Force Perception and Fatigue in The Dorsiflexor Muscles of Younger and Older Men

By
Ian Philip Snow

A Thesis
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GLOSSARY

Force – that which changes or tends to change the state of rest or motion in muscle. A muscle generates force in a muscle action (Knuttgen & Komi, 1992).

Force Perception – the ability to judge the heaviness of objects and the magnitude of frictional and other obstructive forces opposing movement.

Isometric – (iso=same, metric=length) The length of the whole muscle does not change while being activated.

Maximum Voluntary Contraction (MVC) – MVC or sometimes referred to as maximal effort is defined as the maximal torque produced about a joint axis that a person can voluntarily exert in a given physiological state. This is not to be mistaken with maximal activation of the muscle.

Sense of Effort – Centrally generated sensations arising from internal neural correlates (corollary discharges) sent to sensory centers. Presumably these signals reflect the magnitude of the voluntary motor command generated (McCloskey et al., 1974).

Sense of Force/Tension – Sensory information derived from peripheral receptors in the muscles, joints, and skin which signal intramuscular tension and provide a measure of the force that is being exerted by the muscle (Roland and Ladegaard-Pedersen, 1977).

Torque – A rotary force. It is the product of force and distance and is measured in Newton-metres (N·m).

Abstract

The purpose of this study was to compare differences in the perception of force with neuromuscular fatigue between similarly active younger and older male subjects for a task performed with the dorsiflexor muscles. Ten younger (20-30 years) and older (>65 years) healthy, active, volunteers participated in the study. The subjects acted as their own control, participating in two testing sessions where measures of neuromuscular function were taken before, during, and after a fatigue task. In one session the subject completed the experimental protocol and in the other session the control protocol. Subjects were randomly assigned to either the experimental or control protocol so that half the subjects received the experimental protocol during their first session and the other half received the control protocol, and vice versa during the second session. Each subject completed three maximal, isometric, voluntary contractions in a seated position to determine their single, highest peak torque or maximum voluntary contraction (MVC). All subjects then completed 12 submaximal contractions at 60% of their MVC to learn the force perception task. After completing the force perception task, the subjects completed either the fatigue or control task. The fatigue task involved 40 maximal, isometric contractions, each contraction lasted 5 seconds with 2 seconds of rest between contractions. During the control task the subjects rested. All subjects then completed the post-fatigue task. It involved 6 isometric contractions with no feedback at the subjects' 60% MVC to determine if there was a change in their perceived 60% MVC. We expected that the older subjects would be more fatigue resistant, therefore having better perception of a 60% MVC when compared to their younger counterparts. We also

expected the older subjects would make fewer errors in their perception of force after the fatiguing protocol.

The younger and older subjects did not differ on height, weight, or body mass index (BMI). Standard t-tests revealed a significant difference between the groups for physical activity level (P=0.002) and for MVC (P=0.037), with the younger group participating in higher intensity activities and having a 15% higher MVC.

A three-way repeated measures ANOVA (age x pre/post contraction x experimental/control session) revealed that older males had less change in their force perception compared to the younger males. The older males were more fatigue resistant compared to the younger males. There was a significant positive relationship (R=0.62; p=0.003) between the percent change in force perception and the percentage of fatigue. Multiple linear regression revealed that percent fatigue, weight, age group, and physical activity explained 74% of the change in force perception, although age group and physical activity only explained a small portion (12%) of the 74% explained.

In conclusion, the older males were more fatigue resistant during maximal fatiguing contractions of the dorsiflexors compared to the younger males. Force perception was better following a time-specific fatigue task for the older males compared to the younger males mostly due to this fatigue resistance.

Force Perception and Fatigue in Younger and Older Men

INTRODUCTION

With increasing age in humans, there is a decline in most physiological systems in the body. It is well established that skeletal muscle mass is lost with increased age and there is an accompanying reduction in muscular strength (Duta & Hadley, 1995; Evans et al., 1997). Therefore, it is important with increasing age that an appropriate level of neuromuscular function be maintained if we expect the elderly to be able to complete normal daily activities and remain functionally independent.

Since it has been recognized that older individuals are beginning to comprise an increasing proportion of the population, age-related changes in neuromuscular function and the possibilities of attenuating or adapting to these changes have been of interest to researchers. There has been considerable focus on strength changes and the ability to increase maximal force production through weight-training programs (Frontera et al.,1988; Brown et al., 1990; Charette et al., 1991; Grimby et al., 1992.). However, the frequency with which maximal force is actually required under normal circumstances is limited. Therefore, the assessment of performance under conditions of fatigue, rather than absolute strength, may be an equally important measure of neuromuscular function and may provide new information related to the ability to maintain normal daily activities such as walking, grasping, and object manipulation, especially in the elderly.

Force Perception

The basis on which judgments of force and weight are made has been the subject of much debate and experimentation over the past decades (McCloskey, 1981). At issue is whether the perception of force is derived from centrally generated sensations arising from the innervation of the efferent pathway as McCloskey and colleagues (1974) proposed, or from peripheral sensations originating in the muscles, joints, and skin as Roland and Ladegaard-Pedersen (1977) hypothesized. Centrally generated sensations, termed sense of effort (McCloskey et al., 1974) arise from internal neural correlates (corollary discharges) sent to sensory centers. Presumably these signals reflect the magnitude of the voluntary motor command generated. The second source of sensory information, described as sense of force or tension, is derived from peripheral receptors in the muscles, joints, and skin and is presumed to signal intramuscular tension and therefore provide a measure of the actual force exerted (Roland & Ladegaard-Pedersen, 1977). Although sense of effort and force are often presented as two separate systems, they should be considered as complementary rather than competitive, as both appear to be involved in mediating the perception of force.

Sense of Effort

Experiments conducted by McCloskey and colleagues (1974, 1981) have shown that changes in the perception of muscular forces parallel changes in the motor command sent to the muscle. In studies examining the perceived heaviness of lifted weights, McCloskey et al (1974) showed that when a lifting muscle is weakened so that an increase in the efferent signal occurs, there is a corresponding increase in the perceived heaviness of the lifted object on the unaffected side as indicated by the weight the subject chooses.

Similar results were found when subjects were asked to judge the magnitude of a sustained constant force by producing a brief matching contraction on the contralateral side (Jones & Hunter, 1983; Cafarelli & Layton-Wood, 1986; Burgess & Jones, 1997). In these studies the subjects were instructed to make both arms, or the forces produced by both arms, the same. During the experiment the subjects were unaware of the extent to which they were overestimating the forces. There was a progressive increase in the perceived magnitude of the force being maintained. These results suggest that subjects based their judgments of force on a signal related to the motor command sent to the muscle (sense of effort) rather than on the force actually generated by the fatiguing muscle (sense of force).

Sense of Force/Tension

The results of the studies reviewed above suggest that subjects did not perceive the actual forces exerted by the fatiguing muscles, but rather, based their judgements of force on the effort to generate the contraction. Roland and Ladegaard-Pedersen (1977) showed that subjects were capable of distinguishing between a sense of effort and a sense of force. During partial curarization, subjects were able to dissociate a sense of effort from force if they were instructed to disregard the increased effort required to produce the muscle contraction. Although the subjects' judgement of force was more variable than under control conditions, there was not a consistent tendency to overestimate the force, as would be expected if the subjects were basing their judgements on sense of effort.

In an attempt to determine whether peripheral mechanisms are the predominant means of judging forces Cafarelli and Kosta (1981) investigated the effect of muscle vibration on force sensation. They found that, contrary to the previous findings of McCloskey et al. (1974), the matching forces produced during vibration of the reference muscle were considerably greater than those exerted in the absence of vibration. Conversely when the matching muscle was vibrated the forces produced were significantly less than control estimates. These results suggest that muscle tendon vibration leads to the perception that the muscle is producing more force than it actually is. Centrally generated motor commands should diminish with the reflex facilitation elicited by vibration. Therefore the overestimation of force presumably results from the increased activation of muscle receptors.

Estimating Force

Most research on force perception has assumed that the perceived force associated with an isometric contraction is essentially the same as the force exerted by the reference arm across the range of perceptible forces. Some studies (Cafarelli and Bigland-Ritchie, 1979; Jones and Hunter, 1982; Pincivero et al., 2001) have shown deviations from this line of equality that occur when the muscle state is altered.

Jones and Hunter (1982) investigated the perception of isometric contractions across a wide range of forces under normal, unfatigued muscle conditions. Subjects matched isometric contractions for both a control and reference arm on the basis of equal sensation. It was found that smaller forces (under 40% maximum voluntary contraction (MVC)) were consistently overestimated and larger forces (greater than 60% MVC) were consistently underestimated, with the most accurate estimation of force occurring around the middle of the force continuum (around 50% MVC).

Similar results were found in a study conducted by Pincivero et al. (2001) when comparing perceived exertion ratings with actual target intensities. The subjects completed a series of isokinetic contractions at various percentages of their peak torque, 10% to 90% MVC in 10% intervals. Perceived exertion was measured by asking the subjects to provide a number that corresponded to the feelings in their muscle during exercise, at each interval, by viewing a modified category-ratio (CR-10) scale. The results revealed the subjects' perceived exertion was significantly lower for the 50%-90% MVC contractions. This underestimation demonstrates that these subjects were generating more torque than intended.

These studies show that perceived exertion is linearly related to contraction intensity, and subjects usually underestimate larger forces.

Visual Feedback in Force Control

The accuracy with which forces can be maintained voluntarily at a constant amplitude over time has been measured in several experiments. Mai et al. (1985) reported that subjects were able to maintain an isometric grasping force of 2.5 N to within a 6% range over short time intervals (20 s) using only tactile and kinesthetic (ie. haptic) feedback. With the addition of visual feedback of the forces being produced the errors decreased to 1.5%. Jones (2000) examined force control with both haptic, and visual and haptic feedback conditions in the muscle groups controlling elbow flexion and index finger flexion. It was observed that for long periods of time (120 s) subjects were able to maintain an isometric force at a constant amplitude using only haptic feedback. The index finger was able to maintain forces of 2-6 N with an average absolute error less than 1 N. The elbow flexors had an average absolute error of 4.5 N over a force range of 10-30 N. When subjects were provided with visual and haptic feedback, the errors decreased, an average absolute error of 0.22 N for the index finger and 0.76 N for the elbow flexors. The precision with which forces can be controlled, reflected in the coefficient of variation, improves with visual feedback.

Fatigue

Neuromuscular fatigue is often defined as "any reduction in the force-generating capacity of the total neuromuscular system regardless of the force required in any given situation" (Gandevia, 1992). The particular physiological mechanism that is most responsible for fatigue depends on the fiber type composition of the contracting muscle(s), the intensity, type, and duration of the contraction, and the individual's level of fitness (Fitts, 1994). For example, fatigue experienced during high-intensity, short duration exercise depends on different factors than does fatigue experienced in endurance activities. Similarly, fatigue during tasks involving contractions when muscles are heavily loaded such as weight lifting is different from contractions produced during relatively unloaded movements like running or swimming.

Main features of muscular fatigue

The main features of fatigue occur regardless of whether looking at single fibers, isolated fibers, or human muscles contracting in vivo. First, there is a very large drop in the twitch tension and a slowing of the contraction and relaxation time (Bigland-Ritchie et al., 1983; Bergstrom & Hultman, 1986; Fitts, 1994; Fitts, 1996; Fitts & Balog, 1996). The slowing of the relaxation time is thought to be involved with inhibition of the re-uptake of calcium by the sarcoplasmic reticulum (Williams, 1997). Secondly, there is a drop in peak tetanic tension which can be attributed to less force generation of the contractile element (Fitts, 1994; Fitts, 1996, Fitts & Balog, 1996). In addition to this decline in force due to less force per cross-bridge, there is a reduced peak rate of force development and a prolongation of relaxation (Fitts, 1996). The recovery of peak tetanic tension occurs in two phases: a rapid recovery in the first 2 minutes, followed by a slower recovery that takes over an hour or more to reach the prefatigue level (Fitts, 1994; Fitts, 1996). It is believed that the rapid phase of recovery involves the excitation-contraction (E-C) coupling mechanisms with the slower phase affecting the cross-bridges directly (Fitts, 1994; Fitts & Balog, 1996).

Central vs. Peripheral Fatigue

A discussion of muscle fatigue may be broken into central and peripheral components. Considerable controversy exists regarding the relative importance of each component in the etiology of neuromuscular fatigue (Fitts, 1994; Davis & Bailey, 1996;

Fitts, 1996; Fitts & Balog, 1996; Ljubisavljevic et al., 1996; Loscher et al., 1996; Williams, 1997; Cresswell & Loscher, 2000).

Central Fatigue. Central fatigue is related to events of neural input to the higher brain center, central command, recruitment of the alpha motor nerve pool, and the alpha motor nerves themselves (Fitts, 1996). Experimental support for a specific role of central fatigue is limited primarily because of a lack of objective measures. Central fatigue is often accepted only by default when the experimental findings do not support the hypothesis of a study. Even then, it is often dismissed as reflecting a lack of motivation or an unfamiliarity with the experimental situation (Davis & Bailey, 1996). For example, it has been shown that force generation and electromyographic (EMG) activity during repeated maximal voluntary contractions may be enhanced by encouragement (Rube & Secher, 1981; Secher, 1987), and that fatigue is more pronounced in subjects who are concentrating on their performance and is reduced when they are disturbed (Asmussen & Mazin, 1978; Secher, 1987).

The technique routinely used to identify the role of central versus peripheral factors in fatigue is one in which the muscular force that a subject can elicit voluntarily is compared to that elicited by supramaximal electrical stimulations (Twitch Interpolation Technique). Studies by Loscher et al., (1996); Bilodeau et al., (2001); Chan et al., (2000) have used this technique to look at central fatigue. Using this technique investigators determine whether the force exerted by a subject, ie. central drive, can be enhanced by a single or brief train of electrical shocks applied to the nerve supplying the muscle or the muscle itself. Bilodeau and colleagues (2001) found an earlier or more pronounced decrease in voluntary activation in the older subjects during the post-fatigue task, suggesting central fatigue is occurring.

Recent studies have used a similar technique, twitch occlusion technique, to examine the changes in the excitatory drive of the α-motoneuron pool (Bigland-Ritchie et al., 1986a; Loscher et al., 1996). Loscher et al. (1996) investigated the changes in the excitatory drive of the α-motoneuron pool by monitoring the H reflex in order to ascertain MU recruitment. During sustained submaximal constant force plantarflexion, the excitatory drive to the triceps surae α-motoneuron pool increased, indicating additional MU recruitment and/or increased MU firing rates.

However, the most convincing evidence comes from a study by Brasil-Neto et al. (1993) in which a relatively new technique involving transcranial magnetic stimulation (TMS) was used. This technique can be used to assess central nervous system excitability from the motor cortex to the α-motoneuron pool. In this study, the magnitude of the motor responses elicited in the muscle by TMS was transiently decreased after fatiguing exercise. Although there are several possible explanations for this effect, the authors suggested that decreased central drive likely involved the accumulation and depletion of neurotransmitters in CNS pathways located upstream from the corticospinal neurons.

Although recent evidence has shown increased support for centrally mediated fatigue, the preponderance of evidence suggests that the primary site of fatigue lies within the muscle itself (Fitts, 1994; Fitts, 1996; Loscher et al., 1996; Williams, 1997).

Peripheral Fatigue. Peripheral fatigue involves the neuromuscular junction, the process of excitation-contraction (E-C) coupling, activation of the contractile elements involved in the generation of force and power (Fitts, 1996), and changes in muscle blood flow (Bemben, 1998). Excitation-contraction coupling involves generation of a surface membrane potential and the need for that action potential to propagate down the transverse-tubules (T-tubules) into the muscle fiber. Fitts (1996) described how, at discrete positions along the T-tubules there is a link between the T-tubular protein and the sarcoplasmic reticulum. Calcium is stored in the terminal cisternae, the region of the sarcoplasmic reticulum that abuts up to the T-tubules. The sarcoplasmic reticulum calcium release channels are in this region directly underlying the T-tubules. An action potential comes down the T-tubules and causes a charge movement of a T-tubular protein. The protein binds dihydropyridines (DHP) and triggers the opening of the sarcoplasmic reticulum calcium channel. The calcium channel binds ryanodine which causes the release of calcium which activates the contraction process and cross-bridge formation.

In non-fatigued fibers, the resting membrane potential is about –80mV in most cells, while the spike of the action potential reaches about +20 mV (Fitts, 1996). During fatigue there is a reduction in the spike height of between 10 and 20 mV and a depolarization in the resting potential, which is usually about 10 to 15 mV but can reach 20 mV (Fitts, 1996). Therefore, it is possible to have cells with resting potentials of –60 mV. In addition to the depolarized resting potential and reduced action potential overshoot, there is a slowing of the rate of rise and fall of the action potential, which in turn slows the conduction velocity of the action potential. The change in the action potential is believed to be caused by an increase in extracellular potassium (Fitts, 1994; Fitts & Balog, 1996). This increased extracellular potassium causes depolarization of the membrane which causes inactivation of sodium channels. The inactive sodium channels contribute to the reduction in the amplitude of the spike of the action potential. If the T-tubular protein membrane becomes depolarized to –60 mV, which it may do in the case of fatigue, this would cause an inhibition of calcium release and a drop in force.

When calcium is released from the sarcoplasmic reticulum, it binds to the protein troponin which activates the process of myosin binding to actin, leading to cross-bridge formation, generating force and causing muscle shortening (see Fitts, 1996). Initially, when actin and myosin bind, the force produced is low. Then there is a transition where the force goes from low to a high force state due to the increased number of cross-bridges being formed. It is during this transition that there is liberation of phosphate and hydrogen. When phosphate and hydrogen increase during exercise they produce fatigue by preventing/or reducing the transition from the low to the high force state (Fitts, 1996; Fitts & Balog, 1996).

Adenosine diphosphate (ADP) also increases in fatigue. ADP slows down the velocity at which the cross-bridges can cycle by interfering at the ADP release step (Fitts & Balog, 1996). As ADP increases there is a reduction in the free energy of ADP hydrolysis. This reduction in free energy may partly contribute to the slowing down of the sarcoplasmic reticulum reuptake of Ca^{2+} (Williams, 1997).

Force Perception and Fatigue

Studies that have examined the relationship between force perception and fatigue have shown that when there is a change in the voluntary motor command producing a contraction, there is a parallel change in the perceived magnitude of the force produced by the muscles (Jones & Hunter, 1983; Cafarelli & Layton-Wood, 1986; Burgess & Jones, 1997; Pincivero & Gear, 2000). Burgess and Jones (1997) examined perception of effort and heaviness during fatigue and during size-weight illusion. They tested this in the elbow flexors of seven subjects aging from 18 to 61 years. The subjects were required to lift a weight that was approximately 20% of their maximum in repeated sets of 5 contractions. After each set the subjects lifted a 'test' weight and reported the effort required or the heaviness of the weight. The subjects reported an increased heaviness of the 'test' weight as they became more fatigued, but the increased heaviness was not as great as the increased effort required to lift the weight.

Similar result were found by Pincivero and Gear (2000) when they examined perceived exertion during a high intensity, steady state contraction of the quadriceps muscle. The subjects, average age 23 years, maintained an 80% MVC, isometric contraction of the quadriceps muscle for as long as they could maintain it. The subjects rated the feeling in their quadriceps every 5 seconds during the fatiguing test using a CR-10 scale. Pincivero and Gear found that perceived exertion increased with the increase in fatigue.

The above studies have all used diverse groups of subjects ranging in age from 16-65 years of age and have not examined the effects of force perception and fatigue in specific age groups, notably older adults. Thus, the relationship between force perception and fatigue with aging has not been examined to determine if this relationship will hold true. This relationship may change with older adults due to the physiological changes that occurs in the neuromuscular system with age.

The Older Adult

Aging is associated with losses in muscle mass and strength (Frontera et al., 1991; Lexell et al., 1983; Larson et al., 1978), a decrease in the number of motor neurons/motor units (Brown et al., 1988), a process of denervation and reinnervation of muscle fibers (Pettigrew et al., 1991), changes in muscle metabolism (Proctor et al., 1995), a slowing of muscle contractile properties (Vandervoort & McComas, 1986), alterations of the neuromuscular junction, and changes in voluntary activation (Harridge et al., 1999) and motor unit activation (Roos et al., 1997; Laidlaw et al., 2000).

Muscle Fiber Loss

The loss of muscle mass and strength with age has been attributed to a loss of muscle fiber size and number, with preferential atrophy of type II muscle fibers (Brooks and Faulker, 1994; Lexell, 1993). Studies have shown that the relative proportion of type I muscle tissue in the muscle cross-sectional area is greater in older than younger adults (Larsson et al., 1978; Lexell et al., 1988; Grimby et al., 1982; Hunter et al., 1999). Larsson et al. (1978) observed an increase in the relative proportion of type I fibers in 60-65 year old subjects (66% of total muscle), compared to 20-29 year old subjects (39% of total muscle). Lexell (1993) examined the cross-sectional area (CSA) of the quadriceps muscle taken at autopsy from healthy, physically active males aged 20-80 years. Fiber number was reported to decline by 39%, and seemed to be progressive, commencing at about the age of 30.

Muscle Fiber Size

Many studies, whether in humans or animals, have shown a reduction in muscle fiber size, thus a reduction in CSA with increasing age (Lexell et al., 1988; Grimby et al., 1982; Larsson, 1983). Grimby et al. (1982) found a selective reduction in CSA of type II fibers in the vastus lateralis of humans over 70 years of age, with only slight reductions prior to the age of 60-70 years. The decrease in CSA has been attributed to physical inactivity with aging (Grimby et al., 1982). Thus with the decrease in CSA of type II fibers, particularly the IIX fibers (fast-twitch, predominantly glycolyitc and readily fatigable), along with the order of motor unit recruitment, the relative contribution of type II fibers to force generation is less in the elderly than in their younger counterparts (Lexell et al., 1988; Roos et al., 1997).

Motoneurons and Motor Units

A motor unit consists of all the muscle fibers innervated by a motoneuron (Luff, 1988). The number of fibers innervated by a particular motoneuron is referred to as the innervation ratio. Essentially, if a motoneuron is lost, a motor unit is lost and the consensus from both human and animal studies is that motor units are lost with age (Luff, 1998).

Edstrom and Larsson (1987) examined the number of motor units in the soleus muscle in rats. They found that on average the number of motor units declined from 49 in 3 to 6 month old rats to 29 in 20 to 24 month old rats, a reduction of 40 percent. Brown et al. (1988) estimated that the number of motor units in the human biceps-brachialis muscles declined by nearly half, from an average of 911 in subjects aged less than 60 years to 479 in subjects over 60 years.

Both human and animal studies have demonstrated a significant loss of motor units with age, and this loss occurs predominantly after the age of 60 years in humans (Luff, 1998; Brown et al., 1988).

Motoneuron Sprouting and Motor Unit Remodeling

Motor unit (MU) remodeling is the natural cycle of turnover of synaptic connections occurring at the neuromuscular junction by the process of denervation, axonal sprouting, and reinnervation of the muscle (Brooks & Faulkner, 1994). With aging, however, it appears that MU remodeling may be altered such that type II fibers are selectively denervated and reinnervated by collateral sprouting of axons from fibers of the slow MUs (Roos et al., 1997). It has been suggested that the type II fibers which become reinnervated by slow MU axons actually become (or approximate) type I fibers, with respect to physiological and biochemical properties (Roos et al., 1997).

With the larger number of surviving type I fiber population, and the lower fatigability of this population, there may be an increase in the endurance with age (Larsson & Karlsson, 1978). With an increase in endurance with age, it is possible that there would be smaller changes in force perception with fatigue.

Fatigue

The research that has been conducted on age-related changes in muscle fatigability has shown equivocal results with older adults being less fatigable, the same, or more fatigable than younger adults.

Some studies have shown that older subjects are less fatigable than their younger counterparts (Kent-Braun et al., 2002; Bilodeau et al., 2001; Chan et al., 2000; Ditor and Hicks, 2000; Narci et al., 1991). Kent-Braun and colleagues (2002) examined skeletal muscle responses with gender and aging during fatiguing incremental isometric exercise. The fatiguing protocol consisted of 16 minutes of isometric contractions (4-s contraction, 6-s relaxation) beginning at 10% of the subjects MVC and was incremented by 10% every 2 minutes. The older subjects were less fatigued at the end of the fatigue protocol compared with the younger subjects ($P<0.01$). Bilodeau et al. (2001) found similar results in the fatigued elbow flexor muscles. Both younger and older subjects maintained a maximum elbow flexion effort until the torque dropped below 50% of the pre-fatigue MVC for more than 5 seconds. The older subjects had significantly longer times for the time it took the MVC torque to decrease by 50%. Narici et al. (1991) observed a decrease in fatigability with age in the adductor pollicis using a 30-s continuous 30 Hz stimulation protocol. Similarly, Chan et al. (2000) noted a higher fatigue resistance in the thenar muscles of older adults.

Many studies have shown no difference between the fatigability of older compared to younger subjects (Stackhouse et al., 2001; Lindstrom et al., 1997; Bemben et al., 1996; Hicks et al., 1992; Laforest et al., 1990; McDonagh et al., 1984; Larsson and Karlsson, 1978). Lindstrom et al. (1997) examined neuromuscular fatigue and endurance for dynamic knee extension at 90°/s in young and old men and women. They found no discernable difference between the young and old for relative muscle force reduction or muscle endurance. Laforest et al. (1990) had similar results when examining the endurance of the knee extensors between younger and older, active and sedentary individuals. They found no age effects for muscle endurance.

An increase in fatigability in older compared with young adults has been reported when a task is performed at the same absolute level (Makrides et. al., 1985). The usual explanation for this observation is that because older subjects are weaker, a task performed at an absolute level will constitute a higher percentage of their maximum capacity and will thus lead to a greater rate of fatigue (Bilodeau et al., 2001). However, fatigue protocols which utilize relative force levels, have also shown reduced endurance times in the elderly (Lennmarken et al., 1985). When using electrical stimulation to assess skeletal muscle function between younger and older, men and women, endurance time was reduced in the older males compared to the older females, and to the younger males (Lennmarken et al., 1985).

Another possibility for an increase in fatigability in older compared to younger adults may be due to age-related changes in muscle blood flow. It has been proposed by researchers that with increased age, there is a declining muscular endurance capacity due to a decrease in blood flow or a reduced capillarity in the working musculature (Bemben, 1998). Some studies have reported decreased capillary density in older subjects (Coggan et al., 1992), although this is not a universal finding (Grimby et al., 1982). A number of studies have reported changes in the vascular pathology (Cooper et al., 1994) and in vascular innervation in human skeletal muscle (Case & Girling, 1988) with increasing age.

The studies that examined fatigue and muscle blood flow have primarily looked at gender differences (Russ and Kent-Braun, 2003) or physical activity levels (Widrick et al., 1996). In a study conducted by Cole and Brown (2000) examining the response of the human triceps surae muscle to electrical stimulation during varying levels of ischemia, they found the force production declined under ischemic conditions. A similar study by Murthy and colleagues (2001) examined varying levels of ischemia in the extensor carpi radalis muscles. They found that muscle oxygenation and twitch force at 60 mmHg tourniquet compression and above produced significant declines in force production.

One of the major confounding factors in studying age-related changes in function is the failure to account for reduced activity levels. With aging, older people tend to be less active, which could lead to a significant detraining effect. Thus, studies of muscle blood flow in the elderly need to take into account the activity levels of the study subjects.

Rationale for Study

Many physiological changes have been associated with aging, such as, loss of muscle mass and strength (Fontera et al., 1991; Lexell et al., 1983; Larson et al., 1978), a decrease in the number of motor neurons/motor units (Brown et al., 1988), a process of denervation and reinnervation of muscle fibers (Pettigrew et al., 1991), changes in muscle metabolism (Proctor et al., 1995), a slowing of muscle contractile properties

(Vandervoort & McComas, 1986), alterations of the neuromuscular junction, and changes in voluntary activation (Harridge et al., 1999) and motor unit activation (Roos et al., 1997; Laidlaw et al., 2000). Studies have shown that the relative proportion of type I tissue in the muscle cross-sectional area (CSA) is greater in older than younger adults (Larsson et al., 1978; Lexell et al., 1988; Grimby et al., 1982; Hunter et al., 1999). It is therefore plausible that due to the greater proportion of type I tissue in the CSA and the physiological makeup of type I tissue as endurance fibers, that older adults would be more fatigue resistant than their younger counterparts. There is however, very little research regarding the age-related fatigability of muscle, and the results from the studies that have been completed are equivocal.

Research on force perception and fatigue has shown that when there is a change in the voluntary motor command producing a contraction, there is a parallel change in the perceived magnitude of the force produced by the muscles (Jones & Hunter, 1983; Cafarelli & Layton-Wood, 1986; Burgess & Jones, 1997). The studies that have examined force perception and fatigue have used diverse groups of subjects ranging in age from 16-65 years of age but have not examined specific age groups, notably older adults.

Therefore, with the relationship between aging and fatigue being uncertain, and aging and force perception having not been fully examined, it was the purpose of this study to examine the effect of aging on force perception with fatigue.

Statement of Purpose

The purposes of the present investigation are:

1. To investigate the perception of isometric contractions at 60% MVC forces under fatigued and unfatigued neuromuscular conditions.
2. To investigate the difference in fatigue resistance of the dorsiflexor muscles between younger and older subjects.

Hypothesis

We expect there will be less change in the older subjects' perception of force after the fatiguing protocol, due to their increased fatigue resistance.

Methodology

Subjects

Eleven younger (age range 18-30 years) and eleven older (age range 65-80 years) male volunteers participated in the study. A sample size of 10 subjects per group (older and younger) was estimated using Cohen's table 2.41 (Cohen, J. Statistical Power Analysis for the Behavioral Sciences. New York: Academic Press, 1977, pp. 53.). Subjects were recruited through the use of posters and ads placed in community newspapers. All subjects were healthy and physically active, regularly performing various types of routine exercise on at least 2 days per week. Subjects with a prior history or presence of cardiovascular disease, hypertension, neuromuscular conditions, or on medications which could have an effect on muscle function were excluded from the study.

Eleven younger and eleven older men completed all aspects of the study. One younger subject was excluded after he lost sensation in his leg during the fatigue task. One older subject was excluded due to an artifact that was produced during his MVC. Due to this artifact in his MVC, the subject's 60% MVC was miscalculated and the subject was working at a higher percentage of his MVC during the testing session. All results for these two subjects have been excluded from the analyses.

Study Design

All subjects acted as their own control, participating in two sessions where measures of neuromuscular function were taken before, during, and after a fatigue or rest period. In one session the subject completed the experimental protocol and in the other session the control protocol. Subjects were randomly assigned to either the experimental or control protocol within each age group so that half the subjects received the experimental protocol during their first session and the other half received the control protocol, and vice versa during the second session.

After a detailed explanation of the study, subjects signed an informed consent document consistent with the guidelines of the University of Manitoba Ethics Review Board (Appendix A). Subjects also completed a Physical Activity Readiness Questionnaire (PAR-Q) to assess their health status (Appendix B), and an activity inventory questionnaire to measure their overall level of physical activity (Appendix C). The activity inventory questionnaire was rated using the Grimby Scale (Grimby, 1986). The Grimby scale rates physical activity based on the intensity and duration of the activity. The activity inventory sheets used for evaluating the subjects' activity levels were scored with a number from 1-6 based on the Grimby scale.

Pre-Test Instructions

Pre-test instructions (The Canadian Physical Activity, Fitness & Lifestyle Appraisal, 1996) were given to each subject prior to their first testing session. The following pre-test instructions were given;

a. Dress requirements: Shorts or comfortable pants and short-sleeved shirt should be worn. Comfortable shoes for walking are the recommended footwear.

b. Food and Beverages: Do not eat for at least two hours prior to your testing session. Also refrain from drinking caffeinated beverages for two hours and alcoholic drinks for six hours prior to the testing session.

c. Smoking: Do not smoke during the two hours prior to the testing session.

d. Physical Activity: Strenuous physical activity should be avoided for six hours prior to the testing session.

Setting and Apparatus

The study was conducted in the Neuromuscular Laboratory at the University of Manitoba. All torque measurements were examined on a Biodex Series III multi-joint dynamometer with the ankle joint attachment (Biodex Medical Systems, Inc., Shirley, NY). Torques were recorded using a Pentium III (486 MHz) computer connected to the

Biodex. The monitor was used to display torque outputs to the subject during baseline testing as described below in the procedure section. The Biodex chair was adjusted so that the leg of the subject was placed with the ankle in neutral position (foot at 90° angle from the tibia), the knee flexed to 55° from full extension, and the hip flexed to approximately 90°. The subjects were strapped into the machine with shoulder, waist, calf, ankle, and foot straps. The purpose of the straps was to prevent the subjects from using other muscles during contractions because this would alter the force readings collected. Verification of calibration for the Biodex dynamometer was performed according to the specifications outlined by the manufacturer's manual prior to each testing session.

Experimental Procedure (Figure 1)

Prior to the experimental trials all subjects performed a warm-up on a treadmill walking at 3 mph for 3 minutes. Anthropometric measurements (ie. height and weight) were then taken. Following this the subjects were positioned in the Biodex machine. Familiarization with the testing apparatus occurred with the subjects completing 2-3 submaximal contractions. Standardized instructions for the execution of each task during the experimental protocol were used. After familiarization with the testing apparatus, each subject performed a series of 3 maximum voluntary contractions (MVC) with their dominant (right) leg. Subjects were asked which leg they normally kick a ball with to determine their dominant leg. Subjects rested for 2 minutes between MVC's. Isometric strength was defined as the highest peak torque obtained during all of the MVC's. For all subsequent experiments, except the fatiguing protocol, the subjects were asked to produce a constant torque with their dominant leg at 60% of their isometric strength.

Baseline

1. Warm-up – 3 min. at 3 mph on treadmill
2. 3 MVC's
3. 12 Isometric Contractions at 60% MVC
   - 6 contractions with visual feedback from computer monitor
   - 3 contractions with feedback from the investigator(s) only
   - 3 contractions without feedback

Fatiguing Condition

4. 40 isometric MVC contractions, 5 s contractions, 2 s rest between contractions

Rest Condition

4. Rest for 5 minutes

Post Fatiguing Exercise Test

5. 6 Isometric Contractions at 60% MVC
   - no feedback given

Figure 1: The experimental protocol.

For baseline force perception testing, all subjects performed 12 contractions of 5 seconds each, with a 10-second rest between contractions. The 12 contractions were performed so the first 6 contractions had visual feedback from the computer monitor, the next 3 contractions had feedback from the investigator only, and the last 3 contractions were without feedback. The purpose of this was to slowly reduce the feedback given to the subjects. Only the last 3 contractions without feedback were used for analysis; the previous 9 were used for learning the force perception task.

Following baseline testing the subjects performed either the fatigue condition or the rest condition. The order of the fatigue or rest condition was blocked such that half of each group performed the fatigue condition on the first visit. Seven days lapsed between conditions for all subjects except one. Due to sickness of one subject, ten days lapsed between conditions.

The fatiguing protocol consisted of 40 isometric dorsiflexion contractions. Each contraction lasted 5-seconds, with a 2-second rest between contractions. No verbal encouragement was provided by the investigator throughout the fatigue task, but subjects received standardized encouragement from a tape recorder which gave the subjects encouragement every 45 seconds (i.e., six times during the fatigue task). Verbal instructions were given throughout as to when the contraction and relaxation should begin.

Immediately following the fatiguing protocol or the rest period, both the experimental and control groups performed 6 contractions at 60% MVC for five seconds each without feedback. Ten seconds of rest elapsed between contractions. The subjects reproduced what they perceived to be 60% of their MVC. The instructions given to the subjects were:

> "Now you're going to do 6 contractions. Each contraction will last 5 seconds with a 10-second rest between contractions. You're going to hold your contractions at what you think is 60% of your MVC, like you did at

the beginning of the test. Remember the red line on the monitor, that's what you are going to do again".

The purpose of these contractions was to test the effect of fatigue on force perception. To prevent the subjects from adjusting their perception of 60% MVC, no feedback was given.

Data Analyses

For MVC and fatigue trials, the peak torque (PT) produced during each contraction was used for analysis (Figure 2a). PT was defined as the highest point obtained during the contraction. For the fatigue trials, the PT for the first 3 contractions was averaged and compared to the averaged peak torque of the last 3 contractions, to determine the extent of fatigue.

For the baseline force perception and post-fatigue force perception contractions, the average PT for a 3 second period of each contraction after the subject had been contracting for half a second, was used for analysis of force perception (Figure 2b). The 3 contractions with no feedback during baseline force perception were averaged and compared with the first three contractions with no feedback during the post-fatigue test. The purpose of this was to determine the change in the subject's perception of force. Also the errors (i.e., difference from 60%) were calculated.

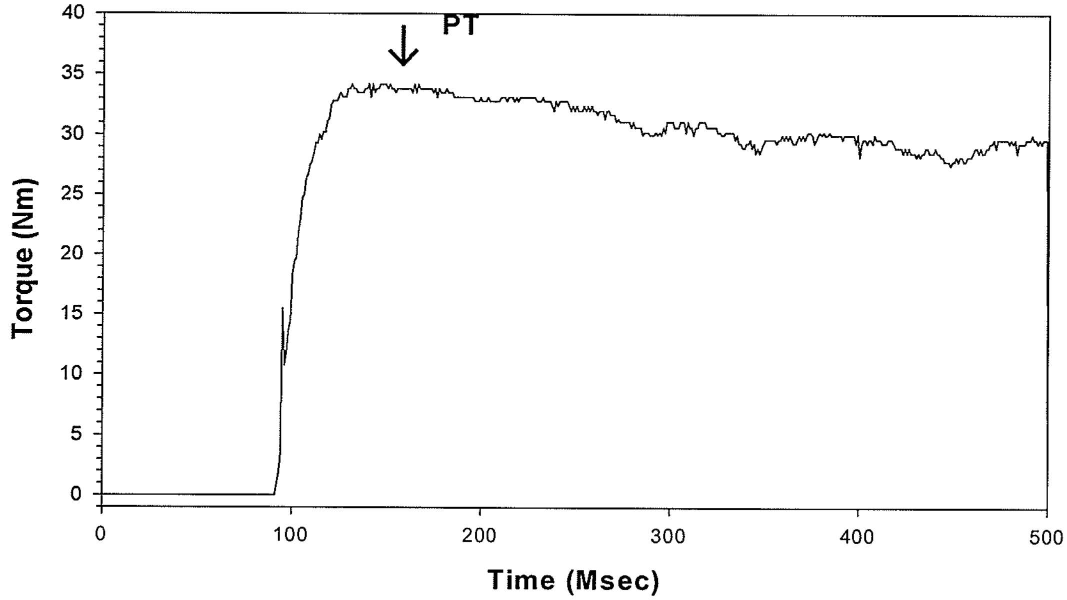


Figure 2a: MVC torque curve recording of a young subject. Peak torque (PT) was defined as the highest point in the curve. The subject had to perform a maximum effort for 5 seconds.

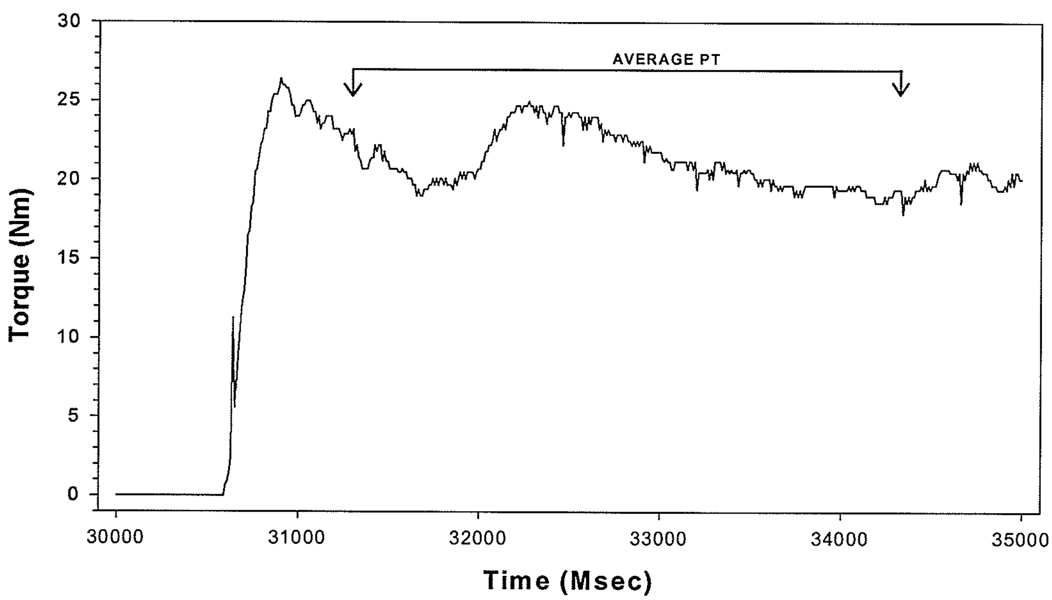


Figure 2b: Baseline force perception torque curve recording of a young subject. Average peak torque (PT) was defined as a 3 second period after the subject had been contracting for half a second.

Statistical Analyses

MVC/Subject Characteristics. Independent t-tests were used to compare between groups for single parameter measures. Repeated measures ANOVA was used for within group comparisons of MVC from the first to the second testing session.

Force Perception. A three-way repeated measures ANOVA with age group, contraction type (baseline force perception vs. post fatigue force perception), and session (experimental vs. control) was used to determine changes in force perception between and within groups over time. Two-way repeated measures ANOVA was used to determine differences between and within groups for baseline force perception from the first to the second session. For within groups comparison of the prescribed 60% contraction to the actual 60% contraction for both experimental and control sessions, repeated measures ANOVA was used.

Fatigue. Two-way repeated measures ANOVA with age group and time (beginning vs. end) were used to determine differences in the amount of fatigue (change in peak torque) within and between groups. Two-way repeated measures ANOVA with age and type of MVC (MVC and Fatigue MVC) were employed to examine differences in the MVC at the beginning of the experimental session with the fatigue MVC. This was done to ensure that subjects were maximally or near maximally contracting at the beginning of the fatigue trial.

Determinants of change in force perception with fatigue. Pearson correlation's were used to examine the relationships between the variables: percent change in force perception, percent fatigue, height, weight, BMI, age group, and Grimby scale. Best subsets multiple linear regression was done to determine the best model to explain the percent change in force perception.

An Alpha level of 0.05 was set for all statistical tests. Post-Hoc comparisons were performed using Tukey's honestly significant difference (HSD) when repeated measures ANOVA yielded significant effects. Statistical analyses were performed using SigmaStat 3.0 (SPSS Inc., Chicago) and Statistica (Statsoft Inc., Tulsa, ON).

RESULTS

MVC/Subject Characteristics (Table 1).

The younger and older subjects did not differ on height, weight, or body mass index (BMI). Younger males were significantly more active than older males due to the higher intensity of activity the younger group participated in (p=0.002). There was a significant difference between the younger and older groups in their MVC (p=0.037) (Fig. 3), with the younger group having higher MVC's by 15%. For the MVC's from the first session to the second session, there was no significant session effect.

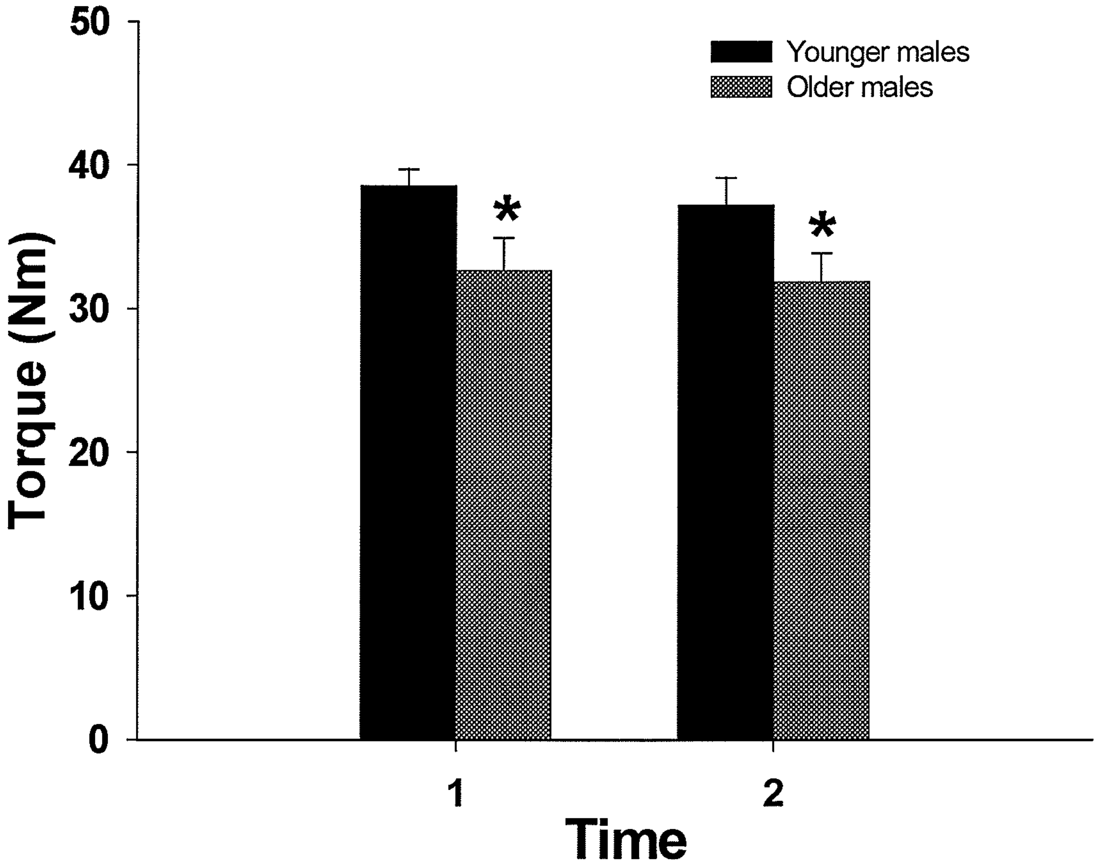


Fig 3. MVC for both groups from their first testing session (time 1) and their 2nd testing session (time 2). The younger men were significantly stronger (* $p<0.05$).

Force Perception

There was a significant change in force perception with fatigue between the older and younger males, with the older males having less change in their force perception. Three-way repeated measures ANOVA (age × pre/post contraction × experimental/control session) revealed a significant main effect for pre/post contraction type ($F(1,18)=8.32$; $p=0.01$), for session type ($F(1,18)=13.17$; $p=0.002$), but not for age ($F(1,18)=2.30$; $p=0.15$). There were no significant interactions for pre/post contractions by age group ($F(1,18)=0.55$; $p=0.47$), or session type by age group ($F(1,18)=0.37$; $p=0.55$), but there was for pre/post by session type ($F(1,18)=129.43$; $p<0.001$). Also, there was a significant interaction ($F(1,18)=11.42$; $p=0.003$) for age group by pre/post by experimental/control sessions (Table 2) (Fig. 4). Both groups showed a change in their force perception with fatigue, with the older subjects having a smaller reduction in torque produced.

Baseline force perception contractions were not affected from the first testing session to the second between or with-in the groups, i.e., there were no learning effects for the task. Two way repeated measures ANOVA revealed no significant main effects for age ($p=0.79$), time (session 1/session 2) ($p=0.28$), or for group by time ($p=0.80$).

During the experimental session both groups tended to overestimate during the baseline no-feedback force perception contractions. However, there was no significant difference ($p=0.57$) between groups for the prescribed 60% contraction and the actual 60% contraction the subjects produced both for the experimental session (Fig. 5), and for the control session (Fig. 6).

Table 1. Group Characteristics

	Younger (N=10)	Older (N=10)	P Value
Age (yrs)	24.4 ± 3.6	70.3 ± 3.4	P<0.001
Weight (kg)	85.0 ± 10.5	80.4 ± 15.7	NS
Height (cm)	180.8 ± 8.6	176.3 ± 5.4	NS
Grimby Scale	5.0 ± 0.9	3.4 ± 1.1	P<0.01
BMI	26.0 ± 2.4	25.8 ± 4.2	NS

Values are presented as means ± SD.

Table 2. Force Perception (3 Way Repeated Measures ANOVA)

Effect	Df	F	P
Age group	1	2.30	0.15
Pre/Post	1	8.32	0.01
Pre/Post * age group	1	0.55	0.47
Exp/Control	1	13.17	0.002
Exp/Control * age group	1	0.37	0.55
Pre/Post * Exp/Control	1	129.43	0.000
Pre/Post * Exp/Control * Age group	1	11.42	0.003

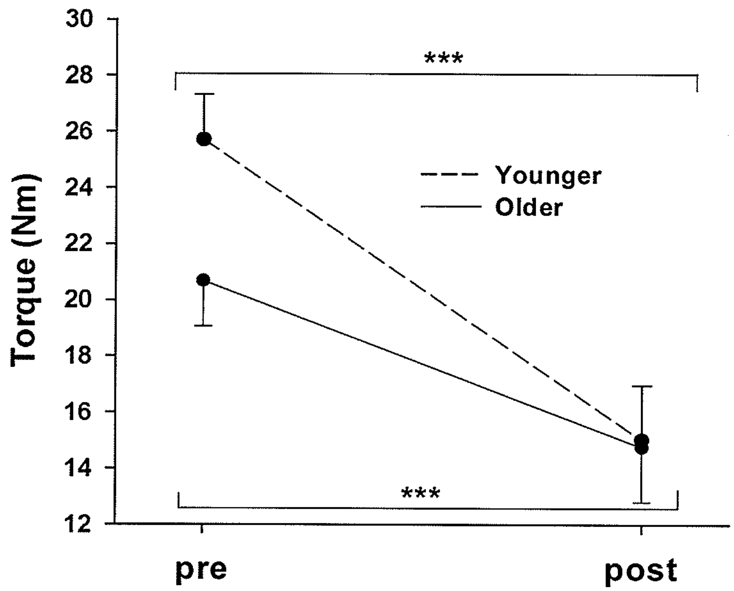


Fig 4a. Experimental Session

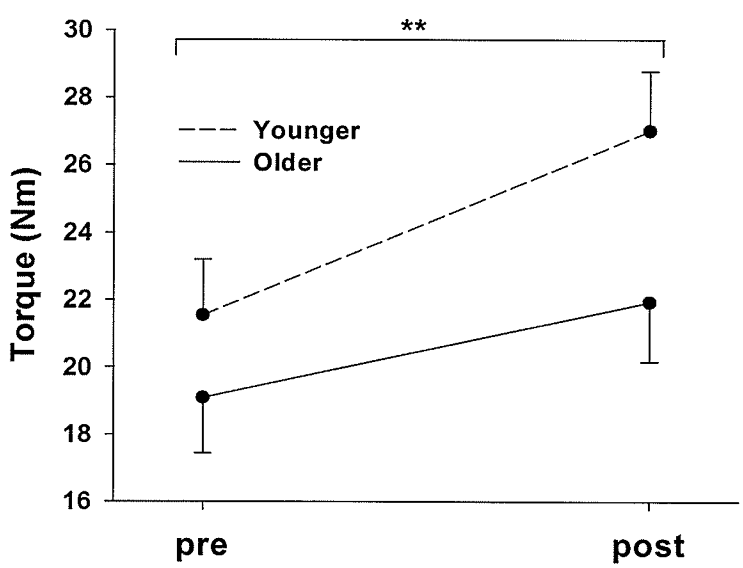
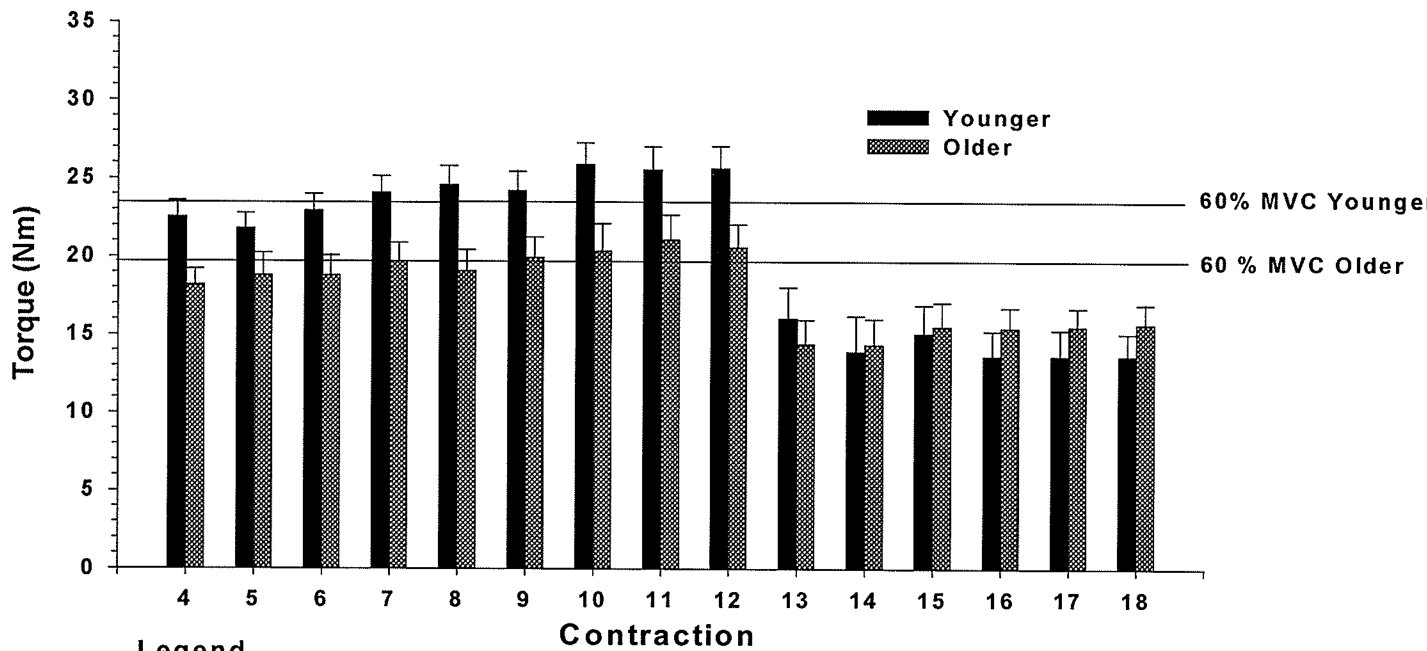


Fig 4b. Control Session

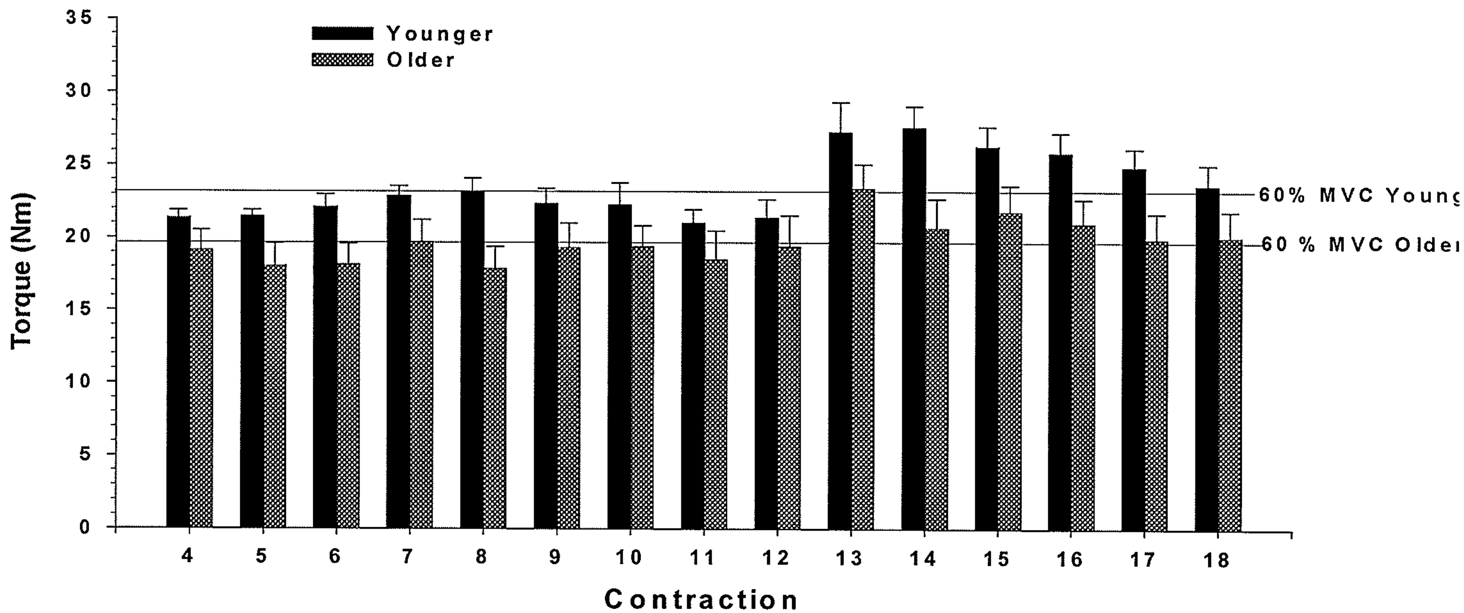
Fig 4. Mean torque (±SE) for the baseline force perception contractions compared to the post-fatigue force perception contractions for younger and older subjects during the experimental (Fig. 5a) and control session (Fig 5b). **p<0.01 ***p<0.001



<u>Legend</u>

Contractions 4-6 Pre-fatigue with visual feedback
Contractions 7-9 Pre-fatigue with audio feedback
Contractions 10-12 Pre-fatigue with no feedback
Contractions 13-18 Post-fatigue with no feedback

Figure 5: Mean (+SE) for baseline and post-fatigue force perception contractions for all subjects for the experimental condition.



Legend

Contractions 4-6	Pre-fatigue with visual feedback
Contractions 7-9	Pre-fatigue with audio feedback
Contractions 10-12	Pre-fatigue with no feedback
Contractions 13-18	Post-fatigue with no feeback

Fig 6. Mean (+SE) for baseline and post-fatigue force perception contractions for all subjects for the control condition.

Fatigue

Two-way ANOVA, with age (younger vs. older), and contraction (avg. first 3 fatigue MVC's vs. avg. last 3 fatigue MVC's) as factors, revealed no significant difference ($F(1,18)=2.93$; $p=0.10$) for age, but a significant difference ($F(1,18)=256.80$; $p<0.001$) for the contractions during the fatigue task. Also, there was a significant age by contraction interaction with the older subjects being more fatigue resistant compared to the younger subjects ($F(1,18)=8.422$; $p=0.010$)(Fig. 7).

Two-way repeated measures ANOVA with age (younger vs. older) and time (MVC vs. fatigue MVC #1) was used to compare the subjects' MVC at the beginning of the experimental session to the first MVC produced during the fatigue task. There was a significant main effect for age ($F(1,18)=7.723$; $p=0.012$) and for MVC/Fatigue MVC ($F(1,18)=17.82$; $p<0.001$). However the interaction for age × MVC/Fatigue MVC was not significant ($F(1,18)=2.401$; $p=0.14$). The younger males had higher MVC's compared to the older males, explaining the significant effect for age. The majority of the subjects had slightly lower fatigue MVC's, with 3 subjects having higher fatigue MVC's, when compared to their MVC at the beginning of the experimental session (Fig. 8). The differences in the mean values for the younger group's MVC to fatigue MVC, and older group's MVC to fatigue MVC were 1.2 Nm and 2.7 Nm respectively.

Determinants to the change in force perception with fatigue

The correlation matrix is shown in table 3. As expected, there was a significant positive relationship between the percent change in force perception and the percentage

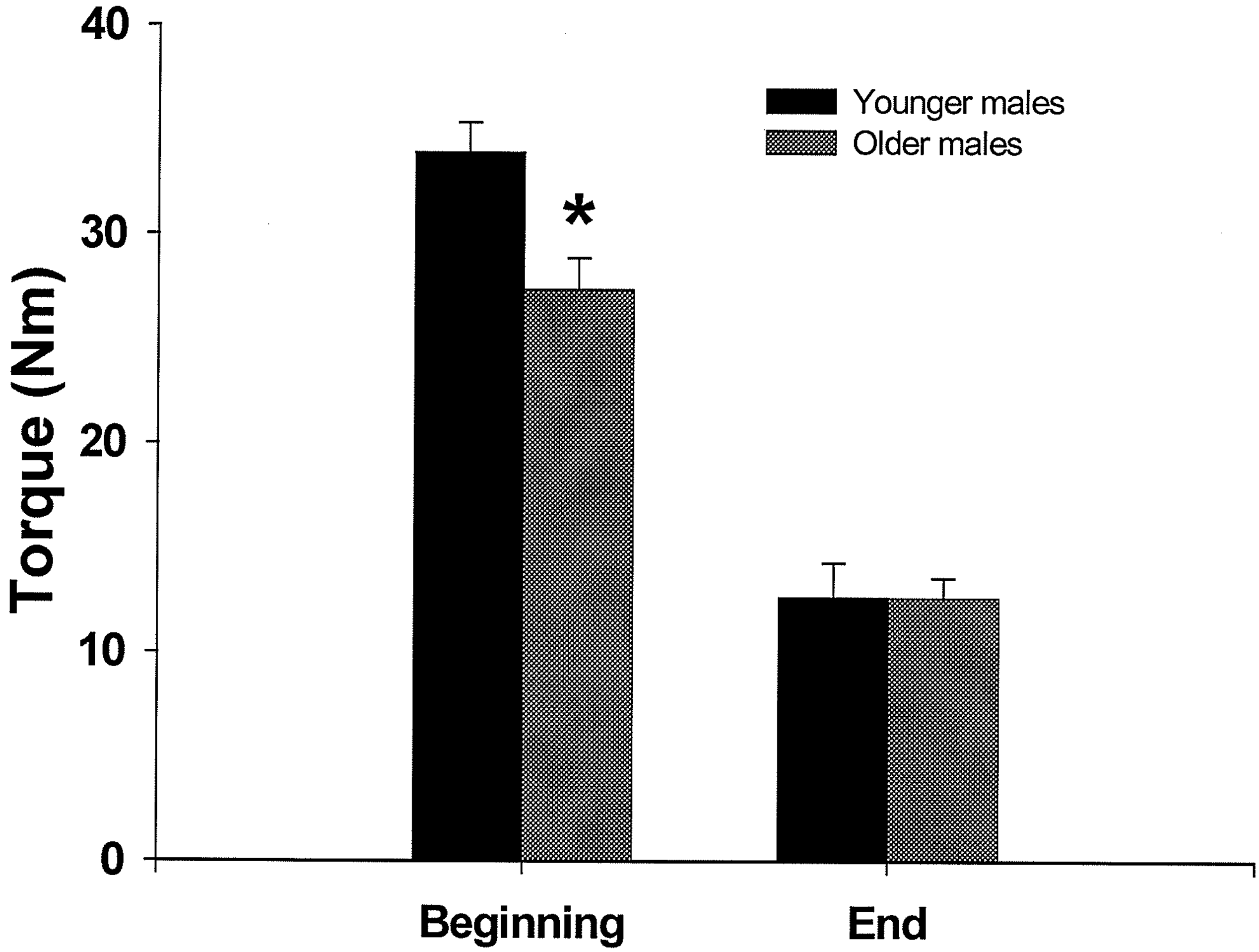


Fig 7. Both groups have a significant decrease in their torque levels from the beginning to end of the fatigue trial, however the younger subjects fatigued more. * $p<0.05$

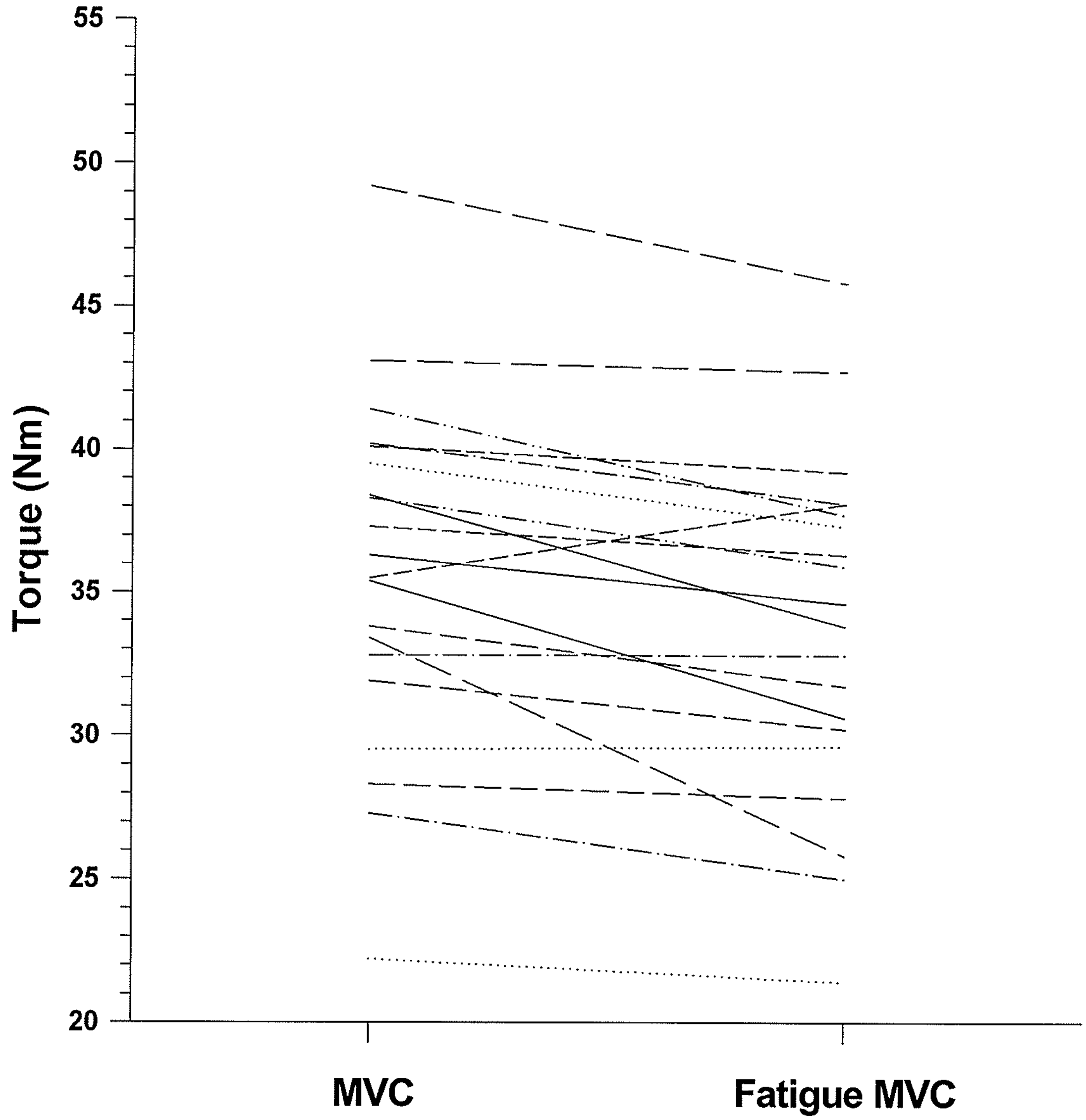


Fig 8. All subjects' mean maximal voluntary contraction on the day of experimental condition compared to mean peak torque (PT) for the beginning of the fatigue task.

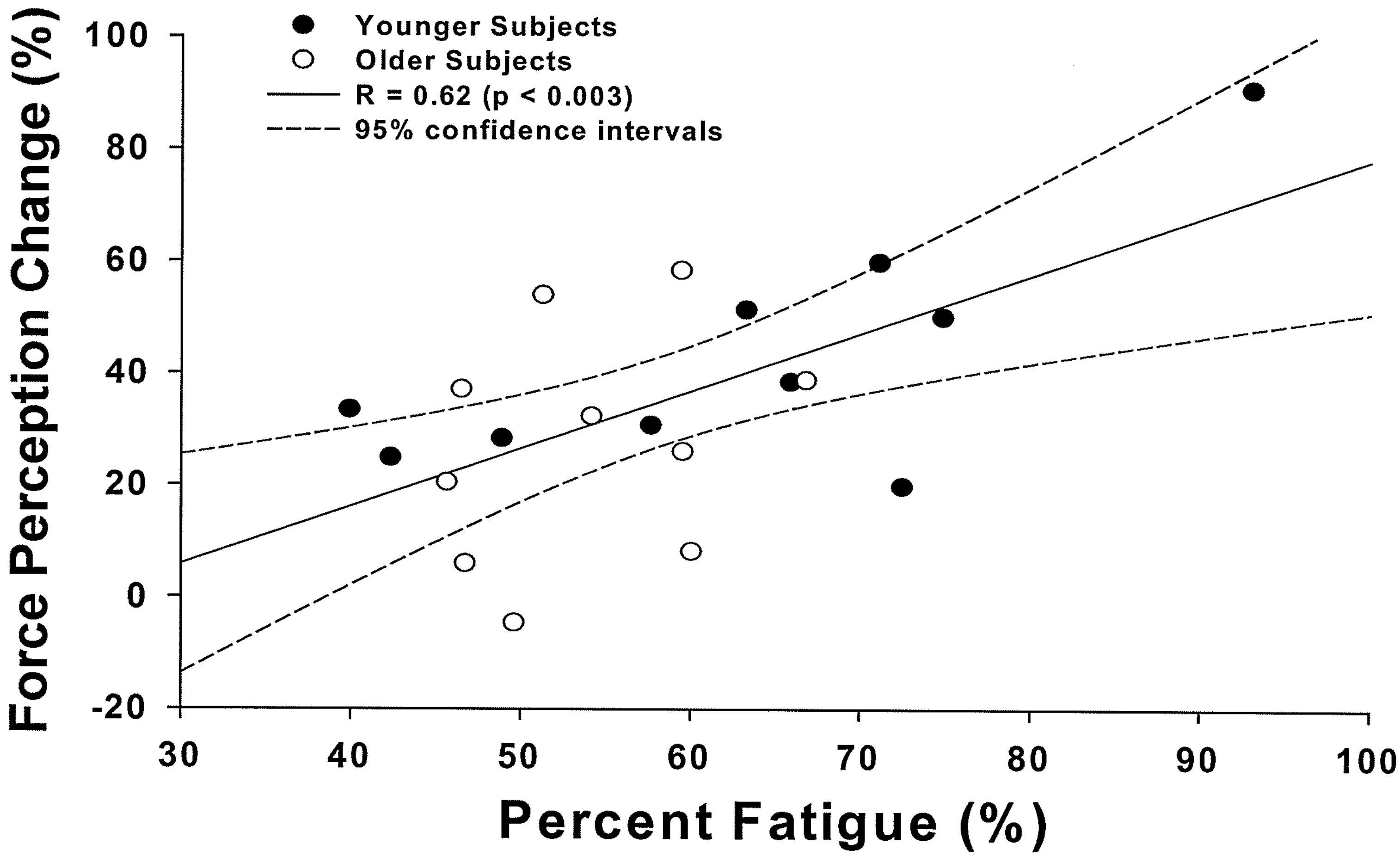


Fig 9. Relationship between the change in force perception and the percentage of fatgiue.

of fatigue for the subjects (R=0.62, p=0.003; Figure 9). Unexpectedly, BMI was negatively related (R=-0.54; p=0.014) to percent change in force perception. Best subsets regression revealed that age group, weight, physical activity, and percent fatigue explained 74% of the change in force perception with fatigue (Table 4). Although model #4 explained more of the change in force perception with fatigue, age group and Grimby scale only explained 12% of the 74% explained. BMI was related to percent change in force perception, however best subsets multiple linear regression determined that weight was a better predictor.

Table 3: Correlation Matrix.

Cell Contents: Correlation Coefficient P Value Number of Samples	Percent Fatigue	Age Group	Weight (kg)	BMI	Grimby Scale	Height (cm)
Pre-Post Exp%	0.622 0.00339 20	-0.357 0.123 20	-0.550 0.1020 20	-0.538 0.0143 20	0.110 0.643 20	-0.261 0.266 20
Percent Fatigue		-0.351 0.129 20	-0.129 0.589 20	-0.0571 0.811 20	0.0575 0.810 20	-0.192 0.416 20
Age Group			-0.177 0.455 20	-0.0320 0.893 20	-0.641 0.00235 20	-0.311 0.181 20
Weight (kg)				0.881 0.000000302 20	-0.106 0.657 20	0.608 0.00444 20
BMI					-0.138 0.562 20	0.161 0.497 20
Grimby Scale						-0.0016 0.995 20

Table 4. Determinants of the percent change in force perception (Multiple linear Regression)

Model #1	**Rsqr = 0.387**			
Variable	Coefficient	Std. Error	T	P
Constant	-25.076	18.313	-1.369	0.188
Percent Fatigue	1.032	0.306	3.372	0.003
Model #2	**Rsqr = 0.612**			
Variable	Coefficient	Std. Error	T	P
Constant	45.871	27.148	1.690	0.109
Weight (Kg)	-0.786	0.251	-3.135	0.006
Percent Fatigue	0.930	0.253	3.680	0.002
Model #3	**Rsqr = 0.684**			
Variable	Coefficient	Std. Error	T	P
Constant	72.144	28.729	2.511	0.023
Weight (Kg)	-0.896	0.240	-3.733	0.002
Age Group	-12.543	6.551	-1.915	0.074
Percent Fatigue	0.744	0.254	2.923	0.010
Model #4	**Rsqr = 0.738**			
Variable	Coefficient	Std. Error	T	P
Constant	122.026	39.116	3.12	0.007
Grimby Scale	-5.66	3.211	-1.763	0.098
Weight (kg)	-1.047	0.241	-4.338	<0.001
Group	-23.533	8.763	-2.685	0.017
Percent Fatigue	0.605	0.252	2.403	0.030

DISCUSSION

The present results are in strong agreement with previous studies (Jones and Hunter, 1983; Burgess and Jones, 1997; Carson et al., 2002) which found that force perception is adversely affected by fatigue. The findings of this study are also consistent with the hypothesis presented in the Introduction; namely, that older subjects will have less change in their force perception because they are more fatigue resistant compared to their younger counterparts.

In the present study, although both groups had decreases in their force perception with fatigue, the older group exhibited better force perception compared to the younger group. This is attributed to the positive relationship between force perception and fatigue. With an increase in fatigue, there was an increased change in the subjects' force perception. The older group was more fatigue resistant compared to the younger group therefore explaining the better force perception during the post fatigue protocol. Jones and Hunter (1983) found similar results for fatigue in their younger subjects during a contralateral limb-matching paradigm. They found a linear increase in the perceived force during a constant force contraction, with the change in force sensation paralleling the increase in the EMG signal of the fatiguing muscle. This earlier finding along with the present data clearly argue that with increasing fatigue at the neuromuscular level, force perception is adversely effected.

In addition to extent of fatigue, weight, age group, and physical activity helped to explain the change in force perception, although age group and physical activity only explained a small portion (12%) of the 73.8% explained. The reason for weight being an explanatory variable can not be explained. The reason for a heavier individual having a smaller percent change in force perception with fatigue alludes the researchers.

Fatigue

There was a significant difference in the performance of the fatigue task between the two groups; the younger males demonstrated a larger reduction in MVC force at the end of the fatigue protocol compared to the older males. It has been speculated that changes in the muscle characteristics of older subjects, larger CSA of type I tissue, explains their enhanced fatigue resistance (Kent-Braun et al., 2002).

Many studies have examined the age-related changes occurring at the neuromuscular level. It has been shown there is decline of 15-20% in the area of Type II fibers (fast twitch) and 39% in the fiber number (Lexell et al., 1988) with aging. Grimby and colleagues (1982) showed a selective reduction in the cross-sectional area (CSA) of type II fibers in the vastus lateralis muscle of humans above 70 years of age, with only slight reductions prior to the age of 60-70 years. Coggan et al. (1992) showed no reduction in the CSA of type I fibers (slow-twitch) in the aged gastronemius muscle. Therefore, with the larger proportion of type I tissue in the CSA, it would be arguable that older subjects, when compared to younger subjects, completing a task relative to their strength, the older subjects would be more fatigue resistant. Kent-Braun and colleagues (2002) found that older subjects were less fatigable compared to their younger counterparts on an incremental isometric fatigue test for the ankle dorsiflexor muscles.

Force Perception

In previous studies by Jones and Hunter (1982; 1983) subjects overestimated small forces (less than 30% of MVC) and slightly underestimated larger forces (more than 60% MVC). The previous findings are consistent with the present study, in that the subjects' actual 60% MVC was much lower than the prescribed 60% MVC level after fatigue. In other words, the subjects believed they were generating more force than what they were actually achieving. A previous study by Carson et al. (2002) found similar results with subjects performing concentric contractions of the triceps brachii. The subjects used their control arm to produce a target level of force representing 25, 50, or 75% of their MVC, and then tried to match it with the experimental arm. For the concentric contractions, the subjects had a tendency to generate a level of force with the exercise arm below the target force applied by the control arm for the target forces representing 50% or 75% of their MVC. Again, the subjects believed they were generating more force than what they actually were.

The results of the present study also lend support to the suggestion from previous studies, that force perception has a large peripheral component to it (Roland and Ladegaard-Pedersen, 1977; Cafarelli and Kosta, 1981). The subjects in the present study produced lower torques than the prescribed 60% during the post-fatigue task. Cafarelli and Kosta (1981) had similar results with their subjects overestimating forces during a matching force protocol when the reference arm was vibrated. They suggested that centrally generated motor commands should diminish with the reflex facilitation elicited by the vibration, not increase.

Learning Effects From Time 1 to Time 2

MVC. MVC's obtained from the first testing session (Time 1) and the second testing session (Time 2) were compared. There was minimal variability within subjects and between subjects in their respective age groups. There was no difference between the groups, or for time, with no interaction for group and time. Patten and Kamen (2000) found similar variability of subject MVC's between testing days (8%) when examining age related differences in the motor unit activity in controlling muscular forces.

Force Perception. In the present study, subjects did not alter their perception from Time 1 to Time 2. Previous studies have shown with training, both younger and older subjects can reduce their variability in force at low target forces (Keen et al., 1994; Patten and Kamen, 2000). Patten and Kamen (2000) looked at adaptations in motor unit discharge activity of the dorsiflexor muscles, with isometric force modulation training. The force modulation training was conducted for 2 weeks and significantly improved both young and older adults force accuracy. The present study had only two testing sessions of 1 hour. Due to the short nature of the study there were no learning effects in the subjects' force perception.

Physical Activity Levels

The reduction in the size and number of type II fibers with aging is similar to the atrophy associated with a decrease in the level and intensity of physical activity due to a more sedentary lifestyle (for review see Faulkner et al., 1994). With the decrease in physical activity and the order of motor unit recruitment, the type I fibers remain in relatively regular use, whereas the type II fibers and particular the type IIB fibers are rarely recruited and therefore subject to disuse atrophy (Luff, 1998). This decrease in intensity of physical activity with age was seen in the present study when rating the subjects' questionnaires on physical activity. The older males scored significantly lower on the physical activity questionnaire due to the method used to rate the level of physical activity, the Grimby Scale. The Grimby scale scores physical activity based on intensity and duration, with lower intensity activities receiving a lower score (see Appendix D). The older males were physically active but the activities they participated in were lower in intensity and longer in duration compared to the younger males.

MVC

Another age-related change of the neuromuscular system is the loss of neuromuscular strength. This loss of strength (force) has been attributed to loss of muscle mass and atrophy of muscle fibers as discussed above (Lexell et al., 1986; Lexell et al., 1988; Porter et al., 1995; Evans et al., 1997; Roos et al., 1997), decreases in the number of motoneurons/motor units (Brown et al., 1988), the process of denervation and subsequent reinnervation of motor units (Kanda and Hashizume, 1989), and muscle activation and co-activation (Akataki et al., 2002; Burnett et al., 2000; De Serres and Enoka, 1998). The present study only examined muscular strength and fatigue. MVC strength was 15% lower in the older men compared to the younger men. The loss of strength reported in the present study was also observed by Kent-Braun and Ng (1999) in their study of specific strength. They found that older men had 25% lower MVC compared with the younger men (197 ± 22 vs. 262 ± 19 N, respectively). Other studies have reported similar (-30%) losses (De Serres et al., 1998; Doherty et al., 1993) of strength with age. The subjects in the present study were physically active so this might explain the smaller difference in strength between age groups.

Limitations of the Study

There are some factors in the present study that limit the ability to generalize the results to a wide population. One of the limiting factors is the physical activity level of the participants. Only physically active individuals were recruited for the study due to the strenuous nature of the fatigue task. It would be conceivable that sedentary older individuals would be more fatigable and therefore would have larger changes in their force perception with neuromuscular fatigue compared to active individuals.

Gender was another limiting factor in the ability to generalize the results to the larger population because only males were studied. Many studies (Clark et al., 2003; Pincivero et al., 2003; Hunter and Enoka, 2001; Fulco et al., 1999; Semmler et al., 1999) have shown that females are less susceptible to muscle fatigue than males. Future studies could examine the relationship between physical activity levels and gender to determine the effects these have on force perception and fatigue.

Future studies could also examine the implications of these results and how they would affect older adults' day-to-day activities. In the present study, the older men were active and their change in force perception with fatigue was only altered slightly. It is possible that a sedentary older adult would experience more fatigue and therefore larger changes in force perception compared to an active older adult. With slower reaction times (Sparrow et al., 2002; Lewis and Brown, 1994), movement times (Yan, 2000), slower activation of muscle (Stevens et al., 2003), and the loss of Type II muscle with aging (Lexell et al., 1986;1988), a large change in force perception with fatigue could affect activities of daily living and lead to more falls and injuries in older adults.

In conclusion, the results of the present study indicate that older men are more fatigue resistant during maximal fatiguing contractions of the dorsiflexors compared to younger men. The present results also indicate that force perception is better following a time-specific fatigue task for older males compared to younger males mostly due to this fatigue resistance.

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APPENDIX A: INFORMED CONSENT FORM

UNIVERSITY OF MANITOBA | Health, Leisure & Human Performance Research Institute

Faculty of Physical Education
and Recreation Studies
Max Bell Centre
Winnipeg, Manitoba
Canada R3T 2N2
Telephone (204) 474-7087
Fax (204) 261-4802

Informed Consent

Purpose

We would like you to participate in a research study titled "Perceived force and fatigue in the dorsiflexors of the older adult". The purpose of this study is to gain a better understanding of how fatigue affects force perception. The information obtained from this study will be used for completion of a Master's degree by the researcher.

If you decide to participate in the study, your involvement will take no more than 1 hour of your time.

Procedure

You will be asked to complete two forms which will ask you questions about your current levels of physical activity. One form will be used to identify the types of activities you enjoy and the other is used to identify the amount of physical activity you participate in on a regular basis. You will be asked to do a warm-up (walking on a treadmill at a comfortable speed) prior to any testing. After familiarization with the testing equipment, we will ask you to perform three contractions pulling your foot against a foot pad as hard as you can, without holding your breath, while we have you stabilized in a chair. After a rest you will hold several contractions around 60% of your maximum for 5 seconds each while you look at a computer monitor. Then you will hold several contractions for 5 seconds without looking at the computer monitor, to learn how to hold a contraction at 60% of maximum without any feedback. We will then ask you to perform 40 contractions pulling your foot against a foot pad as hard as you can to make you tired. After that you will again hold 6 contractions for 5 seconds each without looking at the computer monitor. A computer will be used to record the strength of the contractions.

Risks

You may experience some muscloskeletal or tendinous soreness or discomfort following this study, but this soreness or discomfort will typically last 24-48 hours. There is a remote chance of injury from any type of strength or endurance testing. If you experience pain during any of the contractions the testing will be stopped.

Benefits

Personal gratification of contributing to further scientific knowledge, and learning more about your strength and endurance.

Your participation is completely voluntary and you have the right to withdraw from the study at any time without prejudice or consequences. All information pertaining to this study will be number coded and strictly confidential. This study has been approved by Education/Nursing Research Ethics Board. If you have any complaints regarding the study, you may report them to the Human Ethics Secretariat (474-7122).

Upon your completion of the study you will receive a printout of your strength and fatigability. If you have any questions later, please feel free to contact us.

Philip Snow
Rm. 204
Max Bell Center
University of Manitoba
Phone: 474- 7085

Dr. M.M. Porter
Rm. 204
Max Bell Center
University of Manitoba
Phone: 474-8795

Please read the following paragraph, and, if you agree to participate, please sign below.

I have read the information and understand the nature and risks associated with this study. I also understand that any information about me obtained from this research will be kept strictly confidential. I do understand that I can withdraw from the study at any time without penalty. I agree to participate in this study.

Print name: ________________________

Signature_________________________ Date _____________

Print name: _____________________

Investigator _____________________ Date _____________

Please place your initials here acknowledging receipt of a copy of this consent form. ______

APPENDIX B: PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	**Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	2.	**Do you feel pain in your chest when you do physical activity?**
☐	☐	3.	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	4.	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	5.	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	6.	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	7.	**Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active -- begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ______________________

SIGNATURE ______________________ DATE ______________

SIGNATURE OF PARENT ______________________ WITNESS ______________
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

 Supported by: Health Canada Santé Canada

continued on other side...

APPENDIX C: ACTIVITY INVENTORY QUESTIONNAIRE

Tool #5 ACTIVITY INVENTORY

Have done	Currently doing	Would like to do	
☐	☐	☐	aerobics/exercise-to-music
☐	☐	☐	archery
☐	☐	☐	badminton
☐	☐	☐	baseball/softball
☐	☐	☐	basketball
☐	☐	☐	bicycling (utility or pleasure)
☐	☐	☐	bowling
☐	☐	☐	broomball
☐	☐	☐	calisthenics
☐	☐	☐	camping
☐	☐	☐	canoeing/kayaking
☐	☐	☐	climbing
☐	☐	☐	coaching
☐	☐	☐	curling
☐	☐	☐	dancing
☐	☐	☐	fencing
☐	☐	☐	floor hockey
☐	☐	☐	football
☐	☐	☐	gardening, yard work
☐	☐	☐	golf
☐	☐	☐	handball
☐	☐	☐	hiking
☐	☐	☐	hockey
☐	☐	☐	horseback riding
☐	☐	☐	household chores
☐	☐	☐	ice skating
☐	☐	☐	inline skating

Have done	Currently doing	Would like to do	
☐	☐	☐	martial arts
☐	☐	☐	orienteering
☐	☐	☐	racquetball
☐	☐	☐	ringette
☐	☐	☐	roller skating
☐	☐	☐	rowing
☐	☐	☐	running/jogging
☐	☐	☐	sailing
☐	☐	☐	skateboarding
☐	☐	☐	skiing (X-country)
☐	☐	☐	skiing (downhill)
☐	☐	☐	snowshoeing
☐	☐	☐	soccer
☐	☐	☐	squash
☐	☐	☐	stair climbing
☐	☐	☐	swimming
☐	☐	☐	t'ai chi
☐	☐	☐	table tennis
☐	☐	☐	tennis
☐	☐	☐	volleyball
☐	☐	☐	walking
☐	☐	☐	weight training
☐	☐	☐	wind surfing
☐	☐	☐	yoga
☐	☐	☐	____________
☐	☐	☐	____________
☐	☐	☐	____________