairments of the lower limbs (e.g., ankle joint pain) were not included in the study. As well as old adults who have mobility deficits assessed by the time of execution of the Timed up-and-go Test (TUG) higher than the following cutoff points (BOHANNON, 2006): 65-69 years: 8.1s; 70-79 years: 9.2s; 80-99 years: 11.3s.

4.2.2 Experimental design

Participants made a laboratory visit to respond an anamnesis questionnaire and performed the TUG. While answering the questionnaire, participants remained comfortably sitting during approximately 15 minutes. At the end of the resting period, the ECHO intensity evaluation was performed, followed by the determination of the muscle-tendon unit stiffness. In order to analyze the relationship between muscle performance (i.e., stiffness and infiltrated fat) and fall history in the last year, participants were allocated according to their responses to the questionnaire as fallers (FG; n=11) or non-fallers (NFG; n=20). To determine the relationship between muscle performance and physical activity level, participants were reallocated on to active (AG; n=18) and non-active (NAG; n=13) groups based on their responses to the physical activity level questionnaire as shown in figure 4.1.

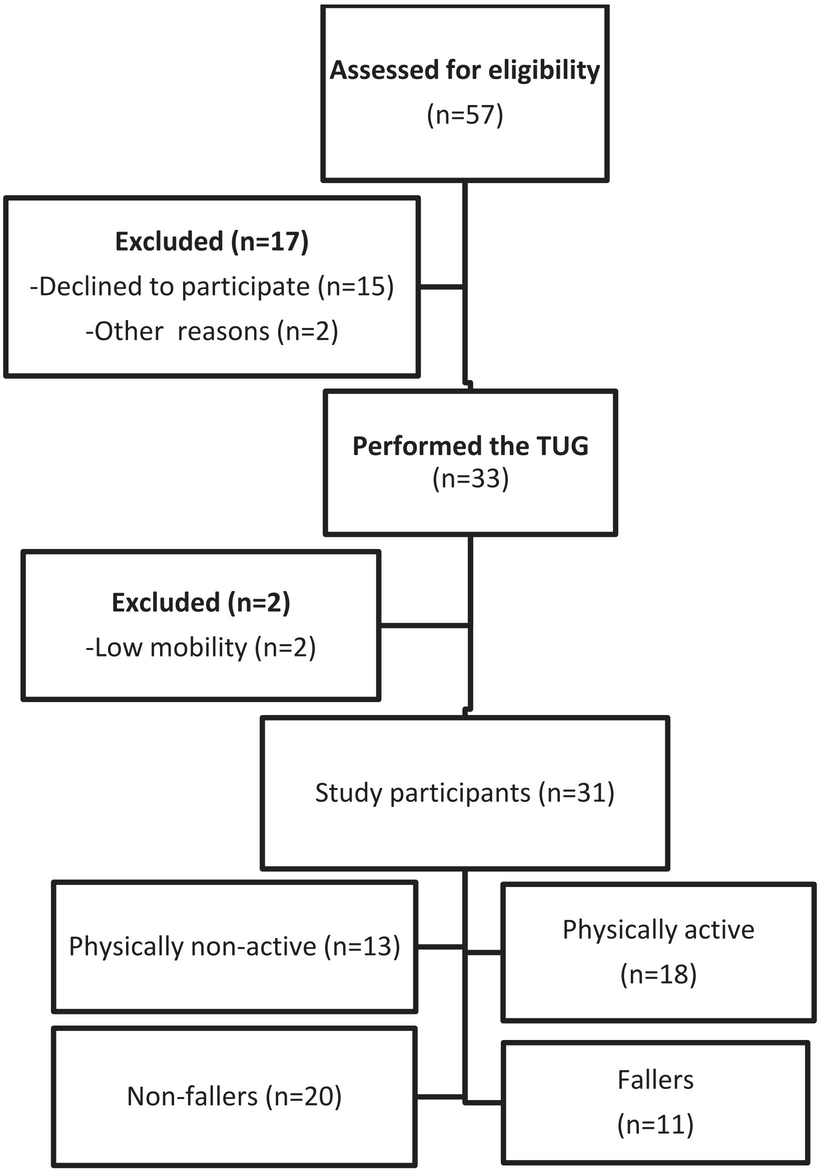

Figure 4.1 – Block diagram describing the recruitment and group allocation history

4.2.3 Fall history

The fall history was assessed by asking participants about their past fall episodes in the last 12 months. A fall was defined as any event in which a person inadvertently or intentionally comes to rest on the ground or another lower level (TIDEIKSSAR, 2002). Then, participants were allocated into two groups according to the fall history: fallers (FG, n= 11) and non-fallers (NFG, n= 20).

4.2.4 PHYSICAL ACTIVITY LEVEL

The physical activity level was determined using the long version of the IPAQ questionnaire (BENEDETTI et al., 2007). The participants were stratified into two groups according to the number of minutes of physical activity per week: physically non-active (NAG; < 150 minutes/week, n= 13) and physically active (AG; ≥ 150 minutes/week (BENEDETTI et al., 2012), n= 18).

4.2.5 Echo intensity

The participants were comfortably seated with their knee, hip and ankle joints positioned at 90° and with their feet fully resting on the floor. A real-time portable B-mode ultrasound apparatus (US) Sonimage HS1 Versão 1.10 (Konica Minolta Medical Imaging Inc. Newark-Pompton Turnpike, Wayne, NJ, USA) with a 10MHz linear-array transducer (4 cm width x 2 cm long) was used to obtain the muscle morphologic and the intramuscular fat of the triceps sural. The images were collected after a 15 min of rest. The participant's skin was marked with a dermatographic pencil at the largest portion of the segment. A thick layer of water-soluble conductive gel was applied to completely cover the surface of the skin. A set of markers were positioned on the measurement site in order to reconstruct the muscle structure. The markers were transversally positioned every 2 cm from the reference point towards the medial and lateral aspects of the thigh to produce a shadow on the image and also served as a guide to the US probe displacement. The figure 4.2 shows the setup of the echo intensity measurements.

Figure 4.2 – Schematic representation of the probe position during the echo intensity test.

Then, the US images were sequentially opened in the Power Point Program (Microsoft, Seattle, USA) and manually rotated until the entire fascia of the triceps surae muscle was aligned (LIXANDRÃO et al., 2014) as shown in figure 4.3. The images were measured and compared by means of pixel intensity and an evaluation using the ImageJ software (Version 1.5, National Institute of Health, Bethesda, MD, USA). The Software was calibrated over a known distance in the image. The pixels in the interest area was processed, resulting in a distribution of 256 shades of gray, being 0 = black and 255 = white. Thus, lighter pixels indicated non contractile tissue such as intramuscular fat, while darker pixels indicated underlying muscle tissue. The intensity of occurrence of fat infiltration was presented as USECHO demonstrated by the average values within the area of interest (medial and lateral gastrocnemius). Therefore, the higher the average, the greater the intramuscular fat present (DAMAS et al., 2016).

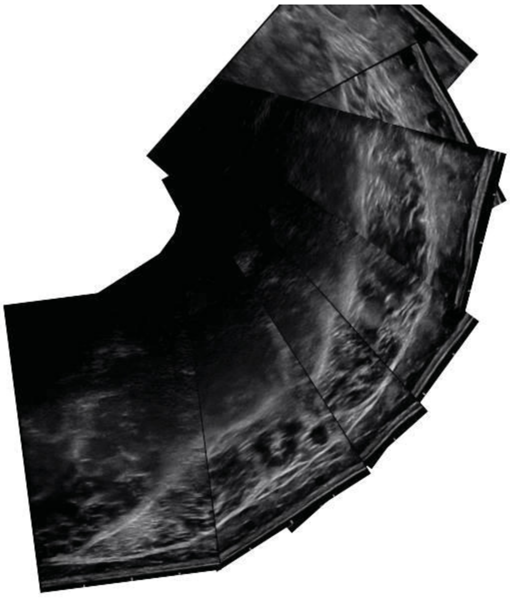

Figure 4.3 - Ultrasound image of the medial and lateral gastrocnemius muscles.

4.2.6 Achilles Muscle-Tendon Unit stiffness

The mechanical properties of the Achilles Muscle-tendon unit were determined at the proximal and distal aponeurosis site of the right leg, with the ankle in the neutral position and with the tibia perpendicular to the sole of the foot. The participants were seated in a rigid steel structure with the knee fully extended and the hip flexed at 90º. The foot was rest on an adjustable steel foot plate with a rotating mechanical shaft that was correspond to the lateral malleolus as shown in figure 4.4.

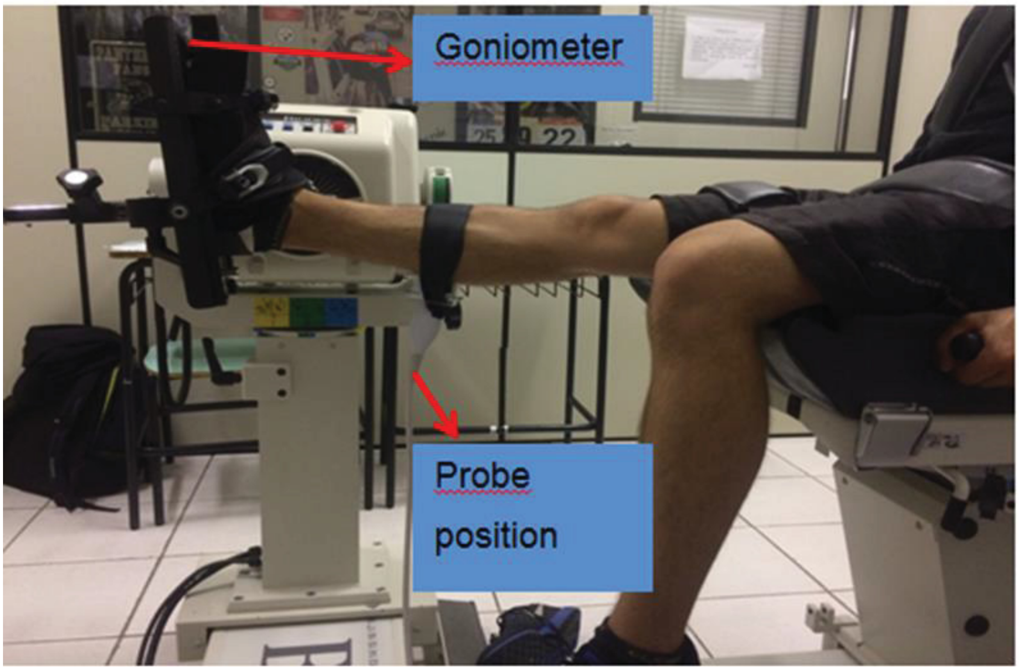

Figure 4.4 - The position of one participant during the stiffness assessment

Initially, the participants were requested to perform at least three vigorous and maximal plantar flexion efforts as a preconditioning trial of the muscle-tendon complex. Then, they were required to perform a maximal isometric of plantar flexion during 5s, while the displacement of the proximal aponeurosis, the plantar flexion force, and the ankle joint angle are measured.

4.2.6.1 Measurement of tendon displacement

A linear probe (Konica Minolta Medical Imaging Inc. Newark-Pompton Turnpike, Wayne, NJ, USA) with a 10MHz linear-array transducer (4 cm width x 2 cm long) was used. For the measurement of proximal aponeurosis displacement, the probe was positioned in the distal (caudal) part of the head of the medial gastrocnemius in the sagittal plane. The probe was firmly secured by a rigid acrylic plastic structure attached to the relevant segment. One reflective marker was positioned on the fifth metatarsal and a second one on the medial malleolus in order to control for probe displacements during the plantar flexion movement. A video camera (CASIO® EX-FH20) was positioned perpendicular to the markers and the images were processed in the Kinovea Software (Kinovea, Version 0.8.24).

The parallel echoes observed in the ultrasound image corresponded to the aponeurosis between the muscle fascicles (FUKASHIRO et al., 1995). The apponeurosis displacement was considered to represent the tendon displacement (mm). The S-VHS output video signal of the ultrasound apparatus was fed to a computer for data collection at a rate of 50 Hz.

4.2.6.2 Joint ankle joint rotation

The displacement of the tendon obtained from the ultrasonography images may be corrected to that attributed only to joint rotation. The passive angular rotation around a joint results in a considerable displacement of the muscle-tendon unit (SPOOR et al., 1990) and that the relationship between tendon displacement and angular rotation of the joint is linear (FUKUNAGA et al., 1996). Therefore, if any angular joint rotation occurs in the direction of plantar flexion during an "isometric" contraction, the tendon displacement was attributed to angular rotation and contractile tension. The angular rotation of the ankle joint, was controlled by an electric goniometer (EMG System, model SAS1000 V8) firmly attached to the lateral side of the foot, over the distal part of the fifth metatarsal and the lateral aspect of the fibula. The ratio between the tendon displacement (Δmm) and the angular rotation (Δrad) around the joint corresponded to the moment arm of the tendon (FUKUNAGA et al., 1996; SPOOR et al., 1990). Therefore, the product of the tendon moment arm and angular rotation (rad) results in the estimated displacement of the tendon caused by the isolated joint rotation.

4.2.6.3 Achilles tendon moment arm

The moment arm was defined as the perpendicular distance from the joint center of rotation (axis through the lower end of the medial and lateral malleoli) (SCHOLZ et al., 2008; ZHAO et al., 2009), for the muscle-tendon unit line of action (LoA). The lower tip of the medial and lateral malleolus was marked and two lines (D1 and D2) from each malleolus for the posterior aspect of the tendon were drawn on the skin. Subsequently, the foot was photographed on the lateral and medial sagittal planes (CASIO® EX-FH20). The length of lines D1 and D2 were measured using ImageJ software (Version 1.5, National Institute of Health, Bethesda, MD, USA), and the average of these two measures was calculated. (M1).

Thereafter, a linear ultrasound probe (Konica Minolta Medical Imaging Inc. Newark-Pompton Turnpike, Wayne, NJ, USA) with an 10MHz linear-array transducer (4 cm width x 2 cm long), was used to obtain a sagittal plane ultrasonography (US) image of the muscle-tendon unit. In this image the intersection lines D1 and D2 indicated by a steel needle and the perpendicular distance (M2) of the intersection D1-D2 to the tendon. The LoA measured using the ImageJ software. The arm was calculated as: MA = M1 - M2 (Zhao et al., 2009). Figures 4.5 and 4.6 show the parameters used to calculate the AT moment arm:

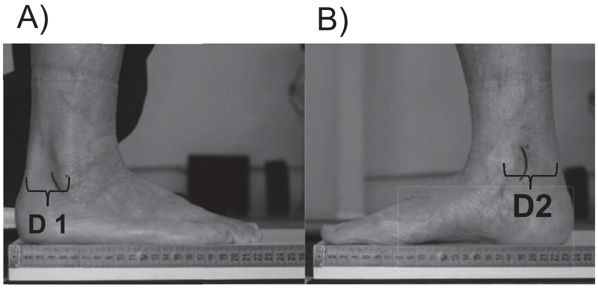

Figure 4.5 – Representation of the skin markers from the lateral (a) and medial view (B) of the joint ankle used to determine the ankle joint moment arm

Figure 4.5 shows the standardized picture of the lateral (A) and medial (B) aspects of the left foot placed on an aligned position and on a reference scaled block. The horizontal distance from the lateral and medial malleolus to the Achilles tendon was determined. The mean distance of D1 and D2 was calculated as M1. A long transducer was used to visualize the intersection of lines D1and D2 (steel needle) and the AT line of action (LOA). From this image the distance from the D1–D2 intersection to the AT LoA was measured as M2. The Achilles tendon moment arm was calculated as MA=M1−M2.

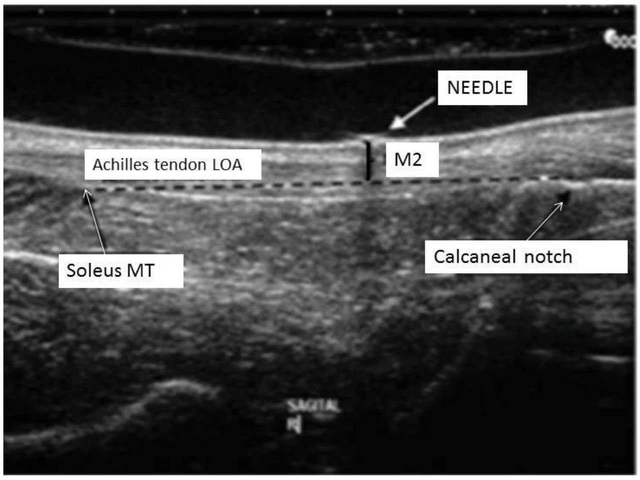

Figure 4.6 – Ultrasound back view image used to determine the ankle joint moment arm.

4.2.6.4 Muscle-tendon unit stiffness

The measured torque (TQ) during isometric plantar flexion was used to calculate muscle-tendon unit force (Ft) by the following equation:

$$Ft = TQ.MA^{-1}$$

where, MA is the moment arm length of the TS measured with the ankle joint positioned at 90°. The stiffness ($N.mm^{-1}$) was calculated from the load displacement relationship between 50 and 100 % of the MVC (MAGANARIS & PAUL, 2002).

4.3 STATISTICAL ANALYSIS

The Shapiro-Wilk test was used to confirm the normal distribution of stiffness and TS fat infiltration. The t-test for independent measures was used in order to compare: a) fall history (FG vs. NFG) and; b) physical activity level (SG vs. AG) The significance level was set at $p<0.05$ and was calculated the effect size (ES) using Cohen's *d* coefficient. All statistical analyses were performed using the SPSS Statistical Software package (version 17.0).

4.4 RESULTS

The physical characteristics of the participants, fat infiltration and TS tendon stiffness of the groups according to fall history (FG and NFG) and physical activity level (AG and NAG) are presented in table 4.1 Fat infiltration and TS tendon stiffness (STF) did not differ when the fall history was considered (FG vs. NFG). When the physical activity level was compared, the NAG presented higher fat infiltration than the AG. In particular, the lateral gastrocnemius (LG; 15.2%), the medial gastrocnemius (MG; 19.4%) and soleus (SOL; 15.2%) of the NAG presented higher fat infiltration in comparison to the AG. The stiffness of the triceps sural tendon of the AG was greater than that observed in the NAG.

Table 4.1 - Mean (±SD) of fat infiltration of the lateral gastrocnemius (LG), medial gastrocnemius (MG) and soleus (SOL) and the muscle-tendon unit stiffness (STF) for older adults with (FG) and without (NFG) fall history and physically active (AG) non-active (NA).

	Fall History				**Physical Activity Level**			
	FG (N=11)	NFG (N=20)	*p*	ES	NAG (N=11)	AG (N=20)	*p*	ES
LG (u.a)	66.11±9.38	71.49±14.16	0.51	0.45	76.24±16.91	66.18±8.66	0.02	0.85
MG (u.a.)	63.57±10.23	64.61±10.65	0.70	0.10	71.81±9.14	60.14±8.63	0.04	1.35
SOL (u.a.)	42.46±6.40	43.06±7.01	0.49	0.09	46.61±6.05	40.45±5.75	0.05	1.07
STF (N.mm^{-1})	114.23±69.93	104.55±61.58	0.70	0.09	51.91±22.96	147.69±51.73	0.03	2.24

LG – fat infiltration in lateral gastrocnemius; MG – fat infiltration in medial gastrocnemius; SOL – fat infiltration in soleus; STF – Triceps sural muscle-tendon unit stiffness; ES - Effect Size; FG: Fallers Group; NFG: Non-fallers Group; NAG: Non-active Group; AG: Active Group.

4.5 DISCUSSION

This study was designed to compare the stiffness of the Achiles muscle-tendon unit and the fat infiltration of the lateral gastrocnemius, medial gastrocnemius, and soleus muscles of older women regarding fall history (with and without fall history). In addition, the relationship between the stiffness of the Achiles muscle-tendon unit and the fat infiltration and physical active status (active and non-active) were also analyzed. The main findings indicated that non-active physically older adults present lesser stiff tendon and higher fat infiltration in all triceps sural muscles than the more physically active counterparts. Besides, fall history was neither differences in stiffness nor to fat infiltration.

There are arguments that less stiff tendons produce delayed sensorial information (NARICI & MAGANARIS, 2006), diminished ability to promptly generate large and fast torques (WILKIE, 1949) and, as a consequence, it may lead to increased risk of falls. Besides, a substantial amount of infiltrated fat also reduces the ability of the muscles to produce force rapidly (GOODPASTER et al., 2001), which may further contribute to increase the latencies for fast responses (VISSER et al., 2005). From a theoretical point of view, the additive effect of these two components (low stiffness and high amounts of infiltrated fat) would make older adults more prone to experience a fall. Indeed, there is evidence that the triceps sural weakness and more compliant tendons limit the ability of adults to effectively increase the base of support and regain dynamic stability after an unexpected disturbance during walking (EPRO et al., 2018). Nevertheless, fall history was not related to the muscle-tendon unit or fat infiltration. Several arguments can be forwarded to explain these results. The first refers to the use of a retrospective questionnaires to assess fall history, which is prone to errors due to senile cognitive changes and memory deficits (GREENE et al., 2014; ROSENBLATT; GRABINER, 2012). There is also some evidence reporting a number of psychological effects after a fall (e.g., increased fear of fall; changes in fall risk awareness) that may influence several physical and muscular outcomes (LORD et al., 2007). In addition, the ability to reestablish balance after a trip does not rely exclusively on the ability of the lower limb muscles to generate strength and power or the properties of the muscle-tendon units to transfer such forces. It seems that a far more intricated set of components (e.g., coordination, balance, solving dual-task demands, perceptive and cognitive aspects, etc.) plays a determinant role (HORAK, 2006). Indeed, physical function is influenced by other sensorial perceptive and cognitive aspects that do not depend only on the ability of the muscle-tendon units to produce and transfer strength and power. Therefore, the hypothesis H_1 that older adults with fall history have higher gastrocnemius echo intensity than older adults without fall history was rejected. Moreover, the hypothesis H_2 that older adults with fall history have less stiff Achilles tendon than older adults without fall history was also rejected.

On the other hand, muscle-tendon unit stiffness and infiltrated muscle fat were associated with the physical activity level. There is robust evidence suggesting that the stiffness of the triceps sural increases in response to long-term mechanical loads applied in exercise routines (increases of 23% in triceps sural stiffness) (EPRO et al., 2018). The structure and dimensions of the triceps sural become more able to sustain and transfer greater mechanical loads in response to training. Indeed, the results support such findings in human and animal models (BUCHANAN & MARSH, 2001; WOO et al., 1980), as there was a 35% difference in the triceps sural stiffness between the physically active group and their less active counterparts. Recently, Epro and colleagues also showed increases in stiffness and Young's modulus of older adult human tendons in response to resistive load exercises (EPRO et al., 2017). Interestingly, training-induced increases in muscle-tendon unit stiffness have been associated with a 25% faster development of joint torque. Therefore, some functional activities which require a rapid generation of joint torque or rely on fast afferent information may benefit activities such as walking fast or even while recovering from a trip or slip is required (DAVIES et al., 2009; NARICI et al., 1996). Consequently, the hypothesis H_3, that active older adults have greater Achilles tendon stiffness than non-active counterparts, was accepted.

The lower amount of fat infiltration of the dorsiflexor muscles in the more physically active group is in line with other reports, that indicated less fat infiltration in the physically active groups in comparison to the non-active groups

(KENT-BRAUN et al., 2000). It may also influence functional performance as it impacts on the ability of older adults to produce power (RECH et al. 2014). It has been demonstrated that regular training reduces muscle fat infiltration and influences the functionality and quality of life of older adults (CADORE et al., 2014; FUJIWARA et al., 2010). A significant association between the amount of fat infiltration and functionality has been reported (GOODPASTER et al., 2001; VISSER et al., 2005). Therefore, the hypothesis H_4, that active older adults have smaller gastrocnemius echo intensity than non-active counterparts, was accepted.

Some limitations must be considered while interpreting the findings of the present study. First, the number of subjects is not expressive, although the number of older adults with fall history was relatively high with respect to the rates reported in the literature. Second, the use of retrospective approaches to determine fall history is a limiting factor because memory issues can not be controlled and may cause underreporting. Third, other variables that have a direct influence on the fall rate and that may be impacted by a more complacent tendon were not measured, for example reaction time, strength and muscle power.

4.6 CONCLUSION

The comparisons showed a substantial difference in muscle fat infiltration and tendon stiffness when active and non-active older adults were compared. However, no differences in muscle fat infiltration and tendon stiffness were found between fallers and non-fallers older adults. It may have occurred due to the use of a questionnaire based on the recall of falls, which does not take into account changes in the lifestyle after a fall. Cognitive and memory issues related to the ageing process may also influence the ability to report fall episodes accurately. Therefore, studies using induced tripping and other variables that encompass multifactorial characteristics of falling are required, (e.g., reaction time, strength and muscular power).

The next chapter was designed to provide a broader relationship between sural triceps fat infiltration and Achilles tendon stiffness, with respect to a set of parameters that may influence falls in older adults, especially the ability of the participants to react promptly to a sudden perturbation.

5 THE RELATION BETWEEN TRICEPS SURAL MORPHOLOGICAL PARAMETERS AND REACTIVE CAPACITY OF FALLERS AND NON-FALLERS OLDER ADULTS

5.1 INTRODUCTION

Approximately one third of older adults living in the community fall at least once a year, from which 5-30% suffer serious injuries or even death (MADIGAN et al., 2014). The exponential increase in the number of age-related falls has been associated with the biological changes inherent in the natural senescence process. This process is accompanied by an important functional decline that is marked by pronounced decrease in neuromuscular performance (DOHERTY, 2003; FRONTERA et al., 2000). These declines are characterized by reduced muscle strength, power and postural control difficulties (PIJNAPPELS et al., 2008; SIEGEL et al., 2004).

The deterioration of the postural control system causes delays to detect and integrate relevant sensory information, select the best response and may result in longer overall reaction times. The ability to perceive an external disturbance (e.g., stumbling), choose an appropriate response and timely recruit appropriate muscle groups are key aspects to restoring balance and preventing a fall (FREITAS JÚNIOR & BARELA, 2006). There is a plethora of factors that may contribute to these age-related changes, including changes in muscle morphology (e.g., muscle quality – (DELMONIACO et al., 2009) and increased passive tissue stiffness – (MAGANARIS, 2002)), which may impact on muscle strength and torque generation (LIN & WOOLLACOTT, 2005), and ultimately influence the ability of older adults to react timely and recover balance to avoid a fall.

Delmonico and colleagues found differences in muscle composition and quality (i.e., infiltrated fat) in the older adults in comparison to young counterparts (DELMONIACO et al., 2009). The ability of the muscles to generate large amounts of force and power are also influenced by the stiffness of the tendon (NARICI & MAGANARIS, 2006). A training-induced increase in muscle tendon stiffness has been associated to a 25% faster development of joint torque (NARICI & MAGANARIS, 2006a). Therefore, functional activities requiring a rapid generation of joint torque or to recover balance after a trip or slip may benefit from these adaptive responses. However, no studies have found conclusive evidence that muscle quality and tendon stiffness may influence the reaction time and, consequently, reduce the risk of falls in older adults.

In addition, fallers and non-fallers are categorized is problematic as retrospective and / or prospective models are prone to errors due to memory and cognitive deficits (GREENE et al., 2014; ROSENBLATT et al., 2017). Another problem with retrospective and prospective studies is that they assume that all physical assessments performed up to one year before or after a fall are still representative of the participants' physical activity status at the time of the event. These studies also disregard changes in regular physical activity status after a fall event. Thus, methodological issues may cloud the identification of fallers and non-faller older adults.

Therefore, this study aimed to analyze the impact of morphological changes, on the ability of the gastrocnemius muscle to generate strength and power and the influence on reaction time of older adults that are able (i.e., non-fallers) and unable (i.e., fallers) to recover balance after a controlled laboratory-induced trip. The older adults who were able to recover balance after tripping were allocated in the non-fallers, while those who were not able to recover balance were allocated in the fallers group.

5.2 METHODS

Ninety older adults were invited via telephone, but only fifty-one individuals, living independently in the community and from both sexes (67.0 ± 3.0 years; 71.0 ± 14.0 kg; 1.58 ± 0.1 m) volunteered to participate in the study. Participants signed a consent participation form approved by the Ethics Committee of the University. The exclusion criteria are described in the previous chapter (item 4.2.1). Older adults with mobility deficits were not included in the study. The older adults with a time greater than the following cutoff points were excluded: 65-69 years: 8.1s; 70-79 years: 9.2s; 80-99 years: 11.3s (Bohannon, 2006). Figure 5.1 shows the schematic representation of the participants' recruitment and allocation.

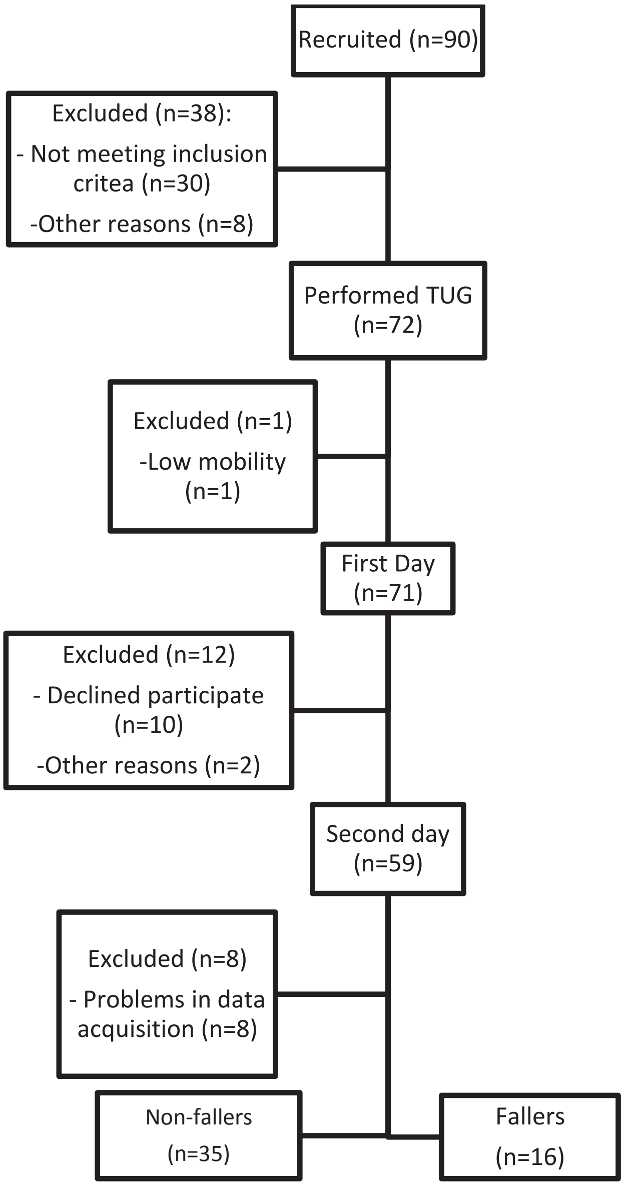

Figure 5.1 – Block diagram describing the recruitment and group allocation history.

5.2.1 Experimental design

In the first visit to the laboratory, participants responded to an anamnesis questionnaire, had their anthropometric measures assessed and performed the TUG test. While answering the questionnaire, participants remained comfortably sitting during approximately 15 minutes. At the end of the resting period, the

ECHO intensity evaluation was performed, followed by the determination of the muscle-tendon unit stiffness. Then, participants attended a second visit to the laboratory from 24-48h after the first one. In this second visit, the reactive capacity was the first test and was followed by the test used to determine the ability to recover balance after an induced trip. Participants that were not able to recover balance after being tripped were allocated in the group of “fallers” (FG; n=16), while those who were able to recover balance in the group of “non-fallers” (NFG; n=35). The reader should have in mind that “non-fallers” and “fallers” refer to the outcome of the trip test used to classify the participants that were able and not able to recover balance, respectively.

5.2.2 Experimental procedures

5.2.2.1 Reactive capacity assessment

The reactive capacity was assessed using the step execution test (Melzer et al., 2007). A three-dimensional force platform AMTI (Advanced Mechanical Technology, MA, USA) 46.4 mm long and 50.8 mm large (OR6-7-2000) coupled to a signal amplifier (GEN 5), sampling at 100Hz, was used to determine the ground reaction forces during the test and allowed the calculation a number of reactive capacity parameters.

The reactive capacity requires specific and integrated actions of the lower limbs in order to reposition one of the segments after a disturbance stimulus. The participants were instructed to remain in a quiet orthostatic position on the top of the force platform, with a comfortable base. Participants were instructed to stare at eye level fixed point located 2m away. The participants were instructed to perform a step forward "as soon as possible", immediately after a manual percussion applied to the calcaneus. A short familiarization period was carried out prior the actual test. Then, three trials were performed and recorded for analysis purposes.

The ground reaction force data and moments used to identify four events: initial stimuli (C), start of step (A), loss of foot to ground contact (FO), foot contact with ground (FC) (MELZER et al., 2007). The process carried out by means of a specific routine developed in Matlab® software (Mathworks Inc.). From the events, four temporal parameters were calculated: step start phase (FI), preparation phase (FP), balance phase (FB) and total time (TT) as shown in figure 5.2. The average of three trials was used for analysis purposes.

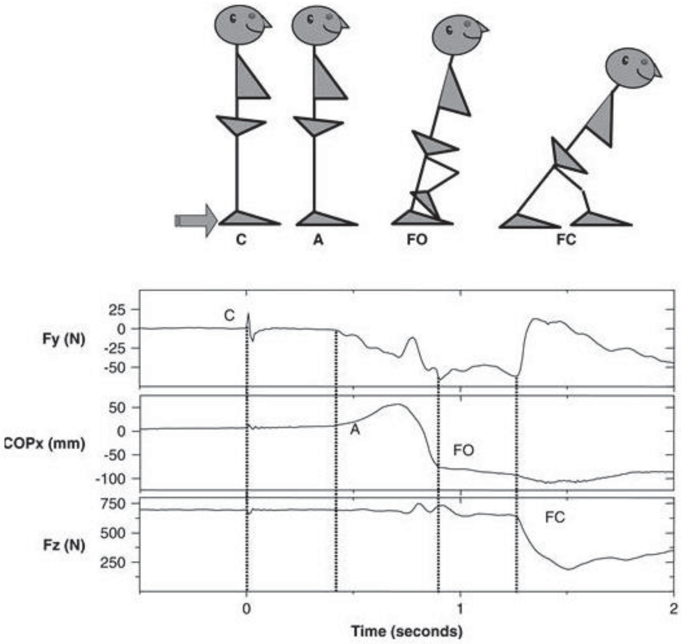

Figure 5.2 – Example of a participant's reactive capacity test (step test).

NOTE: Initial stimuli (C); beginning of step (A); loss of foot to ground contact (FO); foot to ground contact (FC); step start phase (IP); preparation phase (PP); swing phase (SP); time of foot withdrawal (RT) and total time (TT). Fy = anteroposterior component of ground reaction force; Fz = vertical component of FRS; COPx = mid-lateral pressure center. Source: Melzer et al., 2007.

Melzer and colleagues (MELZER et. al., 2007) defined the step test phases as: initial phase (IP) - a phase associated with executive function, which includes peripheral sensory detection, afferent and efferent conduction time, and central processing. Calculated by time from skin stimulation (detected by a spike greater than 3 standard deviations above the basal signal of the FRS antero-posterior component) to the beginning of the step (defined as the first mid-lateral deviation of the center of pressure toward the leg balance (greater than 4mm from basal displacement); the preparation phase (PP) – a phase associated with preparing postural control for step execution. Calculated from the time from the start of the step to the foot removal (defined as a sudden change in the lateral curve of the center of pressure towards the support foot); the swing phase (SP) – a phase associated with muscle power and defined as the time from foot removal to foot contact with the ground (defined as the onset of weight discharge in the FRS vertical component); the total time (TT) – the test total execution time from skin stimulation to foot contact with the ground - provides important information about the ability of a person to withstand a fall.

5.2.3 Echo intensity

The procedures used to determine the ECHO intensity are described in the item 4.2.5.

5.2.4 Achilles Muscle-Tendon Unit stiffness

The procedures used to determine the Achilles muscle-tendon unit stiffness are described in the item 4.2.6.

5.2.5 Muscular function

The muscle function was characterized by the muscle strength and power parameters of the ankle joint. The Biodex Multi-joint System 3 (Biodex Medical Systems, Inc. Shirley, NY, USA) dynamometer was used. Prior to the test, participants were familiarized with the assessment. Three maximal concentric repetitions of ankle extensor and flexor muscles of the dominant segment were performed. The test speed was set at 60 and $180°.s^{-1}$. Dominance was assessed by asking the participants' preference for kicking a ball (DEAN et al., 2004). The tests were carried out from a standard initial positioning, according to the manufacturers' instructions (Biodex System 3 Pro). The position of one participant during the assessment is shown in Figure 5.3

Figure 5.3 - Positioning of a participant during the ankle muscle function test.

5.2.6 Tripping test

To evaluate the ability to recover balance after an induced trip under a laboratory-controlled condition, a customized system was specially built. The system is operated by an electronic circuit mechanism operated by a trigger button. When the system is activated, a wire (polypropylene) is stretched perpendicular to the walkway, at a high of 0.10m, to obstructing the swinging leg and causing a trip during the mid-swing phase. Other false wires (dummy wires) were placed along the walkway to avoid identification of which wire would cause the perturbation (BOHRER, et al., 2018).

The participants wore a full-body harness (Altiseg®, Brazil), which was connected by a rope to a rail fixed on the ceiling of the laboratory. The safety system did not interfere in the balance recovery and was adjusted so that the participants were not able to touch the ground if they were unable to recover balance. Figures 5.4 and 5.5 indicates the tripping mechanism components and the figure 5.6 an example of a participant that was unable to recover balance after the induced trip.

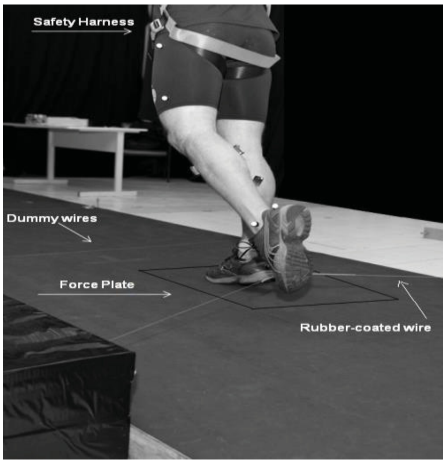

Figure 5.4 - Operation of tripping mechanism at the instant the walking disturbance was applied.

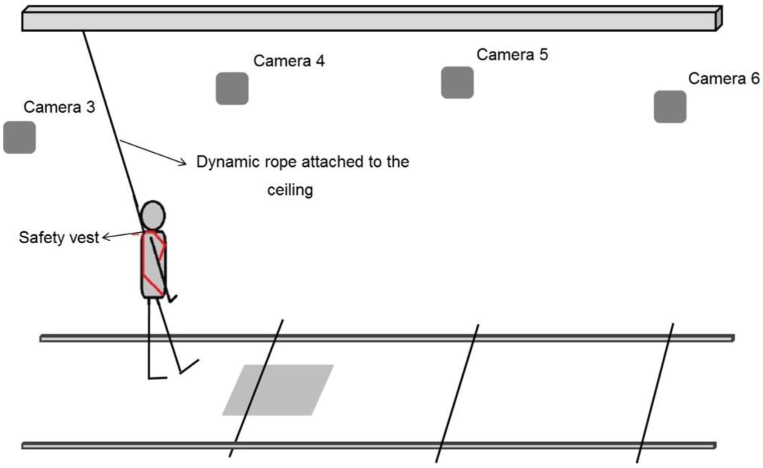

Figure 5.5 – Schematic representation of tripping site configuration as well as individual safety equipment.

Figure 5.6 – Sequence of images of a participant that was not able to recover balance after the trip. The figure also shows the safety mechanism.

5.2.7 Statistical analysis

The Shapiro-Wilk test was used to confirm the normal distribution of stiffness, TS fat infiltration. The Cohen's kappa agreement coefficient (COHEN, 1968) was calculated to determine the agreement between the laboratory-induced trip test outcomes and the questionnaire applied to determine fall history. It was assumed that the non-fallers, as determined by the fall history questionnaire, were able to recover balance in real-life. The Pearson correlation test was performed to determine the association between STF and with ankle power (AP); total step test time (TT); swing phase time (SPT); initial phase time (IP) and the preparation phase time (PP). A number of independent t tests were applied to identify differences between FG and NFG. The significance level was set at $p<0.05$ and was calculated the effect size using Cohen's d (WASSERTHEIL & COHEN, 1970). A logistic regression analysis was performed to determine whether the STF, fat infiltration and the reactive capacity could predict falls in older adults. Thus, the model included TT, GM and STF as independent variables and fall history as a dependent variable (FG and NFG). There was no missing data in all the analyses. The logistic regression, the Chi-squared and the Kruskal Wallis levels of significance were set at $p<0.05$. All statistical analyses were performed using the SPSS Statistical Software package (version 17.0).

5.3 RESULTS

The descriptive statistics of the analyzed variables are shown in the Table 5.1. The results point to a difference in the FTS between the groups of falling and non-falling. The other variables analyzed were similar between groups ($p> 0.05$).

Approximately one-third of the participants (35.6%) were unable to recover balance after the induced trip and were classified as fallers (FG). The agreement between the experimental and the questionnaire applied to identify fall history was moderate (Cohen's kappa coefficient, k=0.55) (Watson and Petrie, 2010).

Table 5.1 - Mean (±SD) of physical characteristics, fat infiltration of the lateral gastrocnemius (LG), medial gastrocnemius (MG), muscle-tendon unit stiffness (STF) and the reactive capacity parameters from non-fallers (NFG) and fallers (FG) older adults.

Variables	**NFG (n=29)**	**FG (n=16)**	**p**
Age (years)	70.29±5.28	70.36±5.31	0.77
Stature (m)	1.61±0.08	1.60±0.08	0.35
Body mass (kg)	69.53±10.71	67.98±10.17	0.63
BMI (kg/cm^2)	26.98±4.09	26.52±4.13	0.18
STF (N/mm)	149.43±83.44	55.23±27.60	0.00*
GM (a.u.)	52.36±30.65	55.96±25.09	0.07
GL (a.u.)	49.56±29.30	61.14±26.61	0.09
Ankle power ($W.kg^{-1}$)	28.15±7.60	12.18±6.63	0.12
Initial phase (s)	0.22±0.16	0.26±0.23	0.06
Preparation phase (s)	0.48±0.30	0.35±0.34	0.58
Swing phase (s)	0.53±0.43	0.28±0.22	0.22
Total time (s)	1.23±0.75	0.84±0.67	0.85

BMI: body mass index. *p<0.05

There were no statistically significant differences between groups in the variables of age, stature, body mass and body mass index (p>0.05). Fat infiltration in the gastrocnemius was similar between groups (FG and NFG), irrespective of the muscle heads (Figure 5.7 a and b); lateral head (GL; p=0.47; ES=0.11) and medial head of the gastrocnemius (GM; p=0.14; ES=0.39). There was a difference between the stiffness of the Achilles tendon of fallers and non-fallers (Figure 5.7 c). There was a high correlation in fat infiltration between the GM and GL heads (r=0.90; p<0.01). It was observed a moderate correlation between the FI and FP (r=0.35; p=0.02); FI and FB (r=0.41; p=0.01); FI and TT (r=0.67; p=0.00); FP and FB (r=0.54; p=0.00). There was a high correlation between the FP and TT (r=0.86; p=0.00); FB and TT (r=0.90; p=0.00). In synthesis, the phases of the reactive capacity test were similar and did not differ between groups (p>0.05).

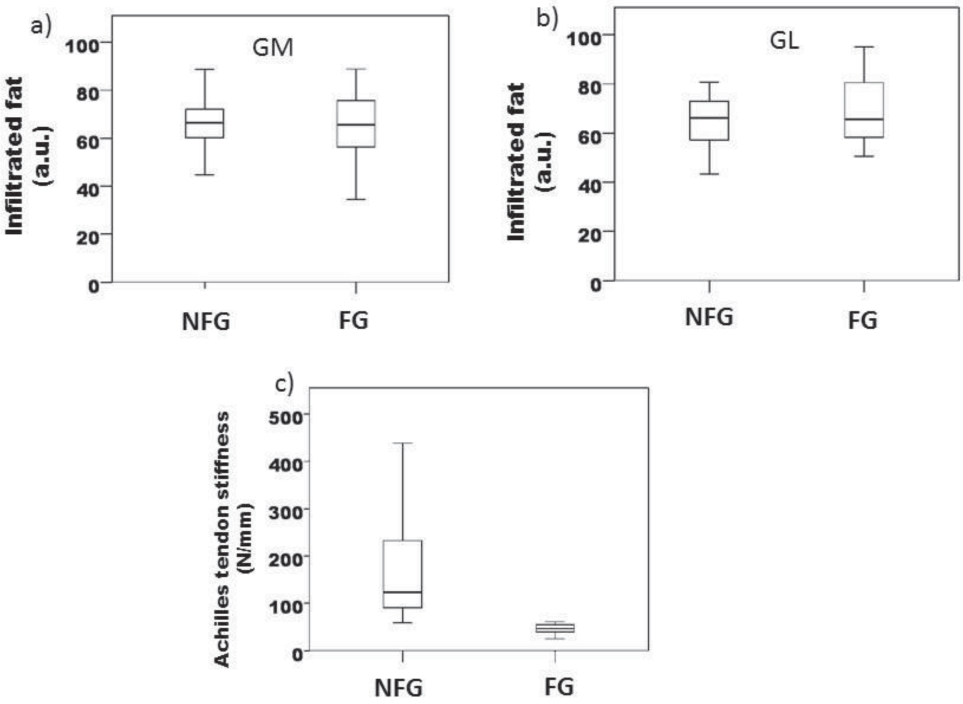

Figure 5.7 - Fat infiltration in Gastrocnemius Medialis (GM; a panel), Gastrocnemius Lateralis (GL; b panel) and triceps sural Achilles tendon stiffness (STF; c panel) between fallers (FG; n=16) and non-fallers (NFG; n=29) based on laboratory-induced tripping. The distribution center is indicated by the median line, in the center of the square. The upper line of the box indicates the 3rd quartile and the lower line indicates the 1st quartile. The dispersion of the data is represented by the range of the lines.

In the FG, a positive and moderate correlation between STF and ankle power; was found. The FG also presented a negative and weak correlation with IP. There was negative and moderate correlation between the SP, PP and TT of the reactive capacity test.

In the NFG, a positive and strong correlation between STF and ankle power was identified. The STF was also moderately correlated with the FP and TT, while a negative and weak association was found between STF, IP and TT in the NFG.

The intramuscular fat infiltration of both gastrocnemius heads showed no significant correlation with the reactive capacity test phases and ankle power.

The Pearson correlation coefficients between the muscle-tendon stiffness and the reactive capacity test of both groups are presented in Table 5.2.

Table 5.2 - Pearson coefficient correlation between the reactive time and muscular function with Achilles tendon stiffness and gastrocnemius fat infiltration.

	NFG (n=29)						**FG (n=16)**					
	STF ($N.mm^{-1}$)		**GM (a.u.)**		**GL (a.u)**		**STF ($N.mm^{-1}$)**		**GM (a.u.)**		**GL (a.u)**	
	r	p	r	p	r	p	r	p	r	p	r	p
Ankle power ($W.kg^{-1}$)	0.85	0.00*	-0.09	0.65	-0.10	0.62	0.66	0.01*	-0.42	0.11	-0.43	0.10
Initial phase (s)	-0.40	0.03*	0.07	0.73	0.13	0.52	-0.49	0.05*	0.20	0.45	0.19	0.48
Preparation phase (s)	-0.55	0.00*	0.15	0.45	0.10	0.60	-0.52	0.04*	0.46	0.07	0.45	0.08
Swing phase (s)	-0.42	0.02*	0.21	0.27	0.27	0.16	-0.62	0.01*	0.40	0.12	0.39	0.14
Total time (s)	-0.53	0.00*	0.19	0.33	0.21	0.27	-0.66	0.01*	0.45	0.08	0.44	0.09

*p<0.05; STF: Achilles tendon stiffness; GM: gastrocnemius medial fat infiltration; GL: gastrocnemius lateral fat infiltration. NFG: non-fallers group; FG: fallers group.

The results of logistic regression showed that STF and ankle power were able to predict falls. On the other hand, GM and TT of reactive capacity were not good fall predictors. The results of the regression analysis are shown in table 5.3.

Table 5.3 - Logistic regression results for fall prediction from muscular and reactive capacity responses in older adults

	B(SE)	Wald	p	OR (95 CI)
Constant	12.42 (5.19)	5.73	0.02*	247.46
STF (n/mm)	-0.06 (0.02)	9.24	0.00*	0.94 (0.90-0.98)
Ankle power ($W.kg^{-1}$)	-0.46 (0.18)	6.96	0.01*	0.63 (0.45-0.89)
GM (a.u.)	0.00 (0.00)	0.20	0.65	1 (1-1)
TT (s)	-0.53 (0.46)	1.33	0.25	0.59 (0.24-1.45)

*p≤0.05; STF: Achilles tendon stiffness; GM: gastrocnemius medial fat infiltration; GL: gastrocnemius lateral fat infiltration. OR = odds ration; (95 CI) = The significance level for model inclusion and exclusion were set at p<0.05 and p>0.10, respectively.

5.4 DISCUSSION

This study was designed to compare TS tendon stiffness and fat infiltration of the lateral gastrocnemius and medial gastrocnemius muscles of older adults who experienced a fall and those who did not experienced a fall after a laboratory-induced tripping.

It is known that approximately one-third of the older adults experience a fall at least once a year (FASANO et al., 2012). It is interesting to observe that using an induced trip to experimentally identify fallers from non-fallers resulted in a similar rate (35%). It may be advocated that tripping older adults in a controlled laboratory condition is more specific to identify those who were more prone to experience a fall from those who were not. Although the agreement between the two methods applied to determine falls (experimental vs questionnaire) was moderate, differences between methods were remarkable. The use of retrospective questionnaires are prone to memory deficits (ROSENBLATT & GRABINER, 2012), which are common among older adults. Older adults may present difficulties to remember fall events that did not cause significant or major injuries (GREENE et al., 2014). It is necessary to highlight the fact that physical activity status may also change after a fall and compromise several physical and physiological aspects used to discriminate faller from non-faller participants (MOREIRA et al., 2018). Furthermore, older adults may develop fear of falling and change their perceived fall risk after a fall event, which may ultimately influence their functional status and the risk of falling (PERRACINI & RAMOS, 2002).

A fall in older adults is caused by the interaction of several intricated and complex factors which are closely related to the decline of several systems (LORD et al., 2007). The declines in the ability of the muscular system to generate force and power have been considered as extremely relevant and to have a large impact on fall incidence. The strength and the power of the muscles spanning the ankle joint have been the focus of several studies, as these muscles play an essential role while recovering balance during a trip (LAROCHE et al., 2010). The mechanical properties of the tendinous structures present a significant role while generating fast responses (NARICI & MAGANARIS, 2006b). It is known that more complacent tendons require longer periods of time to be stretched and to transmit forces in comparison to stiffer tendons (WILKIE, 1949). Therefore, older and less stiff tendons are less able of transmitting fast forces and power than younger and stiffer tendons (NARICI et al., 2003). These differences are likely to have relevant implications for effectively reestablishing balance after a trip and avoiding a fall.

The data of the present study showed that older adults with stiffer triceps sural tendons (approximately 40% stiffer) were more successful to avoid a fall in comparison to their counterparts that experienced a fall after a laboratory-controlled trip was induced, that is, older adults with stiffer tendons have reduced chances of experiencing a fall by 6% (OR = 0.94). Moreover, the FG presents 39% less stiff tendons when compared to normative data (STENROTH et al., 2012), that is, the NFG Achilles tendon stiffness data were similar to those found in the literature. In addition, the stiffness of the FG was lower when compared to older adults that were able to recover balance in the present study and also when compared to the normative data. Therefore, older adults with less stiff tendons are more likely to not recover the balance after an induced trip. This finding corroborates with the current literature that greater stiffness optimizes force transmission (NARICI & MAGANARIS, 2006b), which may facilitate the recovery of dynamic stability after an unexpected disturbance (EPRO et al., 2017). This finding opposes those presented in the previous chapter. This reinforces the idea that retrospective fall questionnaires may not be suitable to identifying faller from non-faller older adults (GREENE et al., 2014). Therefore, the hypothesis H_5 that older people with less stiff triceps sural tendon would be more prone to falls was accepted.

From a theoretical point of view, more rigid tendons may optimize the transmission of forces from muscles to bones, in other words, it can be hypothesized that greater joint powers can be produced with a stiffer Achilles muscle tendon unit (NARICI & MAGANARIS, 2006b). The positive correlation between the triceps sural stiffness and the joint power of ankle extensors supports such arguments. There is evidence that faller older adults have only 10% of the ankle plantar flexor power, when compared to normative data (WHIPPLE et al., 1987). In the present study, the ability to produce torque rapidly (i.e., the ankle power) of the FG corresponded to 43.3% of the other group (i.e., NFG). In addition, the FG and NFG presented a plantar flexor power

27.0% and 51.1% greater than the normative data, respectively (WHIPPLE et al., 1987). The present study showed values of joint power above the data exposed in the literature. Although the power data was lower in the FG, it can be assumed to be still sufficient to restore balance. There must be a critical cutoff in which the ankle power becomes more critical and has a larger effect on the ability to recover balance.

The data regarding the ability to generate torque quickly corroborate with the literature, and point out that elderly fallers present greater deficits in power around the ankle (BENTO et al., 2010; PIJNAPPELS et al., 2005). The present study showed that the ability to produce large amounts of plantar flexor power around the ankle joint reduces the chances to experience a fall by 37% (OR = 0.67). In fact, the plantar flexor muscle group has been associated with falls because they are highly recruited during gait and because they play a fundamental role in maintaining balance after a postural disturbance (LAROCHE et al., 2010). However, with aging the plantar flexors experience greater deficits in comparison to other muscle groups (DEVITA & HORTOBAGY, 2000). These deficits are more pronounced in older adults fallers (peak torque, torque development rate and joint power) (LAROCHE et al., 2010) and may play a role to control the large angular momentum generated during a trip. Thus, it may result in a reduced ability to recover balance after a trip (PIJNAPPELS et al., 2005)(PIJNAPPELS et al., 2008). Therefore, the hypothesis H_6 that older adults with fall history have smaller plantar flexor power than those prone to falls was accepted.

It is known that exercise interventions in older adults emphasizing muscle power were successful in improving other fall-related variables such as the reaction time (BOHRER et al., 2018). Thus, it can be hypothesized an association between the reactive capacity test phases and the stiffness of the Achilles tendon. In fact, negative moderate correlations were observed between the STF and the phases of the reactive capacity test in both groups. Melzer and colleagues (MELZER et al., 2010) identified that recurrent fallers were significantly slower in all phases of the reactive test in comparison to non-fallers. However, no differences were found in the onset phase. The Initial phase indicates perceptual aspects and has no or little influence from the STF in the initial mechanisms. Differences between studies are difficult as the older adults analyzed by Melzer and colleagues were approximately 8 years older than in the current study and more advanced degenerative processes may be present, that is, perhaps the test used may not be able to capture these characteristics that would be more expressive in older groups. It must be also considered that the reactive capacity tests captures the time of each phase and do not encompass the actions performed around other joints (e.g., knee and hip joints), which may present different characteristics (e.g., stiffness, fat infiltration, etc.) and influence the overall outcome of the test.

There is a change in the accumulation of adipose tissue in the muscles with increasing age, which is concomitant with a reduced cross-sectional area of the muscle (BAUMGARTNER et al., 1995; BORKAN et al., 1983). These changes have been associated with loss of contractile muscle fibers (LARSSON, 1983) and reduced strength (VISSER et al., 2005), which may increase the older adults predisposition to experience a fall. Therefore, from a theoretical point of view, older adults with larger amounts of muscle fat infiltration are more likely to experience falls after an induced trip. However, these arguments were not confirmed in this study, as there were no differences in fat infiltration between those who were able and not able to recover balance after a trip in both muscle heads of the gastrocnemius (GM and GL). In the previous chapter, there was an important difference in the infiltration of fat between physically active and inactive older adults. This may have impacted on the analysis, since both groups were formed from their induced trip outcomes rather than their physical activity status. The analysis of the present study included only muscles of the calf, which may have reduced a more comprehensive association between muscle fat infiltration and the ability to recover balance after a trip. For instance, several studies have indicated a relevant role to other muscles of the lower limbs while recovering balance (e.g., quadriceps). Therefore, the hypothesis H_7 that older adults with fall history have higher gastrocnemius echo intensity than those prone to falls was rejected.

The multisystemic nature of sarcopenia, requires a broader understanding of fat infiltrated in the gastrocnemius and its influence on falls. Declines in muscle mass and muscle strength are well documented in aged older adults (FRONTERA et al., 2000; METTER et al., 1999).

The average power of the gastrocnemius was not correlated with the muscle infiltrated fat. The effect of fat infiltration on the mechanical performance of human skeletal muscles is an experimental challenge as muscle forces cannot be directly measured (FRONTERA et al., 2000). Therefore, the analysis of intramuscular fat alone was not sufficient to determine a direct impact on muscle strength or power. Other parameters complementary to fat infiltration (e.g., thickness, muscular quality, penation angle) are required understand their influence on muscle power and the risk of falls.

No associations were found between the fat infiltration from the GM or GL muscles with any phases of the reactive capacity test, irrespective of the participants' success in recovering balance after an induced trip. The time of each phase reveals a number of capacities that are related to avoid a fall (MELZER et al., 2010). The duration of the initial phase is mainly dependent on peripheral sensory detection and afferent nerve conduction time, followed by central processing and efferent nerve conduction time (MELZER et al., 2007). The results suggest that the afferent nerve conduction time, especially the sensory detection thresholds are associated with fat infiltration in the triceps sural. Besides that, time in the preparation phase is not directly dependent on the ankle power, as it reflects the performance of the hip abductor muscles recruited for the anticipatory lateral adjustments to the step (MELZER et al., 2007), which may explain the lack of relationship between ankle power and the fat infiltration. On the other hand, the duration of the swing phase is mainly dependent on the neuromotor mechanisms related to the accumulation of plantar flexors strength and power to perform the task of taking the step (MELZER et al., 2007). However, fat infiltration was not related to muscle power, in other words fat infiltration alone do not influence the extension power around the ankle joint.

The present study presents a number of limitations that must be considered when interpreting the results. First, the lack of control over the level of physical activity among the older adults, which may have influenced some parameters of the study to be higher when compared to normative data. Second, failure to measure data complementary to those analyzed, such as variables of balance and gait. Third, the number of subjects is not expressive. Finally, some older adults were uncomfortable with the safety apparatus during the stumble test, so this fact may have caused some change in the natural gait pattern.

5.5 CONCLUSION

In general, the importance of the present study was to allow the identification of predictors of falls, based on more realistic method to determine the ability of the participants to reestablish balance after an induced trip. This experimental method allows the experimenter to avoid the problems related to the use of questionnaires to determine fall history. When comparing faller and non-faller older adults, greater stiffness reduces the individual's chances of falling by 6%. Furthermore, the present study showed that, greater ankle power reduced the chances of falling by 37%. However, no differences in muscle fat infiltration were found between fallers and non-fallers older adults. There was no correlation between the infiltrated fat and the joint power. Finally, fat infiltration was not correlated with the reactive capacity test, that is, it does not seem to have a clear relationship with the capacities required during the step test.

6 CONCLUSIONS AND PERSPECTIVES OF FUTURE STUDIES

The objective of this dissertation was to evaluate some morphological and biomechanical parameters that distinguish older adults who are capable and unable to recover their balance, from a controlled stumble induced in the laboratory and based on a retrospective questionnaire. The effect of the level of physical activity on the morphological parameters. To this end, two studies were developed, which led to the following conclusions:

When using the retrospective questionnaire to identify falls, no significant difference was found between fallers and non-fallers for TS stiffness and fat infiltration. However, when using the induced stumble in the laboratory, more rigid tendons were found in non-falling elderly, in addition the TS stiffness was able to predict falls in 6% and ankle power in 37%. There was no difference between groups for fat infiltration.

In addition, the level of physical activity seems to influence both parameters, in other words, active older adults had more rigid tendons and less fat infiltrated into the analyzed muscles.

Future studies should analyze a larger set of variables so that it is possible to understand the influence of these variables on gait and balance in the older adults. In addition, other studies should be carried out seeking to identify and monitor falls during the performance of daily activities, outside the laboratory environment. Thus it will be possible to assess whether individuals who were unable to regain balance in the laboratory have the same risk of real falls.

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