THE EFFECT OF AGEING AND PHYSICAL ACTIVITY LEVEL ON MUSCLE FATIGUE DURING ISOMETRIC CONTRACTION OF KNEE EXTENSOR MUSCLES

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ABSTRACT

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Muscle fatigue is defined as the loss of force or power producing capacity in response to contractile activity and is a fundamental characteristic of skeletal muscle. The aim of this study was to identify whether time to failure remains same or increases in elderly people compared with young people. Another aim was to identify time to failure is same or less in active old people compared with inactive old people.

One hundred and ten subjects were recruited in this study. However, complete data was obtained from ninety subjects [32 young (mean age 24±2 years), 28 old active (75±4 years) and 30 old inactive (75±3 years)]. Experimental protocol consisted of measurements before, during and after fatigue test. The electrical stimulation was induced every 10 sec of the fatigue test. To determine the stimulation intensity, double stimulus (doublet) was applied to the relaxed muscle that produced 30 % of maximal voluntary contraction (MVC). To determine the activation level 2×MVC was performed at 90◦ knee angle. During fatigue test, subjects performed sustained contraction at 50 % of the MVC as long as possible. The test was finished when the force dropped below 5 % of the target force.

The results showed that following fatigue test there was no significant difference in time to failure between old and young subjects group. Habitual physical activity did not give any different results compared with old inactive subjects group following the fatigue test. Young subjects group had 18% ($p<0.001$) more peripheral fatigue and 0.6% ($p<0.05$) more central fatigue than old subjects group.

These findings suggest that though the time to failure is similar in this study but it might be difference in mechanism of fatigue between old and young subjects.

Key words: Ageing, fatigue, isometric contraction, torque, physical activity, central activation.

CONTENTS

1 INTRODUCTION

1.1 Ageing and neuromuscular function:

There is a gradual decrease in muscle size and neuromuscular function due to ageing. Due to the normal ageing process, there is a loss of cells from the motor system leading to a decrease in number of motor neurons and muscle fibers (Anthony A, 2002).

In both humans & animals, there is a progressive loss of muscle mass with ageing particularly in the more distal muscle groups and a corresponding loss of muscle strength. As a result, physical capacity and quality of life are impaired. Age related decrease in muscle mass is called sarcopenia (Anthony A, 2002). This age-related sarcopenia reduces muscle strength especially in the lower limbs which leads to potential health problems such as impairment in mobility, obesity, metabolic disorders and also impaired aerobic capacity (Anthony A, 2002).

Age-related loss of muscle mass has two primary causes (Luff AR, 1998) .One is psychosocial factors which relates to a lack of physical activity. The expectations of society are that aged people should be less active which lead to musculoskeletal and cardiovascular diseases. Second, there are intrinsic physiological factors which are discussed below:

1.1.1 Muscle mass & muscle force

The final pathway for movement generation goes through the motor unit (MU) which consists of a single motor neuron and its innervated muscle cells. With ageing the number of MU decreases which affects the capacity to produce force (Anthony, 2002).

In humans, muscle mass and muscle force start to decline from about the age of 50 (Rogers & Evans, 1993). Multiple factors are leading to loss of muscle strength with increasing age (Figure, 1). Some influences are part of normal biological ageing process (e.g. motor unit loss) (Anthony, 2002). The possible reasons for a loss of muscle mass and muscle force can be changes in the intrinsic force-generating capacity of muscle, reduction in size of muscle fibres (fibre atrophy), reduction in the number of muscle fibres, and some combination of the above (Luff AR, 1998).

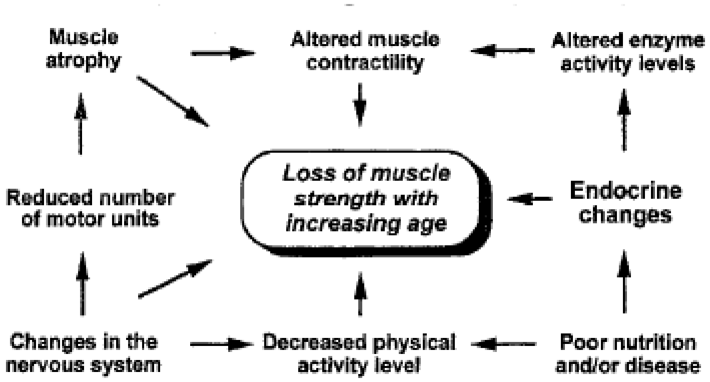

Figure: 1, Multiple factors lead to loss of muscle strength with increasing age (Anthony, 2002).

Aged people have a greater deficit at higher velocity of movement. Initially, the rate of force loss is only about 15% per decade from 50 to 70 years, increasing with age and this rising to a further 30% loss from 70 to 80 years of age (Danneskiold, 1984). Ultrasound measurements of the cross-sectional area of the quadriceps muscle group showed there was a 39% reduction in MVC for people in their 80’s compared with people in their 20’s. (Yong et al, 1985). A similar change in MVC was found in a study of the elbow flexors (Doherty, 1993). It is also evident that the muscles in the arms and legs are affected disproportionately. Between 30 and 80 + years of age, loss of muscle strength in leg muscles was about 40% compared with about 30% in arms (Faulkner et al, 1990).

Age related loss of muscle force was demonstrated by isometric test when compared people with different ages. The people in the seventh or eighth decades had on average about 20-40% lower isometric strength than young adults and in case of very old people even 50% less. Others demonstrated that**,** power output was reduced in aged people when they were tested for maximal rate of work or maximal rate of isometric force development (Anthony, 2002). Concentric actions of muscle also produce less value in aged people compared with younger people (Figure, 2). Several studies in various muscles observed that strength decreased with ageing consistently less for the eccentric contraction than either the isometric or concentric contractions (Figure, 2) and some situations there might be no difference at all. Age related changes in muscle mass, contraction speed and connective tissue results in reduced strength when muscle is shortened but relatively enhanced when being lengthened (Anthony, 2002). The intensity of muscular effort and cardiovascular response was less for exercise of eccentric contractions than concentric contractions which suggested that older people might get some advantage using eccentric or lengthening contractions which attribute to their stiffer muscle structure and prolonged cross bridge cycle of myosin. In terms of aged people, time to failure at a given intensity of work could be enhanced during eccentric loading compared with concentric loading (Anthony, 2002). Figure 2, shows effect of age on maximal strength throughout the human lifespan. The shape and height of the curve were based on the type of strength being measured: isometric, concentric and eccentric movements (Anthony, 2002).

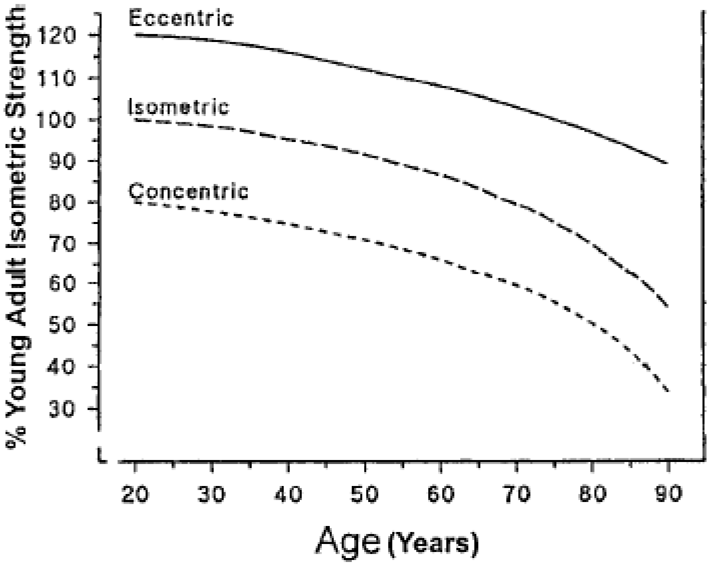

Figure: 2, Effect of age on maximal strength (Anthony, 2002).

Loss of muscle mass might be related to the age-related decline in maximal oxygen consumption (Fleg et al, 1988). A well-documented decline in muscle mass of 20–40% in humans between 30 and 80 years of age in comparable between the ages of 12 and 28 months in rodents (Luff AR, 1998). Another study showed that a loss of muscle mass in humans is about 10% from age 24 to 50 years, with a further 30% loss from 50 to 80 years. But this change may not be strictly a proportional manner (Lexell et al, 1986).

With ageing the loss of muscle mass can be attributed to loss of muscle fibers or atrophy of fibres. From the studies of animals it has been suggested that there is a relative loss of type II (fast-twitch) fibers in advanced age (Jakobsson, 1990). The results from the human and animal-based studies are equivocal. So in general, several studies indicated that there is a loss of muscle fibers with age. The examination of cross-sections of the quadriceps muscle taken at autopsy from males aged from 20 to 80 years of age. 39% fiber number was found to decline which approximately paralleled loss of muscle force (Lexell et al, 1988). Interestingly, the decline seemed to be progressive, commencing at about the age of 30.

With increasing age in humans or animals, nearly all muscles studied, have shown a reduction in muscle fiber size as a reduction of CSA. One study observed a selective reduction in CSA of type II fibers in Vastus lateralis of humans above 70 years of age, with only slight reductions prior to the age of 60–70 years. Another study observed no reduction in CSA of type I (slow-twitch) fibers but a 13–30% reduction in type II fibers in the aged Gastrocnemius muscle. It has been observed that most reduction in muscle fiber CSA was seen in type II fibers, particularly the IIB fibers (fast-twitch, predominantly glycolytic and readily fatigable). According to recruitment of motor units and muscle fibers which dictates that type I fibers are recruited in regular use, even in aged subjects and the type II fibers especially the IIB fibers will rarely be recruited and therefore leads to disuse atrophy (Luff AR, 1998).

The knowledge about the effect of ageing on neuromuscular function was required to find effective treatment and prevention which help to maintain high level of physical function and independency in the rapidly growing population of older adults (Anthony A, 2002).

1.1.2 Age related changes at Neuro-muscular junction (NMJ)

This is the crucial link between the motor neuron and muscle. Both animal and human studies have suggested that there is remodeling and fragmentation of NMJ which indicated a progressive degeneration of the NMJ with ageing. Considerable fragmentation in the distribution of acetylcholine receptors has been demonstrated which suggested fragmentation of the terminal. From animal studies, a gradual and progressive loss of synaptic contact was found in rat soleus and diaphragm muscles aged 21 months with entire NMJ's being lost. Another study about comparison of gastrocnemius NMJ's between young and old mice showed that 85% of NMJ's in young mice could be considered normal but this was reduced to 40% in the old mice. The results suggested a significant age-related deterioration in the structure and functional capacity of the NMJ which ultimately involved outright failure or loss of the NMJ (Luff AR, 1998).

1.1.3 Physical Activity

The widely accepted definition of physical activity is “Any bodily movement produced by the skeletal muscles that result in caloric expenditure” (Caspersen et al., 1985 cited from Nikolaos and Mike, 2007). Exercise is a subcategory of physical activity which is defined as “Planned, structured, repetitive and result in the improvement of one or more facets of physical fitness” (Caspersen et al.,1985, cited from Nikolaos and Mike, 2007).
The level of daily physical activity for each subject has been quantified by using modified questionnaire which was completed by researchers using personal interviews (J. Seghers et al., 2003). Several studies that have reported quantified habitual physical activity level have used accelerometers (Damien et al, 2009 & Lan R. et al, 2004).

Physical activity level was quantified by uniaxial accelerometer in the Damien et al study (2009) who reported that older subjects were more time to failure than younger during isometric contraction but there was a loss of time to failure only during dynamic knee extension exercise in healthy elders. This finding conflicts with Baudry et al (2007) findings who reported greater fatigue in older than young subjects during concentric dorsiflexion contractions that were preloaded by isometric contractions. In addition, some methodological differences were also found between these two studies. In the study of Baudry et al. (2007), habitual physical activity was not quantified or matched between groups. This was an important distinction that might explain a portion of the differences in the time to failure across age groups (Laforest et al, 1990).

Physical activity is a key issue of public health for young and old people (Elaine J. Stone et al, 1998). It has been extensively documented that health is benefited from physically active life style (Nikolaos and Mike, 2007). Physical inactivity is a risk factor for many chronic health problems such as cardiovascular diseases, hypertension, obesity, osteoporosis, diabetes mellitus and mental health problems (cited from Akke et al, 2002). Physical activity, in order to avoid inactivity, could be one of the means to reduce musculoskeletal morbidity in the working population, particularly in sedentary workers (V.H.Hildebrandt et al, 2000). Setting up of many interventions helps to enhance physical activity among elderly people and to improve their health status and functional performance (Akke et al, 2002).

Furthermore it has been proven that physical activity could help to improve muscle strength, aerobic capacity, reduce fractures and general well being in the elderly (Akke et al., 2002). Therefore regular physical activity is important component of health promotion and crucial in delaying the onset and reduce the incidence and severity of many chronic diseases (Akke et al., 2002).

1.1.4 Exercise and ageing

Regularly routine based exercise is an important component of successful ageing. Exercise helps to reduce premature mortality from stroke, coronary artery disease, hypertension, diabetes mellitus and some forms of cancer. It has also many beneficial effects on bone, joints and muscles (Galloway & Peter Jokl, 2000).

It was reported that age related decline in musculo-skeletal function could be markedly reduced by participating in regular exercise. Surprisingly high levels of performance were found from the record of master athletic competitions. It was observed that regular exercise increased capillary density, cross sectional area of type I and type II muscle fibers and 23% of maximal oxygen consumption (Galloway & Peter Jokl, 2000).

Recent studies reported that health gains could be achieved by regular low volume exercise. Current data indicated that an accumulative 30 to 50 minutes of daily aerobic exercise performed 3-5 days per week and resistance exercise for major muscle groups twice a week could produce significant health benefits. Aerobic exercise could include regular participation in many common physical tasks like walking, gardening, housekeeping etc. It was also reported that endurance training could improve muscle capillarity, glucose transport capacity and glycogen reserve. Resistance training helps to improve muscle strength. So active life style is important for elderly people for preserving health and function and it should be encouraged by physicians while caring for elderly patients. At first for constructing an exercise prescription a need for analysis assessment should be essential for physical deficits and functional limitations of elderly people. It would be helpful for elderly individual to find out the specific needs in the exercise program and minimize the risk of injury (Galloway and Peter Jokl, 2000).

1.2 Muscle fatigue

Muscle fatigue is classically defined as the loss of force or power producing capacity in response to contractile activity and is a fundamental characteristic of skeletal muscle (Kent-Braun, 2004). Gardiner has defined fatigue as any exercise-induced reduction in maximal voluntary force or power output. Thus fatigue is an ongoing process that occurs even under conditions where performance is maintained at a constant level. Sub maximal contraction increased effort. Fatigue developed in men and women soon after the onset of sustained physical activity and during maximal or sub maximal exercise, it quantified by a reduction of maximum voluntary contractions (MVC) (Enoka, 2008).

Physiological impairments can cause muscle fatigue. It is known that fatigue can be caused by many different mechanisms such as, from the accumulation of metabolites within muscle fibers to the generation of an inadequate motor command in the motor cortex shows there is no global mechanism responsible for muscle fatigue. The mechanisms that cause fatigue is specific to the task being performed (Enoka, 1992).

Fatigue due to impairment at the level of the muscle is frequently attributed to a failure in excitation-contraction (EC) coupling, which can include failure of surface membrane and T-tubular action potential propagation, the coupling mechanism between action potential and calcium release at the level of the contractile elements (Jones DA, 1996). Muscle fatigue can occur during continuous and successful performance of sub maximal task. Task failure occurs when the sub maximal task cannot be maintained (Hunter et al, 2004). Task failure also involves the limitation of physiological adjustment during fatiguing contractions (Enoka, 2008). Task failure could be achieved by comparing physiological adjustments with variations in the task, sex of the individual or the age of the person performing the task (Sendra, 2009).

1.2.1 Types of fatigue

Muscle fatigue is a complex process. It is attributable to central factors that is arising from structure above the neuromuscular junction (central fatigue) and/ or to peripheral factors that is arising distal to the neuromuscular junction (Peripheral fatigue) (Gandevia, 2001).

1.2.1.1. Central fatigue

Central fatigue can be defined as a progressive exercise-induced reduction in the level of voluntary activation of a muscle (Gandevia, 1998). It appears to be task-dependent and intrinsic motoneural, spinal, and supraspinal factors can generate central fatigue (Gandevia, 1998).

The level of voluntary activation is commonly estimated by interpolation of a single supra maximal electrical stimulus to the motor nerve during an isometric voluntary activation (Merton, 1954). If extra force is evoked by the superimposed stimulus, this means that some motor units were either not recruited or were not firing fast enough to drive the muscle fibers to generate all their force. An increase in the superimposed twitch with exercise indicates central fatigue (Todd et. al, 2002). The amplitude of the superimposed twitch decreases with increasing voluntary force (Merton, 1954).

During maximal voluntary contractions, if all the muscle fibers are fully activated and there is an absence of superimposed twitch, the voluntary activation is equivalent to maximal tetanus. This method is described as ‘twitch occlusion technique’ (Merton, 1954).

Voluntary activation may not be optimal during maximal efforts. During sustained MVCs, the motor unit firing rates decline initially and rapidly and reach a plateau after about 30 s (Taylor et. al, 2001). Woods & Bigland-Ritchie (1983) said that the maximal firing rates vary between subjects and muscles. During maximal isometric efforts, the firing rates decline for a range of upper and lower limb muscles and the fact the rate of this decline vary between muscles may be due to the type of motoneurons (e.g., “slow” vs. “fast”).While muscle relaxation time (and sometimes also contraction time) usually lengthen during sustained or intermittent MVCs (Bigland-Ritchie), twitch interpolation has revealed that voluntary activation becomes progressively lower. Central fatigue has been seen in several muscle groups for sustained and intermittent MVCs including elbow flexors, ankle plantar flexors, ankle dorsiflexors, and quadriceps (Bigland-Ritchie, 1983).

Central fatigue with isometric contractions of limb muscles can occur. The indicator of a central failure of voluntary activation can occur when an initially sub maximal isometric contraction (30% MVC) is held until it can no longer be continued. Before termination of the task, twitch interpolation reveals that voluntary drive is not complete (Figure, 3). Task failure could have been delayed if central fatigue had not interfered the contraction (Gandevia, 1998).

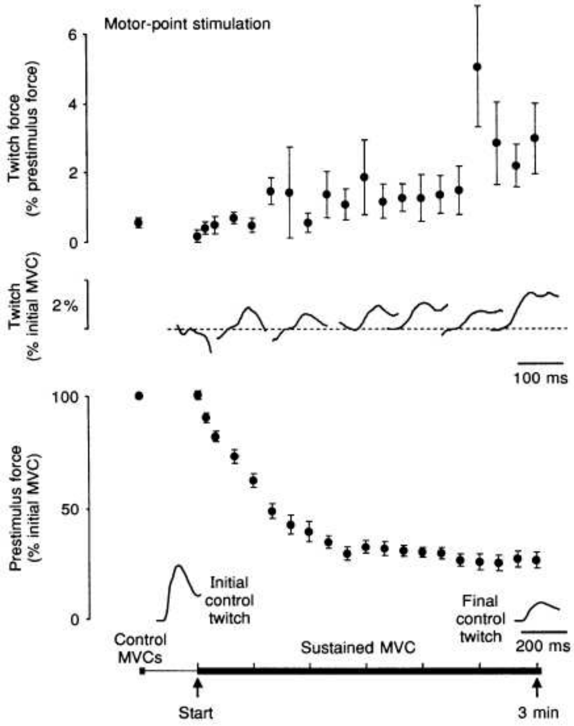

Figure 3: Reduction in voluntary force and increase in superimposed twitch size during a sustained MVC (Gandevia et al, 1996).

1.2.1.2 Peripheral fatigue

Peripheral fatigue is described as exercise-induced processes that lead to reduction in force production and that occur at or distal to the neuromuscular junction. It can be demonstrated by a fall in the twitch or tetanic force which is produced by peripheral nerve stimulation while the muscle is at rest (Taylor and Gandevia, 2008).

Aging is often associated with contractile slowing by increasing in relaxation time of an evoked or voluntary response (Roos, 1997). Peripheral factors are responsible for contractile slowing and might include combination of alterations of sarcoplasmic reticulum calcium kinetics and larger type I fibre area found with increasing age (Hunter S. et al, 1998). The slowed contractile properties of aged muscle and the subsequent leftward shift in the force-frequency relationship might explain the equivocal result of electrical stimulation. Comparing with young, the greater degree of fusion in muscle from aged subjects at low frequencies of stimulation (leftward shift) would result in greater fatigability. Because, the stimulation would elicit a higher percentage of the available maximal tetanic force (Hicks, 2001). Low-frequency fatigue (LFF) is associated with a reduced release of calcium and also muscle damage for a given electrical stimulus following fatigue (Westerblad H, 2000).

1.2.2 Mechanism of central fatigue

Central fatigue involves slowing of motor unit firing rate measured in sustained and repeated maximal efforts (Bigland-Ritchie, 1984 & Marsden 1983). Observation of muscle contraction and relaxation suggested that changes in the firing rate might match the muscle properties to preserve maximal force output (“muscle wisdom” hypothesis) (Bigland-Ritchie, 1983). Furthermore, increase in the superimposed twitch indicated that some motor neurons no longer produce fully fused contraction despite any slowing of the muscle. Thus the muscle wisdom hypothesis is not supported (Fuglevand, 2003).

During rhythmic or sustained types of effort, gradual decline in muscle activation during fatigue due to decreased in firing frequency of motor units, has been observed (Marsden, Meadows & Merton, 1983). This decreasing firing frequency have also been seen in sub-maximal contractions sustained to fatigue even during the time when additional motor units are recruited to maintain the force(Garland et al,1997).

Bigland-Ritchie (1987) and Garland et al. (1988) found the view that a spinal reflex arising via group III and IV afferents caused the decline in motoneuron firing rates. A reflex by which, information is transmitted via afferents from the fatigued muscle to the spinal cord and has an inhibitory effect on motoneuron excitability. This decline in motoneuron firing rates support “muscular wisdom” they observed in human MVC’s.

Some studies have demonstrated that the contribution of group III–IV afferents to the development of fatigue can vary across muscles. The contribution of feedback from group III–IV afferents to the fatigue during sustained 2 min MVC’s with the elbow flexor and extensor muscles exists (Martin *et al.* 2006).

Preferably, the mechanisms that contribute to slowing of motor unit firing rates are fundamental to central fatigue. There are three kinds of actions at the motor neuron pool which might be responsible for the motor neuron slowing: a decrease in excitatory input, an increase in inhibitory input and a decrease in responsiveness of the motoneurons through a change in their intrinsic properties. It is probably because of all three actions occur simultaneously (Taylor and Gandevia, 2008).

1.2.3 Mechanism of Neuromuscular transmission fatigue

Neuromuscular transmission failure means failure of a nerve impulse which is translated into an impulse on the sarcolemma immediately under the motoneuron terminal (Gardiner, 1949). The integrity of neuromuscular transmission can be assessed by the compound muscle action potential (M wave) which is the electrical response of a muscle to electrical stimulation of its motor nerve (Enoka, 1992). Neuromuscular transmission failure can be implicated on the basis of measurements that represent propagation of the sarcolemmal action potential from the motor end plate to the recording electrode. Such as maximal M wave amplitude is decreased during sustained contraction for decreasing in evoked force (Zijdewind, Zwarts and kernel, 1999).

M wave can be used as an indirect index of sodium–potassium pumping (Hicks & Cupido) and the peak-to-peak amplitude of the M wave reflects the muscle membrane excitability (Milner-Brown, 1986).

Age related reduction in M wave amplitude of approximately 20-40% have been reported in a variety of muscle groups including Biceps Brachii and Tibialis anterior. Furthermore, studies have suggested that the magnitude of reduction in M wave amplitude progresses throughout ageing. The progressive alterations in the peripheral factors contribute to a loss of muscle membrane excitability that is demonstrated by a decrease in M wave peak to peak amplitude. Age related changes in the neuromuscular junction represent compensatory alterations that preserve function in the aged system, rather than identify degeneration with increasing age (Brian L. et. al., 2002).

Neuromuscular transmission failure can occur under conditions that are relatively physiological and then some mechanisms should be considered. These are:

a. Axon Branch-Block failure
b. Neurotransmitter Depletion &
c. Post synaptic membrane failure.

a. Axon Branch-Block failure: It occurs when failure of propagation of the action potentials into all of the branches extending to the muscle fibres occur. There is a significant decrease in the excitability of the smaller axons relative to the larger branches (Gardiner, 1949)

b. Neurotransmitter Depletion: With continuous stimulation, the amplitude of end plate potentials (EPPs) decreases due to lowered number of vesicles and/or acetylcholine (Ach) per vesicle or both (Wu &Betz, 1998, Slater& Bewick1991).

c. Post synaptic membrane failure: Neuromuscular junction fatigue is a measurement taken under the post synaptic membrane. Neuromuscular transmission failure (NTF) can occur in two major synaptic sites: at the motor end plate due to desensitization of the cholinergic receptor (AChR) and at the sarcolemma due to decrease in excitability. There is evidence that combination of decreased end plate potential (EPP) amplitude and reduction of sarcolemmal excitability leads to failure at the neuromuscular junction of the rat muscle diaphragm which further leads to a failure in the generation of action potentials in muscle fibers (Krnjevic & Miledi,1959).

1.3 Ageing and Fatigue

Damien et al (2009) reported, "The question of whether skeletal muscle fatigue is preserved or enhanced in older adults is a point of controversy." There was a limited number of studies investigated the effect of old age on neuromuscular fatigue (Brian et al, 2002). It has been tested in most muscles that there is substantial loss of strength and slowed contractile properties in the elderly people (Hunter et al, 1998 and Roos et al, 1997). During the advanced age (=70 years) type I fibres contributed more to force generation than in young people (Roos et al, 1997) and decrease in type II fibre area exists. Thus MU remodeling takes place in the elderly people (Brian et al, 2002).

The study of Brian et al, (2008) reported that age related changing in skeletal muscle structure like muscle mass, motor unit (MU) and fiber number and motor unit remodeling associated with loss of muscle strength and slowed contractile properties might improve the resistance to neuromuscular fatigue in elderly people. But this result could not be generalized due to variability of the results from the limited number of studies. Some studies reported no age related fatigue difference where as some other studies reported that aged subjects were more fatigable than young subjects. The impact of the possible confounding effects of age, sex and physical activity status was found when comparing the fatigability of young and old humans. So it could not be generalized that muscles of old humans are more or less fatigable than the muscles in young people because mechanism inducing fatigue strongly depends on fatigue task performed. Age related changes in the neuromuscular system might have some candidate sites (like central drive, muscle membrane excitability, excitation contraction coupling mechanism and metabolic capacities) where susceptibility to failure occurred under specific task conditions. From this study it was recommended that further studies should control the possible confounding effects of subject’s age, sex and physical activity status when comparing the fatigability between young and old people (Brian et al, 2002).

1.4 Effect of exercise on fatigue in elderly and young people

Exercise-induced fatigue is a poorly understood phenomenon in which many researchers are interested. In the relationship between physical exercise and fatigue is very complex. Fatigue caused by exercise is a common sensation. During the form of exercise, it might create an intense sensation that one has to stop the exercise. Physical exercise is an energy consuming activity which could empty the energy stocks in our body. An unlimited consumption of these stocks during exercise would have deleterious effect on our physical health. That’s why the sensation of fatigue is very essential for maintaining the physical integrity. Physical and biochemical changes during exercise are physiological effects. These effects of physiology during exercise are defined as ‘fatigue’ which could be monitored objectively. The sensation of fatigue is a psychophysical quantity which can change the subject’s behaviours for their own safety (Ament and Gijsbertus, 2009).

Muscle fatigue is associated with reduced power output and work capacity of the skeletal muscle (Pilegaard et al, 1999). Muscle fatigue affects muscular strength and postural control. It is not clear whether impaired postural control after fatiguing muscular exercise. It depends on the nature of the muscle contraction (Paillard et al, 2010). Maximum knee extension and flexion force was significantly reduced post exercise in the presence of muscle fatigue. Maximum force is reduced due to changes at various sites ranging from central nervous system command to the intramuscular contractile machinery (St Claire et al, 2001). Substrate utilization and metabolic accumulation have been considered as the origin of reducing force output in repetitive activity (Nummela et al., 1992). However, studies have been shown reducing force output are not tightly correlated with metabolic imbalances. Other factors such as neural control mechanism are more important determinants of the fatigue that develops in this form of physical activity (Lattier et al., 2004). Fatigue may increase the risk for musculoskeletal injury rates during the latter stage of athletic competition and often occur during unexpected perturbations. Therefore exercise programs for patients and athletes should be carefully monitored for signs of fatigue to avoid the risk of injury (Hassanlouei et al, 2012).

1.5 Different types of protocol used to study fatigue

There have been a limited number of protocols used to compare the fatigability of young and old humans. These are voluntary isometric and isokinetic contraction protocols at maximal and sub maximal intensities and electrical stimulations protocol of continuous and intermittent stimulation at a variety of stimulation frequencies (Brian L.et. al, 2002). Two protocols are discussed below:

The study of Damien et al (2009) was designed to test the hypothesis that older people have less fatigue during isometric contractions and would show similar fatigue during dynamic knee extensors contractions performed at 120°/s compared with younger people. In this study, 3-5 maximum voluntary isometric contractions (MVIC’s) and maximum voluntary dynamic contractions (MVDC’s) were performed and at least 1 min rest was allowed after each contraction until subject had performed 3 contractions within 10% of each other. Fatigue was induced with 4 minutes of intermittent, isometric and dynamic maximal voluntary contractions that were performed on separate days. During this protocol MVIC’s were lasting 5secs with 5secs rest between contractions and MVDC’s were performed every 2 sec. Electrical stimulations were used during both fatigue protocols to evaluate central activation.

The results showed that older people are more time to failure than younger people in the isometric fatigue protocol which supports the hypothesis and is in agreement with some previous reports. However, loss of time to failure was observed in the same subjects during dynamic contractions which also agrees with some previous reports and supports the hypothesis. There was no age related difference in the loss of central activation during both protocols. Thus it indicated that the abolition of time to failure in the older group during dynamic contractions was a result of changes in the peripheral factors (Damien et al, 2009).

The study of Lanza et al (2004) compared fatigue in young and older men during both isometric and dynamic fatigue protocols. The protocols were made to be similar with the exception of contraction mode. In this study young and older adults had similar physical activity levels. Mechanisms of fatigue were assessed by measuring central and peripheral activation and muscle contractile properties which might be altered by the aging process. The ankle dorsiflexor muscles were chosen for this study. Nine young and nine older healthy men were selected for this study.

During fatigue protocol subjects performed 3 min of intermittent isometric contractions (5 s contract/5s relax) and 90MVDCs were performed at 90°/s (1.57 rad/s) after completing the pre-exercise measurements. The range of motion (ROM) about the ankle was limited to 30°. Torque, velocity, and angle data were obtained and digitized at 100Hz. Isometric fatigue was measured as the decline in peak isometric torque, expressed as the ratio of the peak torque produced during the last contraction to the peak torque produced during the pre exercise MVIC. Central activation was measured during the final MVIC of the fatigue task. Dynamic fatigue was measured as the fall in peak power production and expressed as the ratio of the average peak power of the last three contractions to the average peak power of the first three contractions. Taking an average of three dynamic contractions is close to the time frame of the isometric contractions. The end of the exercise and recovery measures was performed as in the isometric fatigue protocol.

The main results of this study were that older men fatigued relatively less than young men during both isometric and dynamic exercise of the ankle dorsiflexor muscles and the magnitude of fatigue was associated with muscle contractile properties (Lanza et al, 2004).

Literature suggests that the ability to resist muscle fatigue might increase with old age. The loss of motor neurons that innervate type II fibers is thought to be partially compensated by re-innervations of some nearby motor neurons associated with type I motor units (Gordon

T, 2004). Thus the shift toward a relatively greater type I fibers population could contribute to enhanced time to failure in older muscle (Mademly, 2008).Although many studies supported the notion of age-related time to failure, other investigators reported unchanged or diminished time to failure in the elderly (Damien et al, 2009). Different results might be due to a variety of causes including variations of study populations, muscle group or the task used to induce fatigue (Damien et al, 2009). These discrepant results across studies could be attributable to differences in contraction mode, protocol, muscle group or subject's characteristics. For example, older adults may be more susceptible to fatigue during high velocity dynamic contractions compared with isometric contractions. Time to failure has a significant impact on functional mobility in adults. The health and habitual physical activities of the study groups are also important design considerations that can affect the results. Clarifications of these discrepancies need further studies.

2 Aim of the study

- Ageing result various changes take place in the neuromuscular system. The age related changes in the neuromuscular system could have an influence on the nature of muscle fatigue. It is true that the relationship between ageing and muscle fatigue is complex and it is less clear, how ageing affects the properties of muscle fatigue. There is a few number of studies have done in this area. That’s why effect of ageing on muscle fatigue still remains incomplete. Different studies concluded different types of result in this area. That’s why the aim of this study was to identify whether time to failure is same or increase in elderly people compared with young people during a sustained isometric contraction at 50 % MVC.

- The level of physical activity is also important issue for elderly people. Physical activity helps to improve muscle strength and it can play a major role in the activities of daily life for the elderly people. That’s why another aim was to identify time to failure is same or less in active old people compared with inactive old people during a sustained isometric contraction at 50 % MVC.

3 METHODS AND MATERIALS

3.1 Subjects

110 subjects were recruited into this study. Old subjects were recruited from the University of 3rd Age, Jyväskylä and from the association for retired people. Younger adults were recruited from the University of Jyväskylä. Participants were medically stable and free from major diseases and other factors are indicated in the exclusion criteria which have been given in the appendix 1. Ethics committee of Central Hospital of Central Finland approved this study. Written informed consent was obtained from the subjects prior to any measurement. Complete data for this study was obtained from 90 subjects whose characteristics are shown in Table 1.

Table 1.

Characteristics	Young (N=32)	Old Active (N=28)	Old Inactive (N=30)
Age (year)	24±2	75±4	75±3
Height (m)	1.73±0.10	1.64±0.08	1.67±0.08
Weight (Kg)	67.9±10.3	69.7±10.2	71.2±9.5
MVC (Nm)	172±54	110±30	117±38

3.1.1 Physical activity for older adults

The recruited older adults had to be socially active. For example, taking part in the University lectures or participating to the association meeting for retired people. The old subjects were divided into physically active and inactive groups (see table 1). Physically active were defined as those who performed three or more training sessions per week. Physically active session was defined as activity that lasted at least 30 minutes where subjects sweat or get out of breath and was done to improve physical fitness or health. Physically inactive were defined as those who performed only one session or did not do any session per week. Physical activity level was assessed just by asking the subjects about their physical activity such as sports, activities of daily life using a telephone interview. Physical activity questionnaire that was used in this study can be found in the appendix. In the interview, the subjects were asked about their physical activities during the last three months or more. Subjects must have consistently maintained the activities for the most of the year and for the past 3 years or more.

Younger adults

The younger adults participating in this study were normally active. Normally active was defined as those involved in moderately intensive activities in the daily life for work or recreational purposes. The subjects were not allowed to participate in competitive sports.

3.2 Experimental protocol

The subjects came to the laboratory in the morning between 8 and 9 am and performed a battery of tests including maximal voluntary contraction (MVC), activation level (AL) and fatigue test. This thesis focuses on the fatigue protocol that is described in detail. Subjects were instructed not to consume alcohol for at least 24 hours prior to visit, no smoking at least 2 hours prior to muscle function measurements, no strenuous exercise for at least 24 hours prior to visit and to inform about the prescription for medications currently being used.

Experimental protocol consisted of measurements before, during and after fatigue test (figure, 4). After instructions to the subjects, measurements started with a short warm up of 6 submaximal (3×50-60 %MVC, 3×80-90 %MVC) contractions of knee extensor muscles. After completing the warm up the subjects were allowed to rest for 1 min. To determine the MVC force subjects were instructed to increase force from zero to maximum and to hold it for about 3 sec. At least 3 repetitions were done but continued until 2 contractions were within 10 % of each. To determine the stimulation intensity double stimulus (doublet) was applied to the relaxed muscle that produced 30 % of MVC. To determine the activation level 2×MVC was performed at 90◦ knee angle. Then the subjects were allowed to take rest for 5 mins. After the rest, the subjects started the fatigue test. During the fatigue test, the subjects performed sustained contraction at 50 % of the MVC as long as possible. The electrical stimulation was induced every 10 sec during the fatigue test. The test was finished when the force dropped below 5 % of the target force. After the fatigue test, pulses were given after every 10 sec for 1 min. The duration of the full procedure was around 25-30 minutes.

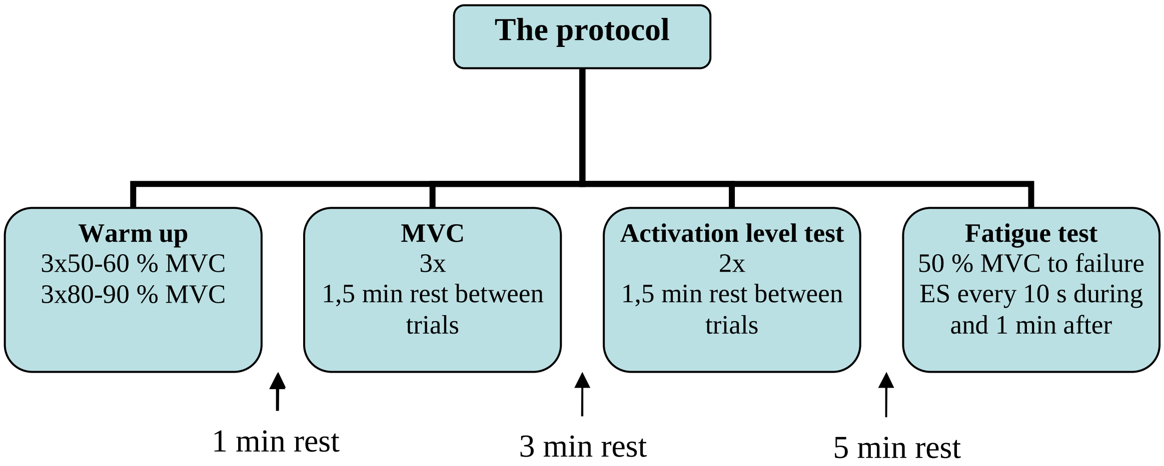

Figure4: Experimental design of the knee extension fatigue protocol where MVC=Maximal voluntary contraction. ES= Electrical stimulation.

3.3 Maximal isometric voluntary contraction

A custom made dynamometer was used to measure isometric knee extension torque (manufactured by University of Jyväskylä, Finland). The MVC of the dominant leg was tested, which was defined as the leg that the subject believed was the strongest one. The subject sat on the testing chair with hip and knee flexed at 90º. Upper-body and hip straps were securely tightened to hold the subject firmly in place. The force transducer lever was positioned at 2 cm above the ankle malleolus. The lever arm length was measured from the point of rotation of the knee joint down to the point where the force transducer measured the force. Isometric dynamometer was used and the subjects were instructed to perform 3 isometric contractions at around 50 % MVC and a further 3 efforts at 80 – 90 % MVC (Figure, 5). The subjects were allowed to rest for 1 min after completing these "warm-up" contractions. When the subjects were ready to perform MVC, "3, 2, 1, PUSH" was commanded. On this command the subject used the knee extensor muscles to apply as much force as possible against the force transducer. Force generated quickly and the contraction was continued for around 3 sec. Then the subjects were instructed to relax. Strong verbal encouragement was given throughout the maximal voluntary contraction (MVC). MVC was measured at least three times but trials continued until there was less than 10 % difference between values for the two best efforts. Between efforts interval was 90 sec and the three best MVCs were recorded (Figure, 5).

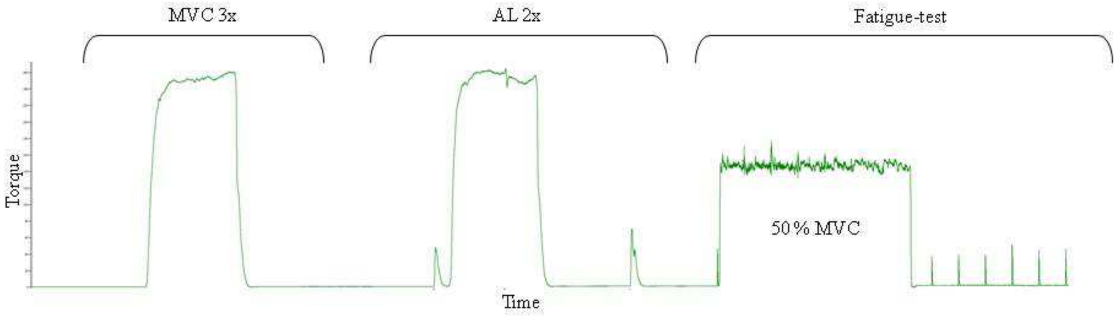

Figure 5: An example of Force-time-curve. MVC was taken 3 times, AL was taken 2 times and the fatigue test was performed within 50% MVC

3.4 Electrical stimulations (ES)

After the MVC measurements, the stimulation electrodes (2 pairs, length 9cm × wide 5cm) were placed on the subject's leg over the quadriceps muscles and covered the proximal and the distal heads of those muscles. The electrodes did not cover any adductor muscles. The electrodes were connected to a Digitimer DS7AH (Welwyn Garden City, UK) via anode and cathode leads. The subjects were informed that electrical pulses will be applied to the muscles and this will make the muscles contract without the subjects' ability for controlling the contraction. Voltage was set at 400 V and the pulse width was set at 1000 µs, these parameters were not altered during the test. The current was increased progressively until the force output reading reached 30 % of the MVC. But it should be supramaximal. The best way to assess voluntary activation is to use supramaximal tetanic twitches of the femoral nerve, but this is very painful! The method which was used in myoage (doublets corresponding to 30% MVC) is valid and is sufficient to reveal differences between groups and between individuals (Rutherford, Jones & Newham, 1986). A computer interface was set to stimulate doublets (2 pulses of 1000 µs separated by 10 ms).

First, the current (mA) was set very low, e.g. 10 mA. Doublets were applied to the rested, relaxed quadriceps muscles and 3 sec interval was allowed between twitches. The intensity was raised with small steps until intensity that elicits 30 % MVC torque was found. When using the doublets, 30% MVC was usually reached at a current of around 150 mA although this varied from person to person. When the subject did not tolerate the electrical stimulation to the level of 30 % MVC the highest tolerable level was used. Four young subjects, two old inactive subjects and six old active subjects did not tolerate to the level of 30% MVC force. The mean force that these subjects were able to tolerate using electrical stimulation was 24% of MVC. Subjects were informed to perform maximal voluntary contraction (MVC) and three doublet stimulations were applied. First doublet was applied 1 sec before the subject performed an MVC that means when the subject was still relaxed. Second doublet was superimposed at the highest point of MVC and the third doublet was applied 3 sec after the subject was again fully relaxed.

The measurement of activation level is based on a hypothesis that the negative linear relationship between evoked twitch force and voluntary force. The test of Voluntary Activation (VA) was repeated at least one further time. Three parameters were analyzed: 1) the force produced during the voluntary effort immediately prior to the superimposed doublet; 2) the additional force elicited by the superimposed doublet and 3) the size of the force elicited by the post-contraction doublet. The relative level of voluntary activation was calculated as follows:

$$\mathbf{VA = \quad 100 - \left\{ \frac{\underline{MVCT/Tst} \times 100}{Tdt} \right\} \quad \ldots\ldots\ldots (1)}$$

Where MVCT is the maximum voluntary contraction torque, Tst is maximal torque during superimposed double pulse and Tdt is the maximal passive twitch torque.

For several parameters calculation like reduction in passive twitch torque (PTw), reduction in activation level (AL) was done in following ways:

Fatigue effect = (post fatigue-pre fatigue)/ post fatigue*100…... (2)

3.5 Measurement of muscle fatigue

After the measurements of the activation level, the subjects were allowed to rest for 5 min. During the fatigue test the subject was asked to hold the contraction at the specified level of force (50 % MVC) for as long as possible.

The subjects received real-time visual feedback of the force level during this test. A horizontal cursor (a line across the screen) was adjusted to show the level of force that was required by the subjects. The subjects were instructed not to relax their muscles until the additional superimposed doublet diminished.

The test was finished when the force dropped below 5 % of the target force for more than 3 sec despite of a very strong verbal encouragement from the researchers or the subject terminated the contraction even though encourage to continue.

During the fatigue test electrical stimulation was induced (same double stimulation that was used for activation level (AL) every 10 sec to calculate AL at the end of the fatigue test and to follow the progression of the peripheral fatigue. The last stimulation at the end of the fatigue test was used for the calculation of activation level at the end of the test.

3.6 Data collection

Data was collected to a PC using AD converter (Power 1401 MK II 24 CED Ltd, Cambridge, UK) at sampling rate of 2000 Hz. Force was measured using strain gauge. Stimulation was given with constant current stimulator (Digitimer DS7A, Digitimer Ltd, UK).

3.7 Signal analysis

Signals were analyzed using spike2 software (Cambridge electronic design, England). Maximal voluntary contraction (MVC) was analyzed as passive twitch torque during the MVC trial. Activation level (AL) was analyzed using the values just prior to electrical stimulation (ES), the superimposed maximal torque and maximal torque of passive twitch. The activation level before fatigue (ALpre) according to equation 1 was taken for further analysis. From the fatigue test, time to failure was analyzed as time that the subjects were able to keep the 50 % of MVC. The variable “ALpost” refers to the activation level just before the end of fatigue test. For “ALpost” Tdt was taken from the passive twitch torque immediately after the fatigue test. The variable “Pre PTw” was taken from the best passive twitch torque after the AL test. Time to passive twitch torque (TPTw), passive twitch torque (PTw) and half relaxation time of twitch torque (HRTw) of the first twitch after the fatigue test (relaxed muscle) were analyzed. TPTw was calculated from the beginning of the twitch torque to the highest value. PTw was the highest torque value during the twitch. HRTw was determined as the time from twitch torque to relaxation divided by two.

3.8 Statistics

The parameters maximal voluntary contraction (MVC), physical activity (PA) and activation level (AL), time to passive twitch torque (TPTw), passive twitch torque (PTw) and half relaxation time of twitch torque (HRTw) and measures of fatigue were analyzed by Kolmogorov-Smirnov to test the normality of the distribution and by Mann-Whitney U test and independent sample t-test to identify specific group differences. Wilcoxon test was used for repeated measurements. The level of significance was set at $P < 0.05$. All data are expressed as means ± Standard Deviation (SD). All of the statistical tests performed with SPSS (version 15.0).

4 RESULTS

4.1 MVC Pre fatigue

Maximum voluntary contractions (MVC) were performed before the fatigue measurements. The results of MVC have shown below (Figure, 6). Old subjects group had significantly 34% lower MVC than young subjects group during isometric contractions (P<0.001) and no significant differences observed in strength between old active and inactive subject group (Figure, 6).

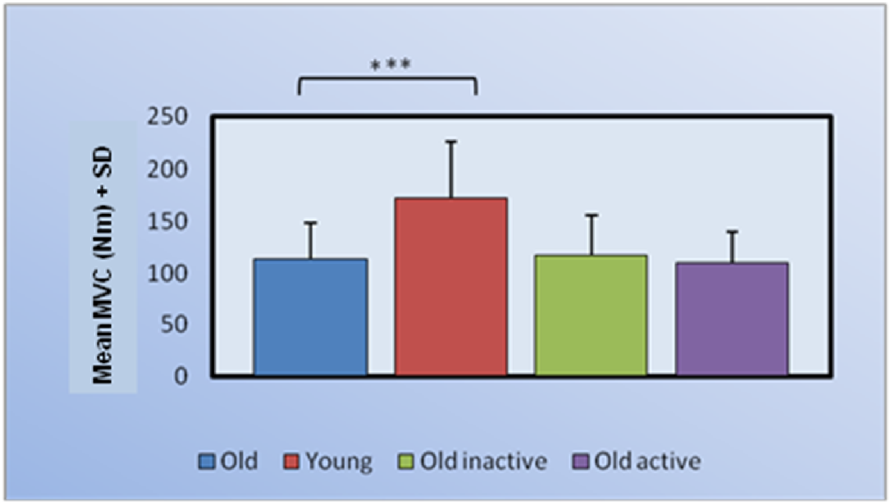

Figure 6: The differences in mean MVC with standard deviation (SD). Here (***) means significant difference between group (P<0.001).

4.2 Time to failure test

Time to failure test was performed at 50% of MVC. The result of time to failure test has shown below (Figure, 7). There were no significant differences observed in time to failure test between old and young subjects group and no significant differences observed between old active and inactive subjects group (Figure, 7).

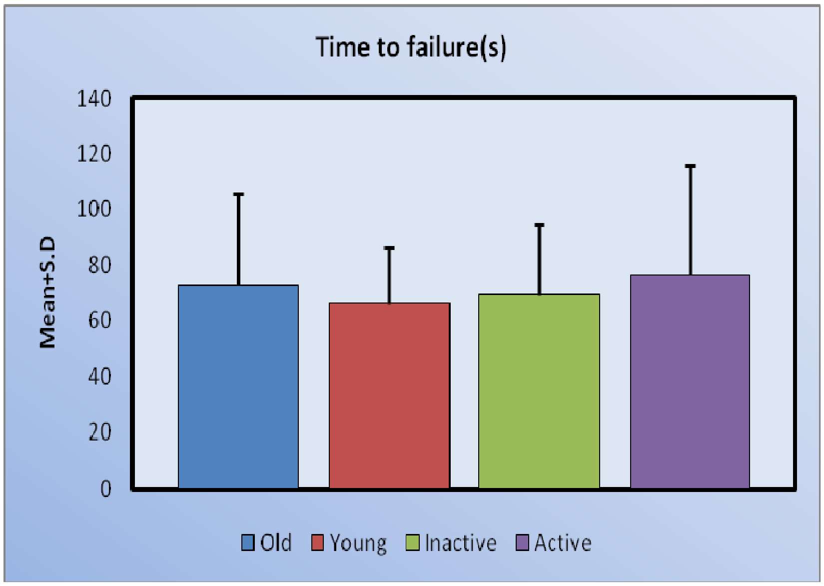

Figure 7: Mean time to failure with standard deviation (SD).

4.3 Twitch properties post fatigue

Time to passive twitch torque (TPTw), passive twitch torque (PTw) and half relaxation time of twitch torque (HRTw) for old active, old inactive and young subjects group are summarized in Table 2. There were no significant differences observed in TPTw or PTw between young and old or between inactive and active old groups. Statistically significant differences were observed in HRTw between old and young subjects group (P<0.001) (table 2). However, there were no significant differences in HRTw between old inactive and old active subjects group.

Table 2. Twitch properties of muscle

Variables	Subjects group	Mean±SD	Test	P
TPTw	Old Young	0.109±0.067s 0.104±0.037s	Mann-Whitney U	0.500
TPTw	Old active Old inactive	0.11±0.07s 0.118±0.08s	Mann-Whitney U	0.253
PTw	Old Young	25.31±7.43Nm 28.30±11.96Nm	Mann-Whitney U	0.438
PTw	Old active Old inactive	25.34±6.80Nm 25.29±8.09Nm	Mann- Whitney U	0.703
HRTw	Old Young	0.42±0.14s 0.32±0.17s	Mann-Whitney U	<0.001***
HRTw	Old active Old inactive	0.45±0.17s 0.39±0.11s	Independent t-test	0.139

Table 2. The differences of TPTw, PTw and HRTw between old and young subjects group and old active and inactive subjects group. Values expressed as mean ± SD. TPTw = time to passive twitch torque, PTw= passive twitch torque, HRTw= half relaxation time of twitch torque and (***) statistically significant.

4.4 Pre fatigue and post fatigue test

Passive twitch torque pre fatigue (Pre PTw)

Before fatigue, the results of passive twitch torque (Pre PTw) have shown below (Figure, 8). Older subjects group had significantly 31% less Pre PTw than young subjects group (p<0.001) (Figure, 8). But no significant differences were observed in Pre PTw between old inactive and active subjects group (Figure, 8).

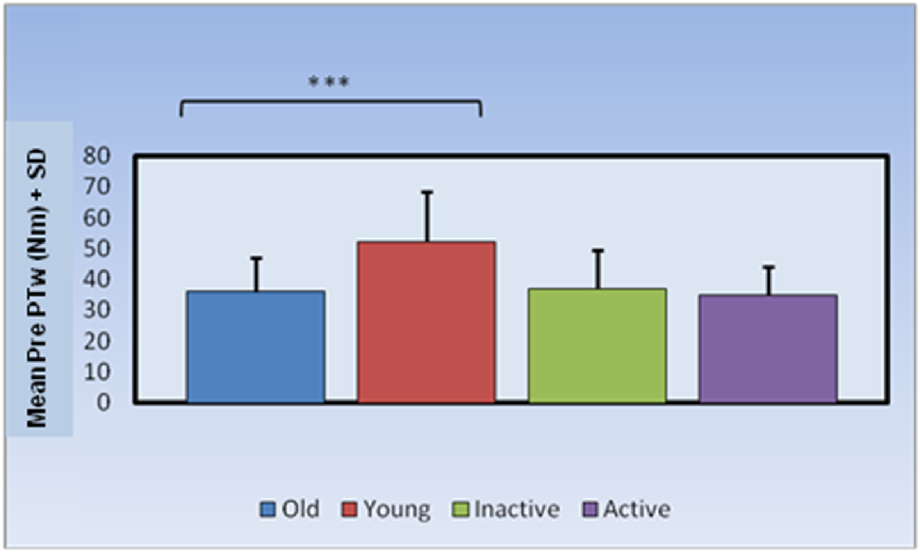

Figure 8: Mean Pre PTw with standard deviation (SD). Here (***) indicate significant difference between old and young groups (p<0.001).

Passive twitch torque post fatigue (Post PTw)

After fatigue, the results of passive twitch torque (Post PTw) have shown below (Figure, 9). Mann-Whitney U test revealed that no significant differences were observed in Post PTw between old and young subjects group (Figure, 9). Also no significant differences were observed in Post PTw between old inactive and active subjects group (Figure, 9).

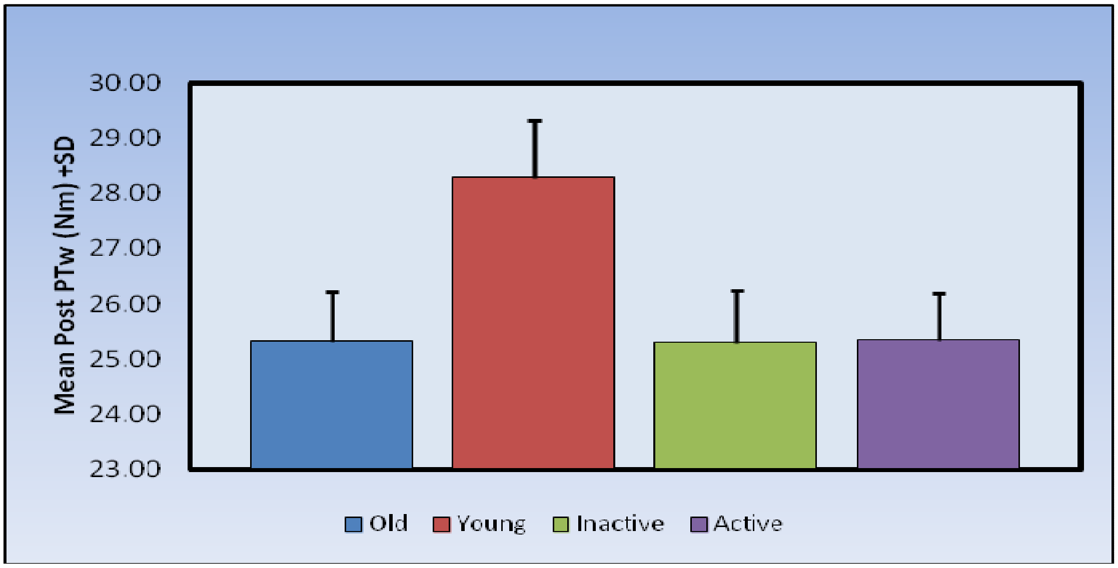

Figure 9: Mean Post PTw with SD for Old,Young, Inactive and active subjects group.

4.6 Fatigue test (Peripheral fatigue)

Following fatigue test the results of the relative reduction in passive twitch torque (PTw) have shown below (Figure, 10). Older subjects group had significantly 18% less reduction in PTw than young subject group (P<0.001) (Figure, 10). No significant difference was observed within the relative reduction in PTw between old inactive and active subjects group (Figure, 10).

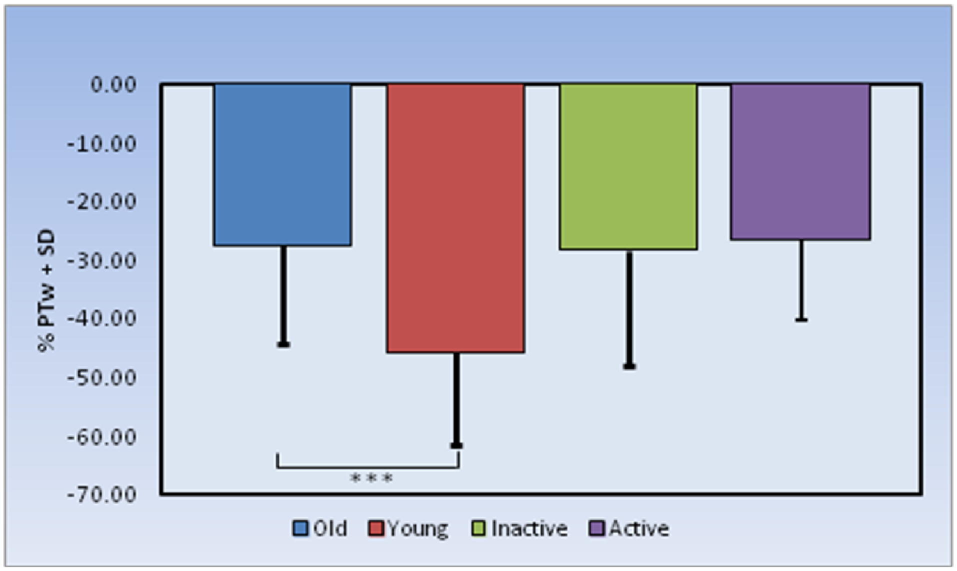

Figure 10: Relative reduction in PTw (with mean and SD) due to fatigue. (***) indicate statistically significant (p<0.001).

4.7 Activation level (AL) pre fatigue and post fatigue test

Activation level Pre fatigue

In pre fatigue test, the results of mean activation level (ALpre) have shown below (Figure, 11). Independent t test revealed, older subjects group had 0.7 % less AL than young subjects group and it was significant (P<0.05) but no significant differences observed in ALpre between old inactive and active subjects group (Figure, 11).

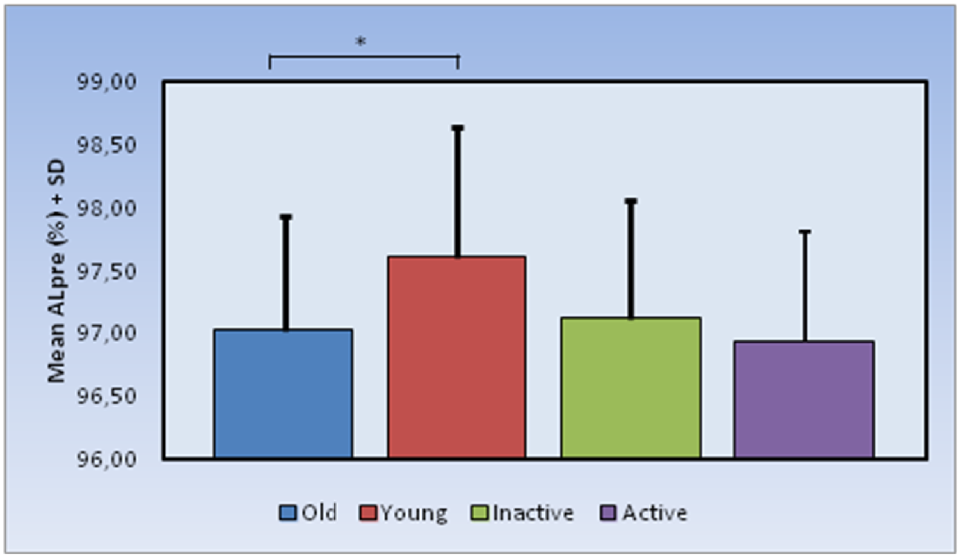

Figure 11: Mean ALpre with SD. Here (*) indicate significant difference (p<0.05) in ALpre between old and young subjects group.

AL post fatigue

In fatigue test, the results of mean activation level (ALpost) have shown below (Figure, 12). No significant differences were observed between old and young subjects group and also no significant differences were observed between old inactive and active subjects group (Figure, 12).

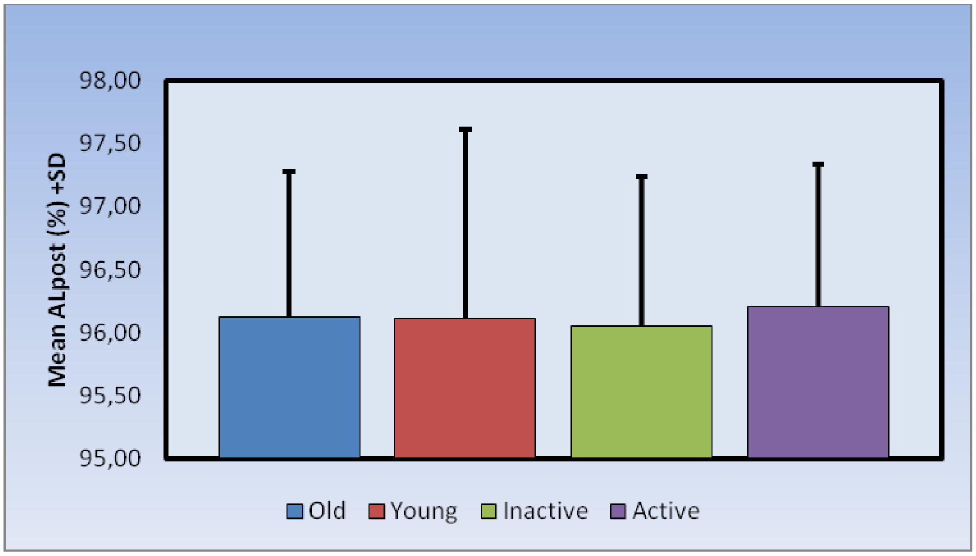

Figure 12: Mean ALpost with SD. No significant differences were observed between the subject groups.

4.8 Reduction in activation level (AL) after fatigue

The results of relative reduction in activation level have shown below (Figure, 13). Old subjects had significantly 0.6 % less reduction in AL than young subject group (P<0.05) (Figure, 13). There were no significant differences in AL reduction between old inactive and active subjects group (Figure, 13).

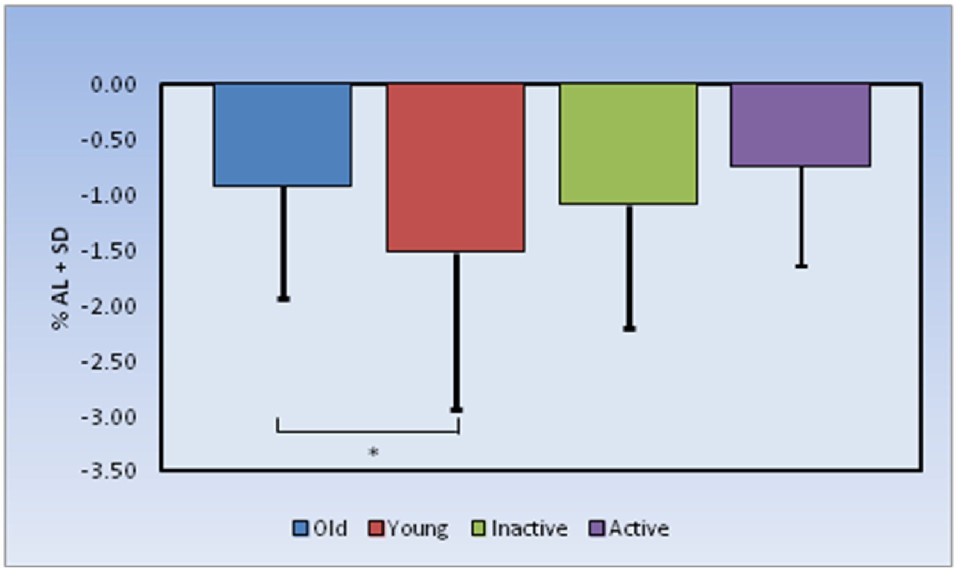

Figure 13: Relative reduction in AL. (*) indicate significant difference between old and young subject group (p<0.05).

5 DISCUSSION

The main findings of the study were as follows:

1. There were no significant differences in time to failure between old and young subjects group. No significant differences were observed in time to failure between old inactive and active subjects group.

2. Significant differences were observed in the reduction of passive twitch torque (PTw) between old and young subjects group. Old subjects had less PTw reduction than young subjects. No significant differences were observed in PTw reduction between old active and inactive subjects group.

3. Significant differences were observed in the reduction of activation level (AL) between old and young subjects group. Old subjects had less reduction in AL than young subjects. No significant differences were observed in the reduction of AL between old active and inactive groups.

Effect of ageing on fatigue

The present study has demonstrated that there were no significant differences in time to failure between old and young subjects during isometric contraction of knee extensor muscles. It indicates that there is no difference in fatigue resistance between old and young subjects group in sustained submaximal contraction of knee extensors. This study was supported by the study of Allman and Rice (2001) who also demonstrated that there was no difference in fatigability between age groups during intermittent submaximal isometric contractions. Another support comes from the study of Stackhouse et al (2001) who stated similar degree of fatigability between old and young subjects during maximum voluntary isometric contractions of the quadriceps femoris muscle. In contrast the study of Damien et al (2009) reported that old subjects fatigue less than young subjects during isometric contraction of the knee extensor muscles. Thus the results of the current study conflicts with the results of the Damien et al study. As it was previously mentioned, Damien et al, (2009) showed that age related fatigue resistance is higher in older adults compared with young during isometric contraction but this difference diminished during dynamic contractions. Most of the studies that have investigated age related fatigability during dynamic contractions; have reported no difference in fatigue resistance between old and young subjects (Laforest et al, 1990, Larsson and Karlsson 1978, Lindstorm et al, 1997). In contrast, Petrella et al (2005) demonstrated an increased fatigability in elderly adults compared with young adults during maximal dynamic knee extensions. The study of Lanza et al (2004) demonstrated that old subjects fatigue less than young subjects during both isometric and dynamic contractions of the ankle dorsiflexor muscles. These divergent results might come from the methodological differences. For example, tetanic stimulus was used in the study of Damien et al, (2009) study when double stimulus was used in the current study. Another factor that may influence these discrepancies is the choice of knee angle (Lindstorm et al, 1997). 105 degree knee angle was used in the maximum voluntary isometric contraction (MVIC) of Damien et al (2009) study but 90 degree knee angle was used in the protocol of the current study. During the fatigue protocol, intermittent MVIC (5 sec contraction and then 5 sec rest) was used but in the current study sustain 50 % MVIC was used. Also variation in subject population can cause differences in these two studies. 32 subjects were used in the study of Damien et al (2009) and 90 subjects were used in the current study. It has to be acknowledged that in this present study motivation of the subjects could play significant role as subjects could terminate the fatigue task without giving their maximal performance. This study could not control that the subjects would not be able to continue any longer. The present study demonstrated that the older subjects group’s knee extensors voluntary force was significantly 34 % weaker than the younger subjects group’s during MVIC. However, this age related reduction in force generating capacity did not affect the time to fatigue.

Central and peripheral fatigue

The ability to detect central activation failure can vary between muscle groups (Jacobi and Rice, 2002). The level of voluntary activation has been shown to decrease with prolonged activity (Bilodeau et al, 2001 and Gandevia et al, 1996). To determine central fatigue, ALpre (before the fatigue test) and ALpost (prior to the end of the fatigue test) were compared for the old and young subjects group and old inactive and active subjects group in the current study. The significant difference was observed in ALpre between old (96.93±0.90%) and young subjects (97.60±1.03%) group. The young subjects group had 0.7% higher ALpre than old subjects group but no significant difference was observed in ALpost between old and young subjects group in this present study. It indicates that young subjects group had 0.7 % higher activation level than old subjects group in non-fatigue state but in fatigue state there was no difference between old and young subjects group. This result is supported by the previous studies reporting that voluntary activation in non fatigue state is high but decreases with a sustained MVC (Garland et al, 1997 & Klein et al, 2001). For the old active and inactive subjects group the current study did not find any significant difference in non-fatigue and fatigue state. There was no difference in the reduction of AL between old active and inactive subjects group which suggest that there are no differences in central fatigue between these two groups. Older subjects group (-0.9±1 %) had significantly 0.6% lower reduction in activation level than younger subjects group (-1.5±1%). It indicates that older subjects group had 0.6% less central fatigue than younger subjects. It could mean that old gave up more easily or young subjects fatigued more due to higher MVC and more fast motor units (IIB) in young subjects. However, a discrepancy was found in the Damien et al study (2009) who demonstrated no central activation failure between young and old subjects during fatiguing isometric contraction of knee extensor muscles.

To be an accurate measure of peripheral fatigue, submaximal electrical stimulation should activate a consistent population of muscle fibers that represent the whole muscle with different fiber types and associated contractile characteristics (Gregory and Bickel, 2005).

Electrical stimulation preferentially recruits more fatigable type II muscle fibers due to difference in the stimulation threshold between the motor neuron types (Vanderthommen et al, 2003). Before the fatigue test, significantly 31% less pre passive twitch torque (Pre PTw) was observed in old subjects group (36±11Nm) than young subjects group (52±16 Nm). It means that old subjects group had 31% less twitch torque than young subjects group before the fatigue test. The reason might be the difference in the contractile properties between age groups and the shift of old subject's type II fiber into type I fiber. However, after the fatigue test when the muscles were fatigued, no differences were observed in post passive twitch torque (Post PTw) between old and young subjects group. In addition, no differences were observed in passive twitch torque before and after fatigue test between old inactive and active subjects group. It indicates that habitual physical activity for old subjects do not affect on passive twitch torque before and after fatigue test. Thus, no differences in the contractile properties exist. In this study, reduced passive twitch torque between old and young subjects was calculated after fatigue test. Significant differences were observed in torque reduction. Old subjects group (-28±17%) had 18% less torque reduction than young subjects group (-46±16%). It means that young subjects group have more peripheral fatigue than old subjects group and this result gives more support the previous assumption that old gave up more easily than young subjects in the fatigue test. No differences were observed in peripheral fatigue between old inactive and active subjects group.

In conclusion, no significant differences were observed in time to failure between old and young subjects and habitual physical activity didn't give any different result compared to old inactive or sedentary people. Young subjects had more central and peripheral fatigue than older subjects. The limitations of this study was low current of the electrical stimulation (ES) used for activation level (AL) test. But supra maximal electrical stimulation was the better option. Another limitation was this study could not measure maximal voluntary contraction (MVC) after the fatigue test and it was not possible to overcome the effect of individual's motivation on the results. In addition, this study could not differentiate the results of the old women and men following the fatigue test. It was also the limitation of this study. So these limitations can be recommended for further studies.

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APPENDIX

Exclusion criteria

Participants were excluded if they were participating in other ongoing study and competing in high level sports and the young women who were pregnant or breast feeding of a child. Those who had no social security, medical cover, not capable of making their own choices and could not commit to attending the research premises for around 6 hours. The subjects who were institutionalized, neurological disorder, metabolic diseases, arthritis, fracture within the previous year (hip, knee or spinal stenosis surgery), severe visual or hearing impairment, amputation, cancer, polymyalgia rheumatica, COPD, myocardial infarction, pacemaker etc.

Subjects were instructed not to consume alcohol for at least 24 hour prior to visit, no smoking at least 2 hrs prior to muscle function measurements, no strenuous exercise for at least 24 hours prior to visit.

Physical Activity Questionnaire

Voorrips (1991): To assess Physical Activity in elderly populations

HOUSEHOLD ACTIVITIES

1. Do you do the light house hold work? (dusting, washing dishes, repairing clothes etc.)

0 Never (less than once per month)

1 Sometimes (only when partner or help is not available)

2 Mostly (sometimes assisted by partner or help)

3 Always (alone or together with partner)

2. Do you do the heavy housework?(washing floors and windows, carryingtrash bags etc.)

0 Never (less than once per month)

1 Sometimes (only when partner or helpis not available)

2 Mostly (sometimes assisted by partner or help)

3 Always (alone or together with partner)

3. For how many persons do you keephouse? (Including yourself; fill in “0” if you answered Never in Q1 & 2.

………………………

4. How many room do you keep clean, including kitchen, bedroom, garage, cellar, bathroom, ceiling etc?

0 (Never do housework)

1 (1-6 rooms)

2 (7-9 rooms)

3 (10 or more rooms)

5. If any rooms, on how many floors?(fill in “0” if you answered Never in Q4

……………………………….

6. Do you prepare warm meals yourself, or do you assist in preparing?

0 Never (less than once per month)

1 Sometimes (once or twice a week)

2 Mostly (3-5 times a week)

3 Always (more than 5 times a week)

7. How many flights of stairs do you walk up per day? (one flight is 10 steps)
0 I never walk on stairs

1 (1-5)

2 (6-10)

3 (more than 10)

8. If you go somewhere in your hometown, what type of transport do you use?

0 (I never go out)

1 (Car)

2 (Public transportation)

3 (Bicycle)

4 Walking

9. How often do you go out for shopping?

0 (Never or less than once a week)

1 (Once a week)

2 (2 – 4 times a week)

3 (Everyday)

SPORT ACTIVITIES

Do you play a sport?

What sport is it?………………………….
Intensity ………………………..(code) 1 a
Hours per week…………………(code) 1 b *Codes are given at end of questionnaire*
Period of the year ………………(code) 1 c

Do you play another sport?

What sport is it?………………………….
Intensity ………………………..(code) 2a
Hours per week…………………(code) 2b
Period of the year ………………(code) 2c

LEISURE TIME ACTIVITIES

Do you have other physical activities?

What is it?………………………….
Intensity ………………………..(code) 1a
Hours per week…………………(code) 1b *Codes are given at end of questionnaire*
Period of the year ………………(code) 1c

Do you have other physical activities?
What is it?………………………….
Intensity ………………………..(code) 2a
Hours per week…………………(code) 2b
Period of the year ………………(code) 2c

Do you have other physical activities?
What is it?………………………….
Intensity ………………………..(code) 3a
Hours per week…………………(code) 3b
Period of the year ………………(code) 3c

Do you have other physical activities?
What is it?………………………….
Intensity ………………………..(code) 4a
Hours per week…………………(code) 4b
Period of the year ………………(code) 4c

0: Lying, unloaded ………………………………………code 0.028

1: Sitting, unloaded …………………………………… ...code 0.146

2: Sitting, movement hand or arm ……………………….code 0.297

3: Sitting, body movements……………………………,…code 0.793

4: Standing, unloaded……………………………………. code 0.174

5: Standing, movements hand or arm………………………code 0.307

6: Standing, body movements, walking…………………….code 0.890

7: Walking, movements arm or hands………………………code 1.368

8: Walking, body movements, cycling, swimming………… code 1.890

Hours per week:

1. Less than 1hr/ wk:……………………………………… code 0.5

2. 1, 2> h/wk………………………………………………..code 1.5

3. 2, 3> h/ wk……………………………………………….code 2.5

4. 3, 4> h/wk……………………………………………….code 3.5

5. 4, 5> h/wk………………………………………………..code 4.5

6. 5, 6> h/wk………………………………………………..code 5.5

7. 6, 7> h/wk………………………………………………..code 6.5

8. 7, 8> h/wk………………………………………………..code 7.5

9. More than 8 h/wk……………………………………………code 8.5

Months a year:

1: Less than 1 month/year………………………………….code 0.04

2: 1-3 months………………………………………………code 0.17

3: 4-6 months………………………………………………code 0.42

4: 7-9 months………………………………………………code 0.67

5: More than 9 months……………………………………..code 0.92

Unit less intensity code, originally based on energy costs