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# An investigation of the effect of exercised arm, training status, and racial background on changes in markers of muscle damage following maximal eccentric exercise of the elbow flexors

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# USE OF THESIS

# An Investigation of the Effect of Exercised Arm, Training Status, and Racial Background on Changes in Markers of Muscle Damage Following Maximal Eccentric Exercise of the Elbow Flexors

By

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# ABSTRACT

Despite the substantial body of research accumulated on exercise-induced muscle damage, there remain several areas that warrant further investigation. Study groups comprised of individuals from differing racial background and /or training status have the potential to influence the intra-group variability in damage markers following eccentric exercise. In addition, if a contralateral arm model is employed, intra- and inter-group variation could be influenced by the formation of groups based on limb dominance and /or the order in which the arms are exercised. Currently there is a dearth of research addressing these factors, however, these types of studies are important as they can shed light on methods to increase statistical sensitivity by minimizing group variability.

Therefore, the overarching aim of the three studies comprising this thesis was to examine these factors suspected of influencing changes in indirect markers of muscle damage and soreness following maximal voluntary eccentric exercise. The exercise model employed in the studies involved maximal voluntary eccentric exercise of the elbow flexors, and the markers investigated in each study were the criterion measures of maximal voluntary contraction (MVC) torque, range of motion (ROM) at the elbow joint, upper arm circumference (CIR), plasma creatine kinase (CK) activity, and muscle soreness (SOR).

The purpose of the first study was to determine whether changes in these markers differed between contralateral arm elbow flexors of untrained males following the exercise intervention. The purpose of the second study was to determine whether changes in the same markers differed between elbow flexors of untrained and resistance trained males following the eccentric exercise intervention. The purpose of the final study was to determine whether these muscle damage and soreness markers differed between elbow flexors of untrained Caucasian and Japanese males following maximal eccentric exercise.

The exercise intervention of all three studies comprised 10 sets of 6 maximal voluntary eccentric actions of the elbow flexors of one arm performed against the lever arm of a

Cybex 6000 isokinetic dynamometer moving at a constant velocity of $90^{o}\cdot s^{-1}$. Subjects were seated on an arm curl bench with the exercised arm supported on the angled platform, and the forearm commenced movement at an angle of $90^{o}$ to the upper arm and moved through a range of motion of $90^{o}$, finishing with a straight arm at $180^{o}$ of elbow extension. Passive recovery periods of 10-seconds and 3-minutes occurred between repetitions and sets, respectively. Subjects were provided with pre-study familiarization sessions during which the criterion measures were performed and a demonstration of the eccentric exercise intervention was provided. The criterion measures were evaluated immediately prior to, and following, the exercise intervention in all studies and for the next seven, five, and four days in the first, second and third studies, respectively.

A total of 18 untrained men (mean age 30.8 ± 1.2 yrs) volunteered to participate in the contralateral limb investigation (Study 1). The study involved a design in which each subject's arms were counterbalanced between first and second exercise bouts resulting in each exercise bout having equal numbers of dominant and non-dominant limbs. The resulting data were then analysed for bouts 1 and 2, and dominant and non-dominant comparisons. Results showed the arm that was exercised second produced smaller post exercise changes in the criterion measures of MVC torque ($90^{o}$ only), CIR, and CK activity ($p<0.05$). When dominant and non-dominant arm groups were compared there were no significant differences in any of the criterion measures. The data showed that the arm that was exercised first appeared to confer a mild protective effect to the subsequently exercised contralateral arm resulting in significant differences in some of the criterion measures between the bouts. When the groups were compared based on arm dominance, resulting in bout order being counterbalanced, there were no significant differences evident between the groups. In order to reduce the confounding bias of conferred protection, it was suggested that a protracted period should be provided between bouts, or that bout order should be counterbalanced between groups.

Thirty men (mean age 29.1 ± 1.7 yrs), 15 resistance trained and 15 untrained volunteered to complete study 2. There were no significant differences between the groups for any of the criterion measures prior to the exercise intervention. With the exception of CK activity in the trained, both groups produced significant changes in criterion measures from pre-exercise values following maximal eccentric exercise.

However, despite similar performance from both groups during the eccentric exercise task, the untrained group produced significantly larger changes for all of the criterion measures (with the exception of SOR) during the following days ($p<0.05$). The results revealed that compared to untrained individuals, resistance trained subjects experienced smaller changes in some markers of muscle damage despite similar performances during the eccentric exercise intervention. It was suggested that further research should investigate the underlying mechanisms contributing to the contrasting results between individuals of different training status.

A total of 28 untrained male volunteers participated in the final study (Caucasian and Japanese). With the exception of CK activity, there were significant differences in all of the subject characteristics and criterion measures pre-exercise ($p<0.05$), therefore normalized data comparisons will be reported for the sake of brevity. Following the eccentric exercise intervention there were significant differences in MVC torque, ROM, CIR, CK activity, and extension soreness between the racial groups ($p<0.05$). The data from this study provided evidence that when exposed to identical eccentric exercise Japanese men produce greater changes in muscle damage markers than Caucasians of the same gender. The aetiology of the racial difference is unclear, however future research focusing on genetic variation may help to elucidate the matter.

In conclusion, the results of the three studies demonstrate that the factors comprising type of contralateral arm design, training status, and racial background all affected the magnitude of changes in markers of muscle damage and soreness following maximal eccentric exercise. In order to increase statistical sensitivity of eccentric exercise-induced muscle damage studies, the results of the final two studies suggest that intra-group variability could be minimized by avoiding the formation of groups containing mixtures of individuals from differing racial backgrounds and / or training status. If the research design employs a contralateral arm model it seems advisable to minimize between group variation by counterbalancing across groups the order in which the arms are exercised.

# DECLARATION

I certify that this thesis does not, to the best of my knowledge and belief:

(i) incorporate without acknowledgment any material previously submitted for a degree or diploma in any institution of higher education;

(ii) contain any material previously published or written by another person except where due reference is made in the text; or

(iii) contain any defamatory material

Signed: ……………………………………

Date: ………………………………………

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Study

Novel exercise of an eccentric nature is associated with damage to muscle and connective tissue, and delayed onset muscle soreness (DOMS), and has been shown to produce profound alterations in muscle function and other markers of muscle injury (Clarkson, Nosaka, & Braun, 1992; Jones, Newham, Round, & Tolfree, 1986; Rinard, Clarkson, Smith, & Grossman, 2000). Depending upon the mode and / or intensity of the exercise, decrements in muscle function can be protracted with complete recovery usually occurring by two weeks (Clarkson & Hubal, 2002; Sayers, Clarkson, Rouzier, & Kamen, 1999), yet requiring up to one month or longer in some severe cases (Nosaka & Clarkson, 1996a; Sayers et al., 1999). A substantial body of research exists examining the effect of eccentric activity on various aspects of exercise-induced muscle damage. Specific markers, often referred to as criterion measures, have been employed to quantify the extent of alterations to muscle arising from eccentric activity. A variety of assessments have been used, but most frequently include changes in muscle torque, range of motion (ROM) about a joint, limb circumference, soreness of a muscle upon movement or palpation, activity of blood borne intra-muscular proteins, magnetic resonance imaging (MRI), and ultrasound echo intensity (Foley, Jayaraman, Prior, Pivarnik, & Meyer, 1999; McCully, Shellock, Bank, & Posner, 1992; Newham, Jones, Tolfree, & Edwards, 1986; Nosaka, Sakamoto, & Newton, 2002; Nosaka, Sakamoto, Newton, & Sacco, 2004).

Several factors such as age (Manfredi et al., 1991), gender (Rinard et al., 2000), training status (Dolezal, Potteiger, Jacobsen, & Benedict, 2000), prior exposure to eccentric exercise (Clarkson & Tremblay, 1988), intra-subject design (Clarkson, Byrnes, Gillisson, & Harper, 1987), and race and genetics (Clarkson et al., 2005) have been proposed to influence the magnitude of changes in markers of exercise-induced muscle damage and DOMS following eccentric exercise. However, limited research is available concerning the effect of intra-subject design, training status, and race on changes in markers of exercise-induced muscle damage and soreness following this type of exercise.

Many studies investigating the response of criterion measures to an eccentric exercise intervention have employed an intra-subject design by using a contralateral limb model (Connolly, Reed, & McHugh, 2002; McHugh & Pasiakos, 2004; Nosaka et al., 2004; Zainuddin, Hope, Newton, Sacco, & Nosaka, 2005; Zainuddin, Newton, Sacco, & Nosaka, 2005). One type of design involves a limb receiving some specialised treatment either prior to and / or following an eccentric exercise intervention while the contralateral limb acts as a control and receives no treatment. A second design involves two separate treatments, where each limb receives one treatment prior to evaluation of the criterion measures.

The rationale for using a contralateral limb model is based on the assumption that the variance in response to the same eccentric exercise intervention is lower in magnitude between limbs of a single subject than it is between the same limb (e.g., dominant arm) of two subjects. On the surface this rationale may seem sound, however, a review of the available literature detected a dearth of research addressing this matter, and an absence of investigations involving the arm musculature. Whether criterion measures of the dominant arm differ appreciably from the non-dominant arm following eccentric exercise is not known, and similarly, whether eccentric activity performed on the arm exercised first exerts any cross over effect on criterion measures of the contralateral arm remains to be elucidated.

Another aspect of research in this field that has received limited attention relates to whether there are differences in criterion measures between untrained and resistance-trained individuals following maximal voluntary eccentric exercise. To date, the majority of research studies focusing on exercise-induced muscle damage have employed either untrained individuals or those with a limited history of resistance training. Furthermore, the few studies that have examined the effects of eccentric exercise in moderate to well trained subjects did not investigate responses of the criterion measures following a bout of maximal eccentric exercise (Bourgeois, MacDougall, MacDonald, & Tarnopolsky, 1999; Dolezal et al., 2000; Gibala et al., 2000; Semark, Noakes, St Clair Gibson, & Lambert, 1999). It is assumed that trained individuals are less susceptible to exercise–induced muscle damage and soreness arising from such exercise but this has not been demonstrated in a controlled experimental manner.

A further line of enquiry that has previously received little attention concerns the responses of differing racial groups to maximal voluntary eccentric exercise. Clarkson et al. (2005) reported that in a recent study involving a large number of subjects from varying racial backgrounds, there were a larger percentage of Asians who produced high CK activity following maximal eccentric exercise of the elbow flexors. In our laboratory we have noted that Japanese subjects elicited more pronounced responses than Caucasians following eccentric exercise, particularly in terms of changes in plasma concentrations of intramuscular enzymes. To provide a more controlled comparison between Japanese and Caucasians, requires both groups to perform identical exercise protocols and have the same criterion measures evaluated before and following the exercise intervention.

## 1.2 Significance of Study

This thesis comprises three separate studies which focus on aspects of eccentric exercise-induced muscle damage and DOMS that have received limited research attention. Each investigation compares responses of the aforementioned criterion measures to a bout of maximal voluntary eccentric exercise of the elbow flexors. The first study focuses on a contralateral limb model in which both arms from a group of subjects are compared for differences following the damaging exercise. The second study examines whether untrained and resistance trained subjects differ in their responses to the exercise intervention. The final study investigates whether the criterion measures of Caucasian and Japanese males differ following the eccentric exercise. To date, there are no published studies comparing the responses of contralateral arms exposed to identical bouts of eccentric exercise. Research focusing on such comparisons will provide insight into whether differences in criterion measures between the limbs following identical eccentric exercise are statistically significant. If the contralateral limbs respond in the same manner to identical bouts of eccentric exercise (i.e., no statistical difference) then this work, or a peer reviewed publication arising from it, will allow others to cite it as supporting evidence for their choice of research design.

The substantial body of literature addressing exercise-induced muscle damage and DOMS is heavily weighted toward responses of untrained individuals.  Comparing responses of untrained and resistance trained individuals to maximal voluntary eccentric exercise will contribute toward understanding whether neuromuscular adaptations due to resistance training are effective in attenuating the decrements in muscle function previously shown in research involving untrained subjects exposed to the same exercise intervention.  If differences are shown to exist between the groups, highlighting them will allow investigators to focus future research efforts on the aetiology of the contrasts. In addition, an understanding of how resistance trained individuals respond to maximal eccentric contractions will be of value to athletes and coaches who may be considering introducing “negative” (heavy eccentric) training into their exercise regimens.

No studies have compared the responses of Asian and Caucasian subjects to maximal voluntary eccentric exercise.  The final study of this thesis compares criterion measures of Caucasian and Japanese subjects to the same maximal voluntary eccentric exercise intervention.  Before more detailed mechanism based investigations are undertaken it is important to first determine whether any differences exist between racial groups.  The value of the final study is that it is designed to investigate this very question.

Findings from the three research studies undertaken in the present doctoral work have the potential to impact future research design.  In order to detect small significant differences due to an experimental intervention intra-group variability should ideally be minimised.  If differences are shown to occur between the groups in each study of this thesis, then during future research consideration would have to be given to the wisdom of employing groups incorporating mixtures of these subjects.

## 1.3 Research Questions

The three research studies of the present doctoral thesis aim to address the following research questions:

1) Will changes in markers of exercise-induced muscle damage and soreness in untrained males differ between contralateral arms following maximal voluntary eccentric exercise of the elbow flexors?
2) Will changes in markers of exercise-induced muscle damage and soreness differ between untrained and resistance-trained (trained) males following maximal voluntary eccentric exercise of the elbow flexors?
3) Will changes in markers of exercise-induced muscle damage and soreness differ between untrained Caucasian and Japanese males following maximal voluntary eccentric exercise of the elbow flexors?

## 1.4 Purposes of the Studies

The purpose of the first study was to determine whether changes in markers of exercise-induced muscle damage and soreness in untrained males differed between contralateral arms following maximal voluntary eccentric exercise of the elbow flexors.

The purpose of the second study was to determine whether changes in markers of exercise-induced muscle damage and soreness differed between untrained and trained males following maximal voluntary eccentric exercise of the elbow flexors.

The purpose of the final study was to determine whether changes in markers of exercise-induced muscle damage and soreness differed between untrained Caucasian and Japanese males following maximal voluntary eccentric exercise of the elbow flexors.

The markers of exercise-induced muscle damage and soreness employed in the present studies are the criterion measures of maximal voluntary contraction torque, range of motion at the elbow joint, upper arm circumference, plasma creatine kinase (CK) activity, and muscle soreness.

# CHAPTER 2

# REVIEW OF LITERATURE

## 2.1 Introduction

This chapter aims to provide the reader with the relevant background information related to the research questions and discussion that follows in subsequent chapters. A concise description of the damage and repair process begins followed by coverage of the exercise models employed by various research laboratories. The effect of novel or unaccustomed eccentric exercise on selected symptoms and markers of muscle damage is then considered, and the review is concluded by examining selected factors known, or with the potential, to influence muscle damage.

## 2.2 Events in Muscle Damage

It is well established that unaccustomed eccentric exercise leads to damage to muscle and connective tissue (exercise-induced muscle damage) and DOMS, and research has also shown that reduced muscle function and other markers of muscle damage are evident following exercise of this nature (Clarkson et al., 1992; Jones et al., 1986; Rinard et al., 2000). Much of our current knowledge has been derived from experimental work employing humans and animals. This work has implicated high mechanical forces associated with eccentric contractions as a possible initiating event leading to loss of function and development of soreness in the exercised muscles (Armstrong, 1990; Lieber & Friden, 1999). The stress associated with the eccentric actions may manifest as "high specific tension" which could affect the sarcolemma, the sarcoplasmic reticulum (SR) and / or the myofibrillar structures of the muscle and allow the influx of extracellular calcium to the sarcoplasm (Armstrong, 1990). The increased intracellular calcium concentration has been suggested to be the trigger for up-regulation of degradative processes within the myofibre. This initiation of cellular autolysis is due, in part, to activation of phospholipase A (Duncan & Jackson, 1987; Jackson, Jones, & Edwards, 1984), and possibly calcium activated proteases (Belcastro, Shewchuk, & Raj, 1998), although the latter has been questioned (Allen, 2001). Activated proteases, such as calpain, may lead to increased proteolysis resulting in the eventual destruction of cytoskeletal and other cellular proteins (Belcastro et al., 1998; Byrd, 1992). Activated phospholipase A is believed to liberate free fatty acids from the triglycerides composing the bilipid plasma membrane surrounding the muscle cell (Jackson et al., 1984). This action in itself may lead to compromised integrity of the sarcolemma, although it is the metabolism of the liberated free fatty acids that is also believed to be linked to further destruction of the cell (Jones & Round, 1990). Free radical mediated oxidation of unsaturated fatty acids in the cell membrane (lipid peroxidation) can result in the generation of additional free radical species, which could lead to eventual destruction of the cell membrane (Pyne, 1994). Although this is an attractive hypothesis, there is little evidence to support such a contention and recent research questions its validity (Child et al., 1999).

At some point during loss of sarcolemmal integrity intracellular proteins such as creatine kinase (CK), lactate dehydrogenase (LDH) and myoglobin leach out of the muscle cell and can be detected in the blood (Newham, Jones, & Edwards, 1986; Nosaka, Clarkson, & Apple, 1992). Within a couple of days following the eccentric exercise bout large numbers of mononuclear cells such as neutrophils and macrophages can be detected in the damaged myofibre and are involved with phagocytosis of the necrotic tissue (Round, Jones, & Cambridge, 1987; Smith, 1991; Tidball, 2005). Phagocytic mononuclear cells involved with the disposal of the necrotic mass are known to produce superoxide and therefore can be assumed to contribute to the free radicals present in the damaged fibre (Warren, Jenkins, Packer, Witt, & Armstrong, 1992). In addition it is believed that certain invading phagocytic cells secrete some factor(s) that initiate satellite cell proliferation (Hurme & Kalimo, 1992; Tidball, 2005). Once the damaged portion of the muscle cell is removed by the phagocytic cells, and satellite cells are signaled to begin proliferation and later differentiation into myoblasts, the cell is said to be in the regenerative stage (Bischoff, 1989; White & Esser, 1989). Regeneration is near completion when myoblastic cells fuse to form myotubes, which begin to be filled with newly synthesized cytoskeletal and myofibrillar proteins (Carlson & Faulkner, 1983). The entire process from the initial eccentric exercise until formation of newly regenerated myofibres can take anywhere from a couple of weeks to over a month.

## 2.3 Exercise Models of Muscle Damage

There have been a number of different exercise models used to induce muscle damage and delayed onset muscle soreness in humans. Those producing the greatest magnitude of exercise-induced muscle damage and soreness have incorporated eccentric muscle actions and include models such as bench stepping (Newham, Jones, Tolfree, & Edwards, 1986), downhill running (Eston, Finney, Baker, & Baltzopoulos, 1996; Schwane, Johnson, Vandenakker, & Armstrong, 1983), downhill backward walking (Nottle & Nosaka, 2005), running down stairs (Friden, Sjostrom, & Ekblom, 1981), plyometric jumping (Jamurtas et al., 2000; Marginson, Rowlands, Gleeson, & Eston, 2005; Miyama & Nosaka, 2004), maximal isokinetic actions of the arms (Chen & Hsieh, 2001; Gleeson, Eston, Marginson, & McHugh, 2003; Philippou, Bogdanis, Nevill, & Maridaki, 2004) and legs (Byrne, Eston, & Edwards, 2001; Paschalis et al., 2005), isoinertial exercise (Fielding et al., 2000; Lee et al., 2002; Nosaka & Newton, 2002b), eccentric cycling (Walsh, Tonkonogi, Malm, Ekblom, & Sahlin, 2001), and electrically stimulated forced lengthening exercise (Gleeson et al., 1998; Nosaka, Newton, & Sacco, 2002c).

It appears that the magnitude of muscle damage varies among the models. In a recent review, Clarkson and Hubal (2002) report that, in terms of strength loss and recovery time, the greatest magnitude of change is associated with high-force eccentric exercise. From work cited in the review it can be determined that high-force eccentric exercise often generates up to 35%-40% greater force reductions than eccentrically-biased downhill running (Clarkson & Hubal, 2002).

Another consideration in terms of exercise model is whether an inter- or intra-subject design is employed. In using contralateral limbs, the intra-subject design has the potential advantage of matching the groups (separate limbs) in terms of genetic and immunological responses to an eccentric exercise challenge. If the goal is to have one limb receive a treatment and the contralateral limb act as a control, then in order to increase the sensitivity of the study ideally there should be no difference in markers of muscle damage between contralateral limbs when they are subjected to identical bouts of eccentric exercise.

Both inter- and intra-subject designs have been used extensively, however there is very little reported research on whether contralateral limbs respond in a similar manner to an identical bout of maximal eccentric exercise.  To the best of the author's knowledge there have been no published studies comparing changes in markers of muscle damage to identical eccentric exercise of contralateral elbow flexors.  As several studies incorporating an inter-subject design, and using one limb as a control, have employed eccentric exercise of the elbow flexor musculature, research needs to establish whether the contralateral musculature responds similarly to identical lengthening actions.

In conclusion, differences in symptoms and / or markers of exercise-induced muscle damage following eccentric exercise are likely to be due, in part, to the various exercise models employed.  One unique type of exercise model is the contralateral limb design, however further research is required to determine the sensitivity of this model.

## 2.4 Effect of Novel or Unaccustomed Eccentric Exercise on Selected Symptoms and Markers of Muscle Damage

### *2.4.1 Maximal Voluntary Contraction (MVC) Torque*

Following eccentric activity in persons not accustomed to such exercise a profound reduction in eccentric, concentric and isometric torques (MVC torque) can be evident immediately following exercise which does not fully recover for many days, or weeks in some cases (Chapman, Newton, Sacco, & Nosaka, 2005; Clarkson et al., 1992; Newham, Jones, & Clarkson, 1987).  The largest decrease in MVC torque is usually apparent immediately following the exercise activity (Nosaka, Clarkson, McGuiggin, & Byrne, 1991) with a gradual recovery of force generating ability over subsequent days or weeks.  Clarkson and Hubal (2002) note that it has still not been positively established exactly how force is lost following eccentric exercise.  It seems that the exact mechanism remains to be elucidated.  It is, however, thought that the decline in MVC torque following eccentric exercise is initially caused by the high mechanical stress negatively affecting structures involved with excitation-contraction coupling (Ingalls, Warren, Williams, Ward, & Armstrong, 1998b).

There are also other theories, one of which suggests that sarcomeres are non-uniformly stretched during lengthening contractions resulting in damage from ‘sarcomere popping’ (Morgan, 1990; Morgan & Allen, 1999). Another suggests that the force loss after eccentric exercise may be due to damage at the level of tendon attachments or within the series elastic elements of muscle (Clarkson & Hubal, 2002). Ingalls, Warren & Armstrong (1998) note that in murine muscle significant reductions in contractile protein begin to occur about five days after the eccentric exercise, and account for 58% of force loss at this time. From 14 to 28 days following lengthening contractions, nearly all of the loss in force production can be accounted for by decreased myosin heavy chain and actin content (Ingalls, Warren, & Armstrong, 1998). As metabolic rate is relatively fast in the mouse it is likely that in humans the reductions in contractile protein, and force loss attributable to this, will not be as marked at five days.

### *2.4.2 Range of Motion (ROM)*

ROM of the elbow joint, determined by the difference between the flexed (FANG) and stretched (SANG) elbow joint angle, has been shown to decrease immediately following novel eccentric exercise of the elbow flexor muscles, reaching the smallest angle around three days post exercise and slowly recovering over ensuing days (Nosaka et al., 1991). Relaxed elbow joint angle, which is determined by the angle at the elbow while the arm is hanging freely by the side of the body, is similarly found to be at its most acute 3 days post exercise slowly recovering to baseline by around 10 days following exercise (Clarkson et al., 1992). The aetiology of the decreased range of motion following eccentric exercise remains to be fully elucidated, however, previous research suggests that shortened non-contractile components, change in calcium homeostasis due to muscle damage, decreased strength, and / or swelling may be implicated (Chleboun, Howell, Conatser, & Giesey, 1998; Jones, Newham, & Clarkson, 1987). If swelling is involved, it is not thought to play an appreciable role in the decreased range of motion evident immediately following the lengthening contractions (Chleboun et al., 1998).

### *2.4.3 Limb Circumference (CIR)*

Following novel eccentric activity circumference of the exercised limb increases, usually peaking between three to five days post exercise (Clarkson et al., 1992; Howell, Gary, & Robert, 1993). The exact mechanism causing the increased circumference is not clear but has been suggested to be due to either swelling within the affected muscle fibres (Crenshaw, Thornell, & Friden, 1994), swelling of the connective tissue (Clarkson et al., 1992), or increased synthesis of connective tissue rather than fluid accumulation (Smith, 1991).

### *2.4.4 Intracellular Protein Release*

Intracellular proteins such as creatine kinase (CK), lactate dehydrogenase (LDH), myoglobin, and myosin heavy chain fragments are detectable in the blood of individuals who have performed novel eccentric exercise (Hirose et al., 2004; Nosaka et al., 1992; Sorichter, Puschendorf, & Mair, 1999). The most commonly measured of these proteins is CK (Ebbeling & Clarkson, 1989), which peaks about three to seven days post exercise and slowly returns to baseline levels thereafter (Newham, Jones, & Edwards, 1986; Nosaka et al., 1992). Each of the three listed proteins show delayed (24 to 48 hour) increases in the blood (Nosaka et al., 1992), suggesting that exit time from the muscle and / or the time taken to drain into the central circulation from the lymphatic system is protracted. The activity of CK in the blood following unaccustomed eccentric activity is variable among subjects (Clarkson & Ebbeling, 1988) and although increased levels of this enzyme can be used as a marker of muscle damage, it is not recommended that it be used as a quantitative measure of the degree of muscle injury incurred (Clarkson, Byrnes, McCormick, Turcotte, & White, 1986).

### *2.4.5 Delayed Onset Muscle Soreness (DOMS)*

Approximately 6 to 12 hours following novel eccentric exercise, discomfort may be felt in the muscles that have been worked (Clarkson et al., 1986) with peak soreness usually occurring at one to two days (MacIntyre, Reid, & McKenzie, 1995). The soreness usually subsides by 5 to 7 days following exercise without the need of analgesic medication (MacIntyre et al., 1995). The exact cause of soreness following novel eccentric exercise remains unresolved although it has been suggested to be due to the acute inflammatory response at this time (MacIntyre et al., 1995; Smith, 1991) or disruption to the muscle fibre and connective tissue (Stauber, 1989). Later work by Malm et al. (2000) though has questioned the role of cellular or humoral inflammation in DOMS, therefore further investigation seems warranted in this area.

### *2.4.6 Magnetic Resonance Imaging (MRI) and Ultrasound (US)*

MR and US imaging of the muscle compartment have been employed as tools for assessing exercise-induced muscle damage, and the resulting increased T2 relaxation time (MRI) and echo intensity (US) in the days after lengthening contractions are considered to indicate oedema in the exercised muscle (Chleboun et al., 1998; Clarkson & Hubal, 2002; Foley et al., 1999). T2 and echo intensity peak between 3 to 7 days following eccentric exercise, however, T2 displays an appreciably protracted recovery (Foley et al., 1999; Nosaka & Clarkson, 1996a; Nosaka, Newton, & Sacco, 2002b). Nosaka and Clarkson (1996a) noted that T2 relaxation time had returned to baseline in all bar one subject by 23 days following maximal eccentric exercise of the elbow flexors. Foley et al. (1999) had subjects perform eccentric exercise with the same muscle groups used by Nosaka and Clarkson (1996a) but of higher volume and lower intensity and recorded elevated T2 images as long as 56 days later. Shellock et al. (1991) reported that in two subjects MR images showed subclinical abnormalities that remained as long as 75 days after exercise-induced muscle damage symptoms disappeared. As oedema has resolved well before this time it remains unclear what the long lasting elevated T2 images represent (Clarkson & Hubal, 2002). Foley et al. (1999) suggest that it could possibly reflect some form of long lasting adaptation.

## 2.5 Factors that are Known, or Suspected, to Influence Muscle Damage

There are many factors that are known, or suspected, to influence the magnitude of changes in markers of muscle damage following eccentric exercise. Section 2.3 discussed the involvement of different exercise models and noted that they possess the ability to influence the magnitude of muscle damage. This section will briefly cover other selected factors known, or thought, to affect changes in damage markers. Due to the exhaustive number of factors that could be addressed, the present review will be delimited to those that are felt to enhance comprehension and readability of the thesis.

### *2.5.1 Exercise Type and Intensity*

The type of exercise is a major determinant of the magnitude of changes in markers of muscle damage (criterion measures). Research has shown conclusively that exercise incorporating eccentric contractions (actions) leads to greater changes in criterion measures than those of an isometric or concentric nature (Clarkson et al., 1986; Friden, Sjostrom, & Ekblom, 1983; Lavender & Nosaka, 2006a). It is also known that the type of eccentric exercise can affect the magnitude of change in these measures. Submaximal eccentric exercise has been reported to cause a similar magnitude of initial damage to that of a maximal bout, however, subsequent damage was smaller (Nosaka & Newton, 2002b). Clarkson and Tremblay (1988) also revealed that eccentric exercise that was lower in volume produced only a modest amount of damage when compared to a higher volume bout.

The velocity and range of motion of the eccentric exercise have also been shown to affect the magnitude of subsequent muscle damage. Chapman, Newton, Sacco and Nosaka (2005) reported that in untrained subjects, when time under tension is constant, fast velocity eccentric exercise produces a larger magnitude of muscle damage than slow velocity exercise. Some, but not all, research has shown that a greater magnitude of damage is caused by eccentric exercise which is performed at long compared to short muscle lengths (McHugh & Pasiakos, 2004; Nosaka & Sakamoto, 2001). Nosaka and Sakamoto (2001) noted that the greater changes following eccentric exercise at the longer ranges of motion appeared to be due to a larger magnitude of damage to the brachialis and biceps brachii. In contrast, however, eccentric exercise of the human rectus femoris at a short muscle length induced greater muscle damage and declines in peak torque than the corresponding long length (Paschalis et al., 2005).

### *2.5.2 Muscle Group*

It appears that responses to eccentric exercise are different between leg and arm muscles; and the magnitude of muscle damage seems greater for arm muscles compared with leg muscles. However, little research has been conducted directly comparing the magnitude of muscle damage between different muscle groups employing the same relative intensity of eccentric exercise. A recent study by Jamurtas et al. (2005) had subjects perform sub-maximal eccentric exercise of the knee extensors and elbow flexors while relative intensity was controlled. The results suggested that the magnitude of muscle damage was greater and the recovery of muscle function was slower in the elbow flexor muscles. Whether such variability exists between other muscle groups remains to be elucidated.

### *2.5.3 Training*

The majority of research focusing on exercise-induced muscle damage has employed untrained subjects. Findings from these studies have provided important information in furthering our understanding of the effect of eccentric exercise on muscle function and delayed onset muscle soreness, however, they do little to inform us how trained muscle responds to such exercise. In a recent review Falvo and Bloomer (2006) noted that there is little research that has investigated the response of “trained” individuals to exercise-induced muscle damage. This is unfortunate as there is a wealth of research describing the neuromuscular and endocrine adaptations gained from exercise training.

When resistance exercise is employed as the training modality, muscles have been shown to improve their ability to produce force in all contraction modes and improvements in strength have been shown as early as during the first training session (Hakkinen, 1989). Early increases in strength are believed to be primarily neural in nature (Gabriel, Kamen, & Frost, 2006; Jones, Rutherford, & Parker, 1989) and may involve increases in maximal firing frequency, down regulation of inhibitory pathways (Aagaard, 2003) and increased motor unit synchronization (Gabriel et al., 2006). With chronic resistance training, peripheral adaptations such as muscular hypertrophy begin to contribute appreciably to the gains in strength (Deschenes & Kraemer, 2002). Increased absolute amounts of connective tissue have been reported in resistance-trained individuals (MacDougall, Sale, Alway, & Sutton, 1984) leading Stone (1992b) to speculate that strength training may cause adaptations to these structures allowing them to better resist injury. Depending upon the view one takes of such neuromuscular adaptations it could be argued that resistance-trained individuals are more, equally, or less susceptible to exercise-induced muscle damage. The increased strength may allow them to produce and absorb more force and hence increase their chance of incurring damage. Alternatively, the improved peripheral adaptations may provide more resilient muscle and tendon structures and render them less susceptible to exercise-induced damage, or both increased strength and muscular resilience may exert equal influence causing the resistance-trained and untrained individuals to exhibit similar susceptibility.

In one of the only studies to investigate CK response, soreness and muscle function following a strenuous resistance training regimen, Vincent and Vincent (1997) reported that trained subjects produced a blunted CK response but soreness and loss of muscle function was no different to the untrained group. The paucity of data involving the response of trained individuals to exercise-induced muscle damage suggests that further research is warranted.

As a resistance-training regimen typically incorporates multiple sets of both concentric and eccentric contractions performed at relatively high intensity, it seems plausible to presume that individuals undertaking this type of training over a period of time may be conferred some degree of protection against exercise-induced muscle damage.

### *2.5.4 Repeated Bout Effect*

Support for the suggestion that resistance-trained individuals may be at least partially protected against exercise-induced muscle damage is found in the phenomenon referred to as the “repeated bout effect”. Research has shown that an initial bout of eccentric exercise in untrained individuals can confer protection against a subsequent bout of the same activity (Clarkson et al., 1992; Ebbeling & Clarkson, 1989). The extent of protection varies depending upon the damage marker examined and lasts for at least six months for most damage markers but is lost between nine and twelve months (Nosaka, Sakamoto, Newton, & Sacco, 2001a). Protection has also been shown to occur when the initial eccentric exercise bout was lower in volume and produced only small changes in the markers of damage (Clarkson & Tremblay, 1988). Nosaka et al. (2001b) demonstrated that as little as two maximal eccentric contractions performed by untrained individuals can confer protection against a subsequent bout of 24 maximal eccentric contractions performed two weeks later. It has also been shown by Nosaka et al. (2005) that an initial bout of maximal eccentric exercise of the elbow flexors performed at short muscle length (0.87 – 1.74 radians) provided partial protection against the same exercise performed at long muscle length (2.27 – 3.14 radians). In contrast, McHugh and Pasiakos (2004) reported that in the quadriceps an initial eccentric exercise bout performed at short muscle length did not confer protection against strength loss and pain in a subsequent bout at longer length.

Although there have been a large number of studies investigating the repeated bout effect there remains little consensus as to the mechanism behind the phenomenon (McHugh, Connolly, Eston, & Gleim, 1999). In a review addressing the phenomenon McHugh et al. (1999) suggests that neural, connective tissue, excitation-contraction coupling, inflammatory response, or cellular adaptations may be responsible for the protective effect.

### *2.5.5 Age*

The effect of eccentric exercise on markers of muscle damage in humans of differing age is not clear. Some studies have reported that young and old subjects differ little in their susceptibility to exercise-induced muscle damage (Clarkson & Dedrick, 1988; Roth et al., 1999), whereas others (Lavender & Nosaka, 2006b; Manfredi et al., 1991; Ploutz-Snyder, Giamis, Formikell, & Rosenbaum, 2001; Roth et al., 2000) note that older individuals incur a greater magnitude of muscle injury.

These conflicting findings also extend to when a repeated bout of eccentric exercise is performed. In a study comparing young and older (>60 years) women Clarkson and Dedrick (1988) had both groups perform two bouts of eccentric exercise of the forearm flexors spaced seven days apart. They noted that, with the exception of muscle shortening, the damage process follows a similar course for both age groups and the repair process is equally as effective with both groups showing the same ability to adapt. In contrast, Lavender and Nosaka (2006b) reported that in older men (>65 years) the protective effect conferred by the initial bout was of lower magnitude than that of the younger adults. They suggested that this may have been due to the older men incurring less muscle damage following the first bout of eccentric exercise, however, they could not rule out the possibility that the protective effect in older adults does not last as long as the younger men.

Data from a recent, as yet, unpublished study shows that young and middle-aged men do not differ in their susceptibility to exercise-induced muscle damage (Lavender and Nosaka - unpublished data). Soreness, however, did differ significantly between the groups with middle-aged men reporting approximately half the level of younger men following eccentric exercise.

### *2.5.6 Gender*

Many studies investigating the response to eccentric exercise have employed research designs that include both genders. Due to greater circulating levels of the hormone oestrogen in women it has been the common belief that this gender may be protected from exercise-induced muscle damage more so than men. Whether the markers of exercise-induced muscle damage are affected to the same extent in both genders has been a point of interest and has attracted considerable investigation (Dannecker, Koltyn, Riley, & Robinson, 2003; Rinard et al., 2000; Sayers & Clarkson, 2001; Stupka et al., 2000). In reviewing the available literature Clarkson and Hubal (2001) note that contrary to the commonly held belief women are not conferred greater protection and may in fact experience a greater magnitude of damage, based on indirect measures, than men. In order to reduce any possible variations due to gender differences and the effect of oestrogen, the studies comprising the present research were restricted to men.

### *2.5.7 Genetics*

To date, there has been little research addressing the question of whether genetic differences affect the responses of markers of muscle damage following maximal eccentric exercise. Two recent studies employing maximal eccentric exercise of the elbow flexors provide contrasting findings, with Gulbin and Gaffney (2002) reporting that variability in changes of markers of exercise-induced muscle damage cannot be attributed to genetic differences, whereas Clarkson et al. (2005) reveal that phenotypic responses to muscle damaging exercise are influenced by variations in genes coding for specific myofibrillar proteins. The studies differed in their research approaches with Clarkson et al. (2005) studying genotype associations via blood samples, while Gulbin and Gaffney (2002) investigated responses of 16 pairs of identical twins without genetic assessment of blood or muscle samples. Clearly additional research is required to resolve the issue of whether and / or to what extent genetic variation is associated with phenotypic responses to exercise-induced muscle damage.

### *2.5.8 Racial Background*

There is a dearth of research investigating the effect of racial background on responses to exercise-induced muscle damage. In a recent study Clarkson et al. (2005) reported that there were a disproportionate number of Asian subjects who were homozygous for the MLCK 49T rare allele of the gene coding for the myofibrillar protein myosin light chain kinase (MLCK). These subjects produced significantly elevated CK and myoglobin activity following maximal eccentric exercise compared with the other subjects suggesting that ethnicity could be a factor. However, the researchers noted that the sample size of Asians was too small to draw any firm conclusions. Whether this apparent difference between Asian and Caucasians extends to other markers of muscle damage remains to be elucidated and warrants further investigation.

### *2.5.9 Treatment Strategies*

Although not directly related to the present research, it is important to acknowledge that various treatment strategies have been employed in a prophylactic manner and / or following exercise to influence the magnitude of changes in markers of muscle damage. In a recent review Cheung, Hume and Maxwell (2003) reported that nonsteroidal anti-inflammatories, massage, and exercise seem to exert some positive effects on selected markers of muscle damage and soreness, however, cryotherapy, stretching, homeopathy, ultrasound, and electrical current modalities have shown no effect.

Studies investigating immobilization have shown reductions in magnitude of some of the muscle damage markers such as CK response (Chen, Nosaka, & Lin, 2005; Sayers, Clarkson, & Lee, 2000b) and swelling (Chen et al., 2005), and an enhanced recovery of muscular strength (Chen et al., 2005; Sayers, Clarkson, & Lee, 2000a; Sayers et al., 2003). Wearing a compression garment on the limb following eccentric exercise has also been shown to reduce some of the markers of muscle damage. Recent research by Kraemer et al. (2001) showed that compression prevented loss of elbow extension, decreased soreness, reduced swelling, and enhanced recovery of force.

Finally, nutritional supplementation has also produced mixed results with differing responses between supplements. Four supplements that have received some attention are creatine monohydrate, beta-hydoxy-beta-methylbutyrate (HMB), and vitamins C and E. Rawson et al. (2001) reported that 5 days of creatine supplementation did not reduce indirect markers of muscle damage or expedite recovery following eccentric exercise. Van Someren et al. (2005) reported that combined supplementation with HMB and alpha-ketoisocaproic acid reduced signs and symptoms of exercise-induced muscle damage in non-resistance trained males. Another study by Paddon-Jones et al. (2001), however, noted that short term supplementation with HMB had no beneficial effect on a range of symptoms associated with eccentric muscle damage. Similar contradictory results have been reported with respect to supplementation with vitamin E. In reviewing the available literature Goldfarb (1999) noted that the effects of vitamin E supplementation has produced mixed results and warrants further research. With respect to vitamin C and muscle damage, Goldfarb (1999) reports that there is a paucity of good research on the effectiveness of this supplement.

## 2.6 Summary

It is known that novel eccentric exercise results in damage to muscle and connective tissue (exercise-induced muscle damage) and delayed onset muscle soreness. It has also been shown that reduced muscle function and other markers of muscle injury are evident following this type of exercise. A number of different exercise models have been employed to induce muscle damage and soreness, and the magnitude of symptoms and changes in markers of damage are likely attributable to the structure of these models. A number of factors such as age, exercise, muscle group, gender, genetics, racial background, and various interventions such as massage, immobilization and nutritional supplementation are thought to affect the susceptibility to exercise-induced muscle damage, although some of the above factors such as contralateral limb usage, training status and racial background of individuals have received limited attention and hence further research is warranted in order to fully elucidate their effects.

# CHAPTER 3

# METHODS

## 3.1 Study Design

The three studies comprising the research chapters of the thesis investigated the effects of arm dominance and exercise bout order (Study 1), training status (Study 2), and racial background (Caucasian and Japanese; Study 3) on markers of muscle damage and DOMS following a bout of maximal eccentric exercise. The first study employed an arm to arm comparison model in which each subject exercised both arms separated by a period of 4 weeks. The other two studies used separate groups of subjects to evaluate the effects of the eccentric exercise intervention. All three studies employed the same eccentric exercise intervention although there were minor differences in the duration of each study and the number of dependent variables (criterion measures) evaluated. Further design details specific to each study will be presented in the relevant study chapters.

In order to determine a suitable sample size for the studies a power calculation was performed based on the work of Sayers et al. (2000a) . Using an effect size of 1.0 for Study 1 and 1.2 for Studies 2 and 3, an alpha of 0.05, and a power of 0.8 in a two tailed design the estimated sample size for Studies 1, 2, and 3 were 17, 12, and 12, respectively. The effect size chosen for Study 1 was lower due to the assumption that the difference in criterion measures between arms of an individual would be smaller than that recorded between arms of different subjects (Studies 2 & 3).

It is also noteworthy that previous peer reviewed studies focussing on exercise-induced muscle damage have employed sample sizes of less than 14 per group (Clarkson & Tremblay, 1988; Nosaka & Sakamoto, 2001; Rawson et al., 2001; Saxton et al., 1995; Sayers et al., 2000a; Sayers et al., 2003), lending further weight to the adequate sample size selection in the present studies.

## 3.2 Subjects

Volunteers for each study were recruited by word of mouth from staff and students of Edith Cowan University, and from their friends, family, and sporting team members. Subjects completed a medical questionnaire prior to their participation in any testing or exercise sessions and all were found to be free of any disease or injuries that would contraindicate their inclusion in the study (Appendix A). All subjects reported that they did not use any medications for the duration of their study.

Subjects were requested not to alter their usual eating patterns during the course of the studies and not to perform any exercise, other than that prescribed by the investigator, for one week prior to and during the course of each study. Subject characteristics such as age, height and weight are described in each of the relevant study chapters (i.e., 4 to 6).

## 3.3 Ethical Considerations

Ethical approval was granted by Edith Cowan University's ethics committee and subjects were required to complete a written informed consent document consistent with principles set out in the Declaration of Helsinki before they were able to participate in the study. Subjects were informed of the procedures that they would undergo and were free to withdraw from the study at any stage for any reason without prejudice. Consent forms for each study are shown in Appendices B - D.

## 3.4 Pre-exercise Familiarisation

In the week preceding commencement of the study proper, subjects visited the laboratory on two occasions, separated by at least 48 hours, during which they were familiarized with the testing and exercise protocols. Static and dynamic maximum voluntary elbow torque were recorded, and range of motion (ROM), upper arm circumference, plasma creatine kinase activity (CK), and soreness measured. The data collected during the two familiarisation sessions was used to determine reliability of the criterion measures (section 3.7 below). During the first of the familiarisation sessions subjects were provided with a demonstration by the investigator of the eccentric exercise intervention to be performed.

## 3.5 Eccentric Exercise Intervention

The exercise intervention comprised 10 sets of 6 maximal voluntary eccentric actions of the elbow flexors of one arm, performed against the lever arm of a Cybex 6000 isokinetic dynamometer (Ronkonkoma, New York, USA) moving at a constant velocity of $90^{o}\cdot s^{-1}$. Subjects were seated on an arm curl bench with the exercised upper arm supported at $45^{o}$ of shoulder abduction and their elbow aligned with the axis of rotation of the dynamometer's lever arm. The forearm remained in a supinated position throughout all sets of exercise. The forearm commenced the movement at an angle of $90^{o}$ to the upper arm and moved through a range of movement of $90^{o}$, finishing at $180^{o}$ of elbow extension (i.e., straight arm; Figure 1). Subjects were exhorted to maximally resist the lever arm of the dynamometer throughout the entire lengthening phase of the movement. A 10-second passive recovery period occurred between eccentric repetitions while the lever arm was returned to the starting position at $9^{o}\cdot s^{-1}$ by the motor of the isokinetic dynamometer. A 3-minute passive recovery period was undertaken between sets to allow for phosphagen resynthesis.

Raw torque and displacement signals of each repetition of the exercise and strength testing bouts were output from the Cybex 6000 dynamometer and captured by a data acquisition hardware and software system (Minirack, AMLAB II, Lewisham, Australia), and a purpose designed schematic allowed torque and work output to be saved to disk and displayed in real time on an IBM desktop computer.

Peak torque and total work were determined for every repetition of the eccentric exercise bout and saved for later analysis.

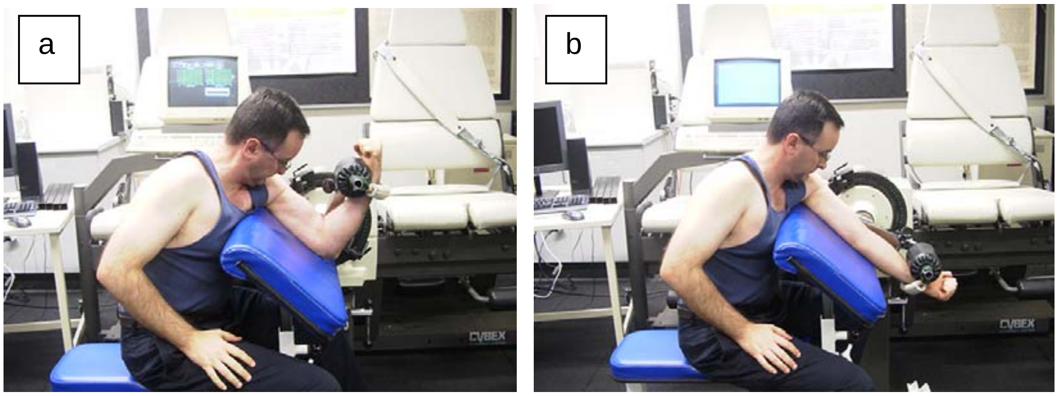

*Figure 1*: Starting (a) and finishing (b) positions for each of the 60 maximal eccentric actions of the elbow flexors.

## 3.6 Criterion Measures

The criterion measures of maximal voluntary isometric and isokinetic torque, ROM, upper arm circumference, plasma CK activity, and muscle soreness used in the present series of studies have been employed extensively in studies of exercise-induced muscle damage and DOMS (Chapman et al., 2005; Gleeson et al., 2003; Rinard et al., 2000).

All of the criterion measures mentioned above are considered indirect markers of muscle damage and were chosen as appropriate dependent variables due to the acceptance of such measures in the peer reviewed literature. Warren, Lowe and Armstrong (1999) believe that maximal voluntary contraction torque is the best measure of injury resulting from eccentric contractions and provides the primary means for determining muscle function in human studies.

ROM is also considered a useful marker of the functional decrements resulting from eccentric exercise and as such Warren et al. (1999) suggest that these measurements should, ideally, be included in human studies.

Following eccentric exercise muscle swelling, which is likely related to tissue damage and the inflammatory response, is generally estimated from the change in limb circumference (Chelboun, Howell, Conaster, & Giesey, 1998), and Clarkson and Hubal

(2002) noted that blood CK activity provides an indirect qualitative marker of muscle damage.

The time course over which the criterion measures were evaluated varied slightly between the studies and have, therefore, been described under the same heading in the relevant study chapters.

### *3.6.1 Maximal Voluntary Contraction (MVC) Torque*

Isometric MVC torque was measured at fixed joint angles of $90^o$ and $150^o$ of elbow extension, and MVC isokinetic torque at concentric velocities of $30^o \cdot s^{-1}$, $90^o \cdot s^{-1}$, $150^o \cdot s^{-1}$, $210^o \cdot s^{-1}$, and $300^o \cdot s^{-1}$. The order of measurement was as it appears above.

Subjects assumed a position on the arm curl bench as described in the exercise protocol section above. Subjects were exhorted to produce a continuous maximal voluntary contraction of the elbow flexors for three seconds against an immovable lever arm of the Cybex 6000 isokinetic dynamometer at fixed elbow joint angles of $90^o$ and $150^o$ (Figure 2a & b). Two efforts were allowed at each joint angle and the highest torque production of the two was recorded. A 30-second passive rest period was provided between attempts at a given angle, and one-minute of passive recovery was employed between testing at the two joint angles. Torque data from the Cybex 6000 dynamometer was collected using AMLAB and saved for later analysis.

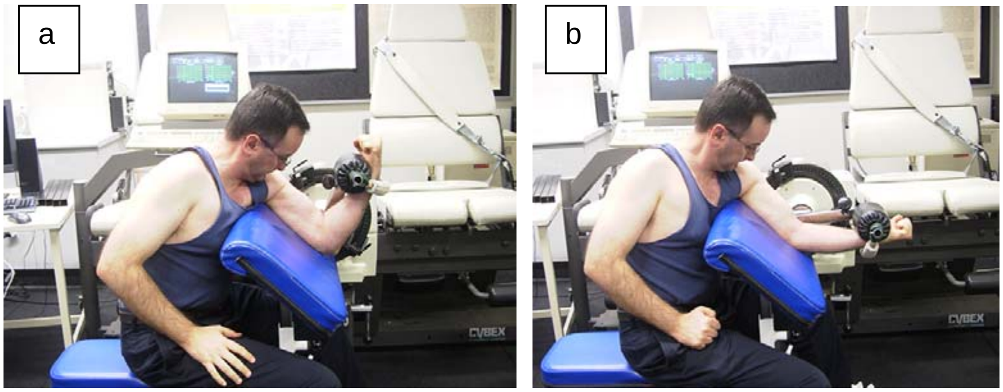

*Figure 2.* Determination of maximal isometric torque at fixed angles of (a) $90^o$ and (b) $150^o$ of elbow extension.

Isokinetic MVC torque at concentric velocities of $30^{o}\cdot s^{-1}$, $90^{o}\cdot s^{-1}$, $150^{o}\cdot s^{-1}$, $210^{o}\cdot s^{-1}$, and $300^{o}\cdot s^{-1}$ were also collected during each testing session. Isokinetic assessment followed the isometric measurements during every session with a two-minute passive recovery provided between the different testing modalities.

Arm curl bench and Cybex 6000 set-up were the same as for isometric strength assessment, and the range of motion used for the eccentric exercise intervention was employed for the concentric contractions (i.e., $90^{o}$).

Torque was recorded throughout the range of motion, however, only peak torque was used for analytical purposes. Two maximal attempts were made at each concentric velocity and the highest of the two retained for later analysis. The two attempts at each velocity were made consecutively and a one-minute passive recovery was provided between successive velocities. Isokinetic testing velocities were ordered from slowest to fastest for all subjects and testing sessions.

Subjects were verbally encouraged throughout the eccentric exercise intervention, and the isometric and isokinetic concentric contractions in an attempt to obtain maximum effort.

### *3.6.2 Range of Motion (ROM) and Elbow Joint Angle*

Range of motion of the elbow joint was determined by the difference between the flexed (FANG) and stretched (SANG) elbow joint angle as measured by goniometry. FANG was determined by the angle formed at the elbow when it is held by the side while the subject attempted to fully flex the elbow joint to touch their shoulder with the palm of the supinated hand (Figure 3a). SANG was determined as the angle formed at the elbow joint when the subject attempted to extend their arm as much as possible with the elbow held by their side and the hand in mid pronation (Figure 3b). To obtain consistent measurements four marks were drawn on the skin with a semi-permanent ink pen, one laterally approximating the level of the deltoid tuberosity, the second at the level of the lateral epicondyle of the humerus, a third at the mid-point of the wrist, and the fourth laterally at the styloid process of the radius (Figure 3a & b).

*Figure 3*. Upper arm, elbow and hand positions adopted for determination of (a) FANG and (b) SANG.

A plastic Jamar E-Z Read goniometer (Sammons Preston Rolyan, Illinois, USA) was used to record the FANG and SANG measures (Figure 4a & b). Two measurements were taken for FANG and SANG with the mean value of the two used for the determination of ROM.

*Figure 4*. FANG (a) and SANG (b) as measured by goniometry. The hole in the centre of the goniometer is located over the mark made on the lateral epicondyle of the humerus.

### *3.6.3 Upper Arm Circumference*

Upper arm circumference was determined using a Gulick constant tension tape measure (model J00305, Lafayette Instrument, Indiana, USA) at five sites on the upper arm 3, 5, 7, 9, and 11 cm from the elbow crease (Figure 5a). Measurements were collected with the subject's arm relaxed and hanging by their side (Figure 5b). Two measurements were taken from each site and the mean value was determined. An overall mean for the five sites was then calculated and used for later analysis. To obtain consistent measurements over the study period the five sites were marked on the skin with a semi-permanent ink pen.

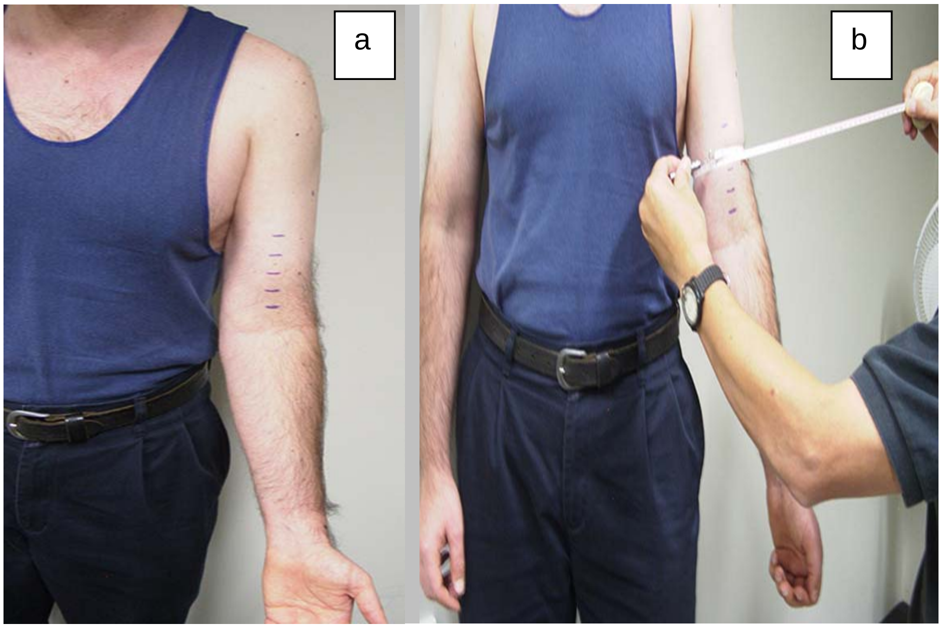

*Figure 5*. Upper arm circumference markings (a) and measurement with a constant tension tape.

### *3.6.4 Plasma Creatine Kinase (CK) Activity*

Approximately 30 μl of blood was collected in a heparinised capillary tube following the piercing of the subject's pre-cleaned finger with a spring loaded lancet. The blood was immediately transferred by pipette to a CK test strip and assayed by a Reflotron spectrophotometer (Boehringer-Manheim, Pode, Czech Republic) for plasma CK activity.

According to Boehringer-Manheim information slips provided with the CK test strips the "normal" reference range for CK using this method is 24 to 195 $IU \cdot L^{-1}$ when assaying at $37^{o}C$. When CK activity exceeded the linear accuracy of the spectrophotometer (approximately 1500 $IU \cdot L^{-1}$) another blood sample was obtained from the subject and diluted with saline solution before being assayed. The resulting CK activity was then adjusted to account for the dilution.

### *3.6.5 Muscle Soreness*

Muscle soreness was assessed by the investigator palpating the subject's upper arm and forearm, and extending and flexing the elbow joint while the subject attempted to relax the arm. Subjects rested their arm on a table during arm palpation and flexion measures, however, during measurement of extension soreness the investigator raised the subject's relaxed arm off the table to perform the evaluation (figure 6a, b, & c).

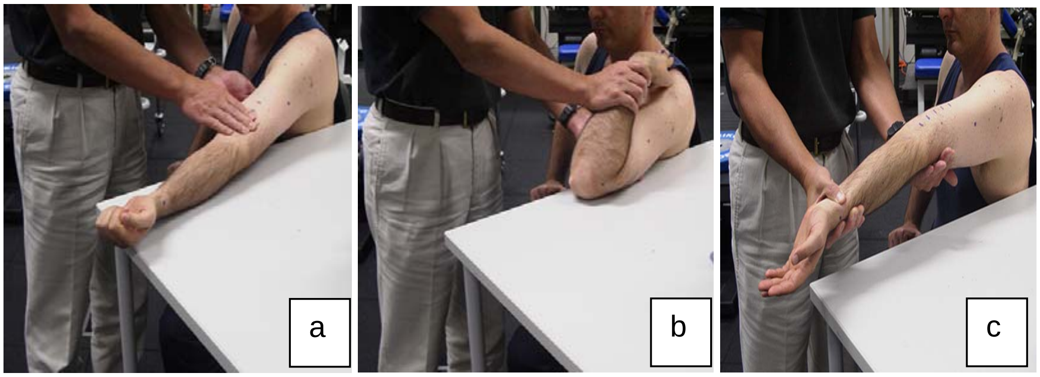

*Figure 6*. Upper arm (a), flexion (b), and extension (c) soreness positions.

Palpation soreness was assessed by the examiner applying firm pressure to the specific location on the arm or forearm, directing pressure primarily through the index and middle fingers (Figures 6a & 7). Two of the four sites employed for palpation soreness were located using the lines marked for upper arm circumference measurements. The first site was located on the belly of the biceps brachii between the lines marked 3 and 5 cm above the elbow crease. The second site was located between the lines marked 9 and 11 cm above the elbow crease and pressure was once again applied to the belly of the biceps brachii. The third site was located on the lateral side of the upper arm just above the elbow and was targeted at the brachialis musculature (Figure 7a). The final site for palpation soreness was located on the forearm and was targeted at the brachioradialis (Figure 7b).

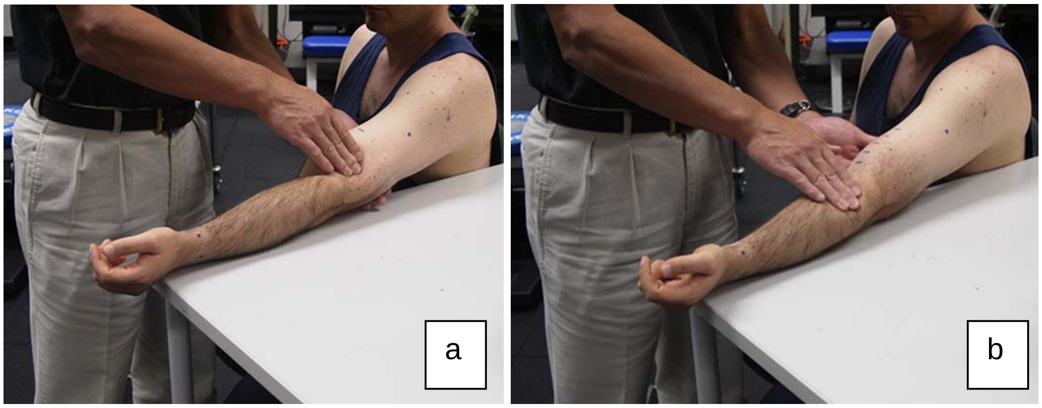

*Figure 7*. Locations used for measurement of (a) arm palpation site 3 (brachialis) and (b) forearm palpation.

During flexion and extension soreness measures the subject was asked to relax their arm as much as possible while the investigator passively flexed and extended the elbow joint (Figure 6b & c).

In line with the previously employed protocol of Cleary et al. (2002), a visual analog scale (VAS) was used to provide a quantitative measure of the subject's soreness . The VAS incorporates a 100 mm line marked with 0 at one end, indicating no discomfort at all, and 100 at the other, representing extreme soreness (Appendix E). The subject marked the 100 mm line with a pen, using the hand of the arm not being assessed, at a point along the scale that coincided with their perceived level of soreness. The investigator provided each subject with the verbal anchors for both ends of the VAS during each soreness recording. The distance from zero, in mm, was measured and the numerical result recorded for later analysis.

### 3.7 Reliability of Criterion Measures

Data collected from the two familiarisation sessions were used to determine the test-retest reliability of selected criterion measures. The criterion measures assessed for reliability were isometric and isokinetic MVC torque, ROM, upper arm circumference, and plasma CK activity. Upper arm palpation, forearm, extension and flexion soreness were not assessed for test-retest reliability due to all subjects recording VAS scores of zero for each soreness class during both familiarisation sessions. All of the criterion measures in each study were collected by the one investigator who was familiar with the measurement procedures.

Intraclass correlations were used to determine the test-retest reliability of the two familiarization sessions for the selected criterion measurements. Statistical Package for the Social Sciences (SPSS) version 13.0 for Windows was used to perform the reliability computations, and statistical significance was set at $p<0.05$ for all analyses. The reliability across the two familiarisation sessions ($R_1$) was similar between the three studies, with the ranges for isometric and isokinetic torque, ROM, upper arm circumference, and plasma CK activity of 0.96 – 0.99**,** 0.91 – 0.99**,** 0.98 – 0.99**,** and 0.80 - 0.93, respectively. According to Vincent (1999) the reliability of isometric and isokinetic torque, ROM and upper arm circumference are considered “high”, with CK activity being regarded as “moderate”.

## 3.8 Analysis of Results

Both absolute and “normalised” data were used for analysis of selected criterion measures. In terms of both isometric and isokinetic MVC torques, “normalised” referred to percentages of pre-exercised values (i.e., normalised to pre-exercise). For ROM and upper arm circumference “normalised” referred to changes from pre-exercise values, however, in the case of these two criterion measures the differences were presented as actual units of measure (i.e., degrees for ROM and mm for circumference). Both CK activity and soreness were analysed using only absolute values.

Changes in all criterion measures over time were compared between the groups in each study using a between-within factorial analysis of variance (ANOVA). Two-way repeated measures ANOVA were applied to the data to calculate the main effects and interaction. When the ANOVA returned a significant main effect for the normalised “between group” comparison in the trained versus untrained and Caucasian versus Japanese studies, independent t-tests with Bonferroni correction were applied post hoc to locate any significant interactions. Paired t-tests with Bonferroni correction were employed post hoc for the Bout 1 versus Bout 2 - Dominant versus Non-dominant study when a significant “between group” main effect resulted.

When the two-way repeated measures ANOVA returned a significant main effect for "within group" comparisons, one-way repeated measures ANOVAs with Bonferroni corrected pairwise comparisons were applied to the absolute value data of each group to locate any significant differences over time.

Independent t-tests with Bonferroni correction were applied to the subject characteristics and pre-exercise absolute values of the criterion measures for the trained versus untrained and Caucasian versus Japanese studies to locate any significant differences between the groups. For the Bout 1 versus Bout 2 - Dominant versus Non-dominant study, paired t-tests with Bonferroni correction were employed to locate any significant differences between the groups for pre-exercise absolute values of the criterion measures.

Pearson's product moment correlation coefficients were calculated for selected time points in the Bout 1 versus Bout 2 - Dominant versus Non-dominant study to determine the relationship between the groups. Scatterplots of individual subject data with fitted lines of equality were also used to highlight the degree of agreement between the groups.

Data analysis was performed using the Statistical Package for the Social Sciences (SPSS) version 13.0 for Windows. Statistical significance was set at $p<0.05$ for all analyses. Where Bonferroni corrections were employed a single-test alpha level of 0.05 was divided by the number of tests performed. As the single test alpha level of 0.05 was employed for all analyses, for brevity in the textual results $p<0.05$ will be reported for all comparisons including those involving Bonferroni correction. Data are presented as means ± SEM, unless otherwise stated.

## 3.9 Limitations and Delimitations

Subjects were all male and aged between 18 and 42 years, therefore results may not be representative of the entire population in terms of gender and age. The present studies employed a maximal eccentric exercise model incorporating the elbow flexors which may not be representative of other muscle groups. The criterion measures used in the present studies provided indirect measures of muscle damage and, therefore, should not be inferred to represent actual ultrastructural damage to muscle and connective tissue.

The measurements of soreness used in the three studies are subjective by nature, however, they have been used extensively in peer reviewed exercise-induced muscle damage and DOMS literature to quantify soreness.

# CHAPTER 4

## 4.1 Introduction

The exercise-induced muscle damage literature is replete with examples of wide inter-subject variations in criterion measures following exercise of an eccentric nature (Clarkson & Tremblay, 1988; Gulbin & Gaffney, 2002; Newham et al., 1987; Nosaka & Clarkson, 1996; Nosaka et al., 1991; Sayers et al., 1999). The criterion measure typically exhibiting the greatest inter-subject variability is the intramuscular enzyme CK (Clarkson & Tremblay, 1988; Newham et al., 1987; Nosaka & Clarkson, 1996b), however, force loss (Gulbin & Gaffney, 2002; Sayers et al., 1999) and limb circumference (Sayers et al., 1999) have also been reported to exhibit appreciable variation. The aetiology of the large variability in these measures is not well understood, although recently genetic factors have been implicated (Clarkson et al., 2005).

Two common experimental models have been employed during the study of exercise-induced muscle injury and soreness. The more common of the models uses two groups of subjects, one of which receives an exercise intervention while the other acts as either a control or receives a different intervention. The second model is similar with regard to the intervention and control scenario, however, only one group of subjects is required due to the use of contralateral limbs. The attraction of the contralateral limb model lies in the belief that variances in the criterion measures will be minimised following identical bouts of maximal voluntary eccentric exercise if the same subject is used for both exercise bouts. Certainly this has been shown to be the case for some of the criterion measures when eccentric exercise has been performed twice on the same limb of a subject with a lengthy non-exercise period interspersed between the bouts (Nosaka et al., 2001a). Nosaka et al. (2001a) showed that with a non-exercise period of 12 months between maximal eccentric exercise bouts of the elbow flexors of the same arm there were no significant differences for changes in strength, limb circumference, muscle soreness, CK activity, and MRI T2 relaxation times.

Loss of ROM about the elbow joint, however, was significantly greater following the second bout performed 12 months later ($p<0.05$).

The problem with using the same limb for both bouts of eccentric exercise lies in the protracted non-exercise period required between the bouts which would be impractical for most studies. Criterion measures of the same limb have been shown to differ significantly if shorter periods are employed between the eccentric exercise bouts (Clarkson et al., 1992; Nosaka, Newton, & Sacco, 2005). This phenomenon is well described in the literature and is referred to as the repeated bout effect (McHugh et al., 1999; Nosaka et al., 2001b; Thompson, Clarkson, & Scordilis, 2002). Nosaka et al. (2001a) have shown that a non-exercise period as long as six months still resulted in significantly smaller changes in the criterion measures of muscular strength loss, limb circumference, muscle soreness, CK activity, and MRI T2 relaxation times following the second bout of eccentric exercise. This protective effect of prior eccentric exercise causes statistically significant differences in the ipsilateral limb and would likely mask any small effects of a treatment under investigation, which effectively renders the same-limb within-subject model unsuitable for studies completed over short periods.

Another option is to implement a contralateral limb model. This model, which involves eccentrically exercising both limbs of subjects separated by a short period, has been used to study the effects of various phenomena and interventions such as cross-education protection (Connolly et al., 2002), immobilization (Zainuddin, Hope et al., 2005) massage (Zainuddin, Newton et al., 2005), muscle length (McHugh & Pasiakos, 2004), and muscle temperature (Nosaka et al., 2004). Chen et al. (2003) noted that this type of model allows elimination of molecular noise from genetically heterogenous humans. A period of at least one to two weeks is usually employed to allow for recovery of blood borne markers of muscle damage. The success of such a model relies on almost identical changes in criterion measures of the contralateral limbs following the same eccentric exercise intervention. Any significant differences between the contralateral limbs could act in the same manner as a repeated bout on the same limb, effectively masking any effect due to the treatment.

To the best of the author’s knowledge there has been no published study addressing whether criterion measures of contralateral elbow flexor musculature differ when exposed to identical eccentric exercise treatment. Variation between the limbs could potentially be caused by dominance and / or cross education effects. To date, there appears to be no published studies examining whether a dominant limb would respond differently to eccentric exercise than its non-dominant counterpart. In terms of cross education, research has shown that uni-lateral resistance training leads to appreciable increases in strength of the untrained contralateral limb (Farthing & Chilibeck, 2003; Hortobagyi, J., & P., 1997; Shima et al., 2002). Limited research has suggested that eccentric exercise performed on one limb does not confer any protective effect by way of cross education to a non-exercised contralateral limb, although these studies were not performed on the elbow flexors (Clarkson et al., 1987; Connolly et al., 2002).

The importance of continued investigation of this kind was highlighted in the conclusions of a study by Connolly et al. (2002) where it was stated that “further work in this area [repeated bout crossover effect] is warranted and should consider a greater degree of damage than was induced in the current study, use of an upper body model or a model that revisits the initially damaged muscle before the contralateral limb” (p. 85).

Therefore, the purpose of the present study was to determine whether changes in the markers of muscle damage and soreness in untrained males differed between contralateral arms following maximal voluntary eccentric exercise of the elbow flexors.

In order to address this purpose, a period of one month was interspersed between exercise of contralateral arms to allow the indirect markers of damage and soreness (criterion measures) to return to baseline levels. Arm dominance was counterbalanced between bout 1 (arm exercised first) and bout 2 (arm exercised second). As the contralateral arms were not exercised at the same time, two separate research questions were required.

The first addressed the issue of exercise order by asking whether the indirect markers of damage and soreness of the elbow flexors of the arm exercised second would be influenced by the preceding exercise on the contralateral arm.

The second research question addressed the issue of arm dominance by asking whether the indirect markers of damage and soreness would differ between the elbow flexors of the dominant and non-dominant arms.

## 4.2 Methods

### *4.2.1 Experimental Design*

The study employed one group of subjects who performed the eccentric exercise intervention on both arms, one at a time, separated by a period of one month. This contralateral arm model resulted in two bouts of exercise being performed by the group, one involving the dominant arm and the other the non-dominant. The data was then arranged allowing it to be analysed as two separate parts, one of which focused on comparisons between dominant and non-dominant arms, while the other compared responses associated with the first and second bouts of eccentric exercise. Each part of the study utilised a 2x10 factorial design to investigate the effect of the manipulation of the independent variable on the dependent variables. The independent variables for the first and second parts were arm dominance (dominant or non-dominant), and bout number (bout 1 or bout 2), respectively. The dependent variables were the criterion measures described in chapter 3 (section 3.6). The main experimental period consisted of two blocks of 8 consecutive days of measurement preceded by two familiarization sessions. The time course of the testing sessions is described in section 4.2.4 below.

Dominant and non-dominant arms were randomly assigned to the first bout of eccentric exercise in such a way that dominance was counter balanced among subjects (i.e., 50% of subjects performed the first bout with the dominant arm). As a contralateral arm model was used for the study, counterbalancing the first bout resulted in the second bout automatically being counterbalanced for arm dominance.

### *4.2.2 Subjects*

Eighteen male subjects volunteered to take part in the study. The mean ± SEM age, height, and weight were 30.8 ± 1.2 years, 170.9 ± 5.4 cm, and 80.6 ± 3.2 kg, respectively. All subjects completed informed consent forms and a medical questionnaire and were free of any disease or injuries that would contraindicate their inclusion in the study.

### *4.2.3 Eccentric Exercise Bout*

The exercise intervention consisted of 10 sets of 6 maximal voluntary eccentric actions of the elbow flexors against the lever arm of the isokinetic dynamometer (Cybex 6000, Ronkonkoma, NY, USA.) moving at constant velocity of $90^{o} \cdot s^{-1}$. A detailed explanation of the protocol was described in chapter 3 (section 3.5).

### *4.2.4 Timetable of Criterion Measures*

All of the criterion measures were recorded during the two familiarisation sessions which were completed in the week preceding the eccentric exercise intervention. Table 1 shows the other testing sessions during which the criterion measures were evaluated. During each testing session the order in which the criterion measurements were taken remained consistent commencing with CK followed by muscle soreness, ROM, upper arm circumference, and concluding with MVC torques (isometric preceding isokinetic). The criterion measures that were collected in this study employed the techniques described in chapter 3 (section 3.5).

Table 1

*Timetable of Criterion Measure Testing Prior to and Following the Eccentric Exercise Intervention*

| Criterion measure | Testing session in relation to the eccentric exercise intervention | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pre | Post | | Day following eccentric exercise | | | | | | |
| | Pre-ex | Imm | 30 min | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| MVC torque | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ROM | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Circumference | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| CK activity | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Soreness | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Note. A tick "✓" indicates that testing has taken place at this time point. "Circumference" refers to upper arm circumference. "Pre-ex" and "Imm" refer to immediately preceding and immediately following the eccentric exercise intervention, respectively.

A full description of the methods used to analyse the data of the present study is outlined in chapter 3 (section 3.8).

## 4.3 Results

### *4.3.1 Differences in Pre-exercise Criterion Measures*

There were no significant differences between the groups in the pre-exercise absolute values of any of the criterion measures for the Dominant versus Non-dominant and Bout 1 versus Bout 2 study.

### *4.3.2 Peak Torque During Eccentric Exercise*

Dominant versus Non-dominant Arms

Mean peak torque for dominant and non-dominant groups were similar for each of the ten sets of eccentric exercise (Figure 8a).

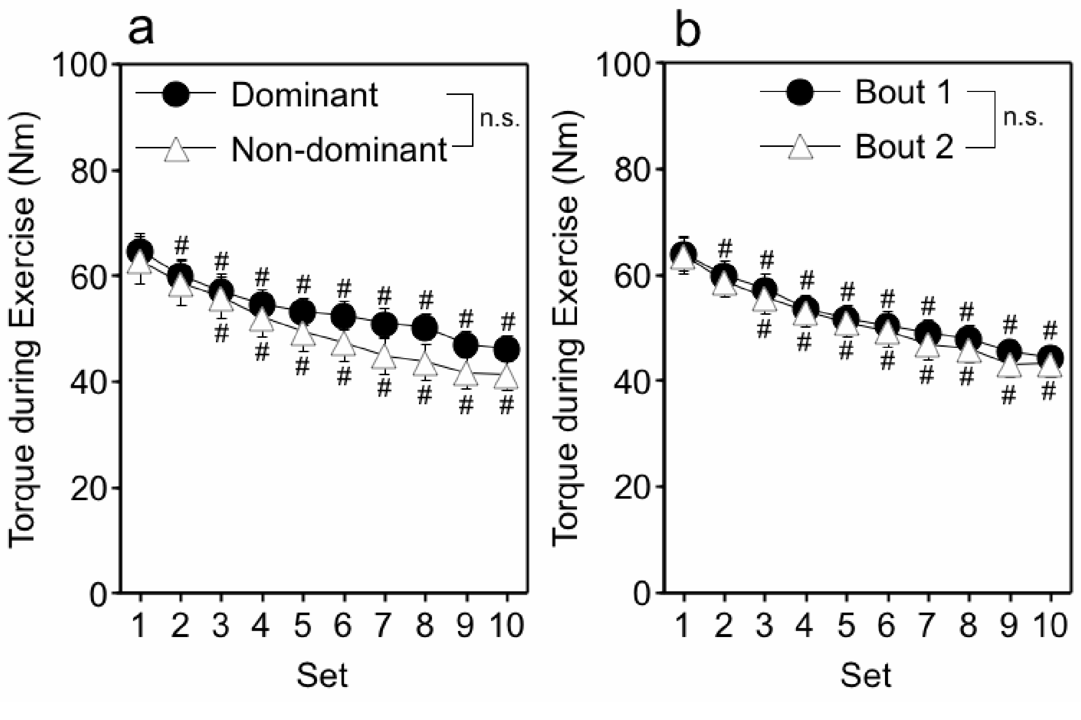

*Figure 8.* Comparison of changes in mean peak torque of 6 eccentric actions over 10 sets of eccentric exercise between dominant and non-dominant arm bouts (a) and first and second bouts (b). n.s.: not significantly different between bouts, #: significantly different from the 1$^{st}$ set.

During the first set of exercise the mean peak torque for the dominant and non-dominant groups were approximately 65 Nm and 63 Nm, respectively. Over the course of the ten sets mean peak torque declined in the dominant and non-dominant groups by approximately 30% and 35%, respectively. Despite the apparent contrast there were no significant differences between the groups for this torque measure during any of the sets of exercise. Both groups, however, recorded significant declines in mean peak torque from baseline (set 1) over the course of the ten sets of exercise ($p<0.05$). In the dominant group sets 2 to 10 were all significantly below baseline, as were sets 3 to 10 for the non-dominant (Figure 8a).

#### Bout 1 versus Bout 2

Figure 8b shows that the mean peak torque of bout 1 and bout 2 groups were also similar for each set of eccentric exercise. The measures of approximately 63 Nm for both groups during the first set were similar to those of the dominant and non-dominant arms. The decrement in mean peak torque over the ten sets of exercise was also similar with bout 1 and bout 2 groups declining by approximately 30% and 32%, respectively. There were also no significant differences evident for this measure between bouts 1 and 2 for any of the ten sets.

In terms of mean peak torque decrements from baseline, sets 2 to 10 and 3 to 10 were significantly lower than set 1 for bouts 1 and 2, respectively ($p<0.05$).

### *4.3.3 Work During Eccentric Exercise*

#### Dominant versus Non-dominant

Total work per set was similar for both dominant and non-dominant groups for each of the ten sets of eccentric exercise with no significant differences found between the groups (Figure 9a).

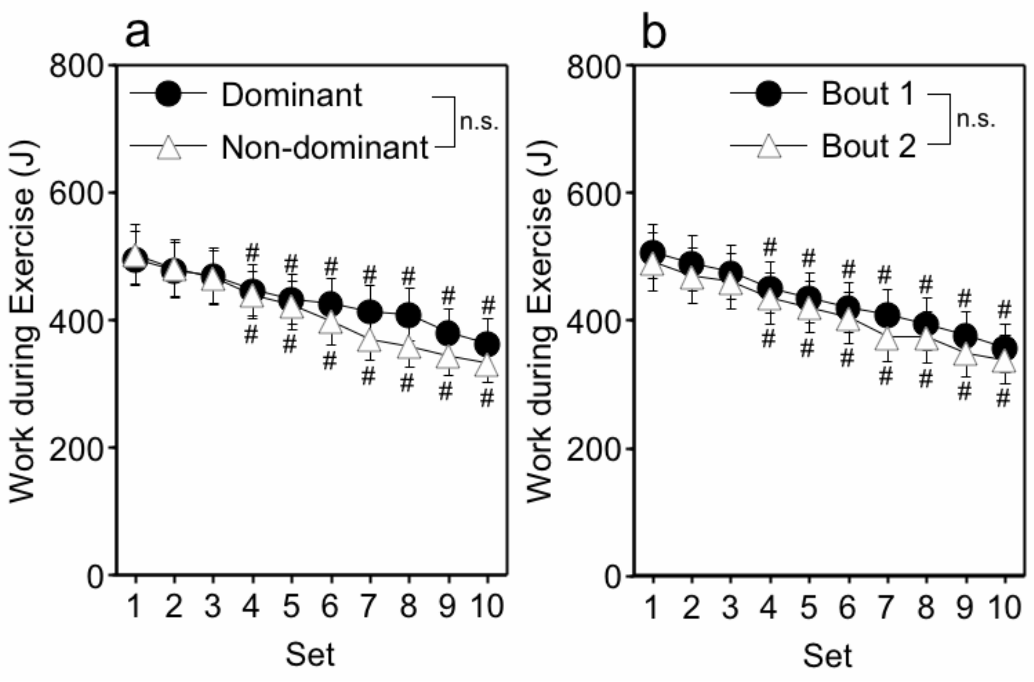

*Figure 9.* Comparison of changes in the total work per set over 10 sets of eccentric exercise between dominant and non-dominant arm bouts (a) and first and second bouts (b). n.s.: not significantly different between bouts, #: significantly different from the 1st set.

Both groups recorded total work of approximately 500 Joules (J) for the first set which had decreased by approximately 30% by the final set. The total work per set was significantly lower than the initial set in both groups by set 4 and remained so for the final six sets ($p<0.05$). Total work over the ten sets of 4319 J for dominant and 4119 J for non-dominant were not significantly different between the groups.

### Bout 1 versus Bout 2

Bouts 1 and 2 produced nearly identical results to the dominant and non-dominant groups (Figure 9b). A total work per set of approximately 500 J was recorded by both groups for the first set and was approximately 30% lower by the conclusion of set 10. In parallel to the results of the dominant and non-dominant groups, the total work per set in bouts 1 and 2 was significantly lower than baseline from sets 4 through 10 ($p<0.05$). Total work over the ten sets of eccentric exercise was not significantly different between bouts 1 and 2 with both groups recording values of slightly over 4000 J.

### *4.3.4 Isometric Torque*

Dominant versus Non-dominant

Figure 10a shows that mean peak torque at a fixed elbow joint angle of $90^o$ was not significantly different between the dominant and non-dominant groups at any time following the eccentric exercise intervention. Peak torque of both groups decreased by approximately 40% immediately following exercise and gradually increased over subsequent days to remain approximately 15% below pre-exercise levels by the final day of testing ($p<0.05$).

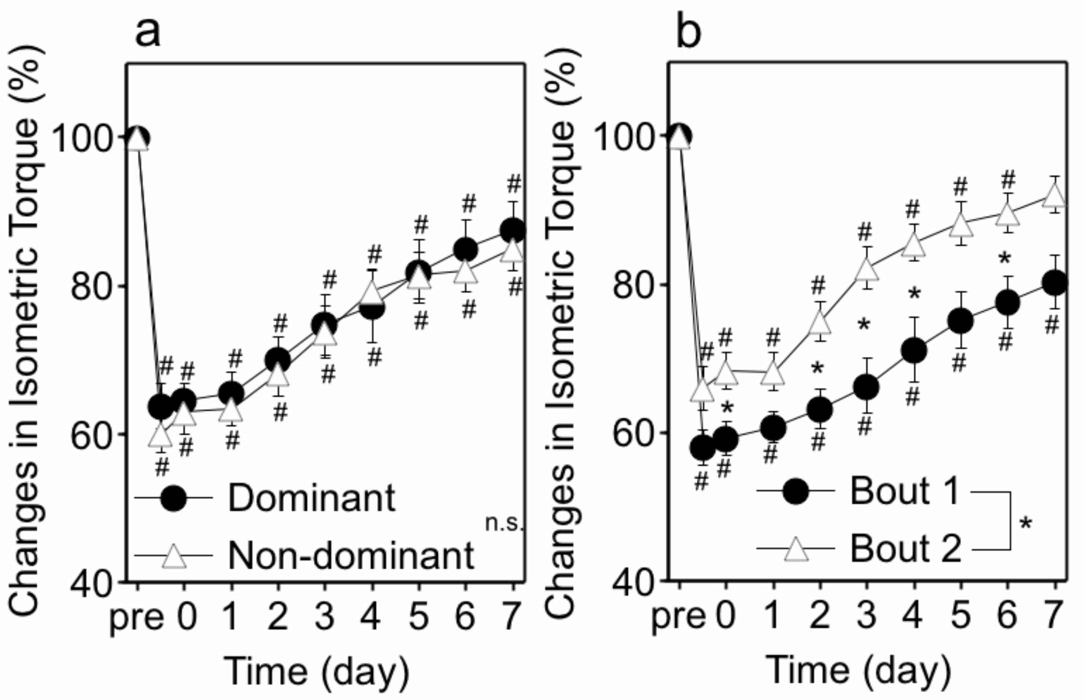

*Figure 10.* Comparison of changes from baseline (pre: 100%) in maximum isometric torque at 90° immediately (0) and 1-7 days following exercise between dominant and non-dominant arm bouts (a) and first and second bouts (b). Pre-exercise isometric torque (mean ± SEM) at $90^o$ was 68.4 (0.9) Nm. n.s.: not significantly different between bouts, #: significantly different from pre-exercise levels (pre). *: a significant difference between bouts (over all: $p<0.05$, each time point: $p<0.006$).

Despite the lack of significant differences between the groups for this measure, inspection of the scatter plots (Figure 11a & b) and resulting correlation coefficients for immediately after exercise, and 7 days post, reveals that there is minimal agreement between the dominant and non-dominant arms of individual subjects. The line of equality has been provided to highlight the variance of many subjects between the dominant and non-dominant conditions.

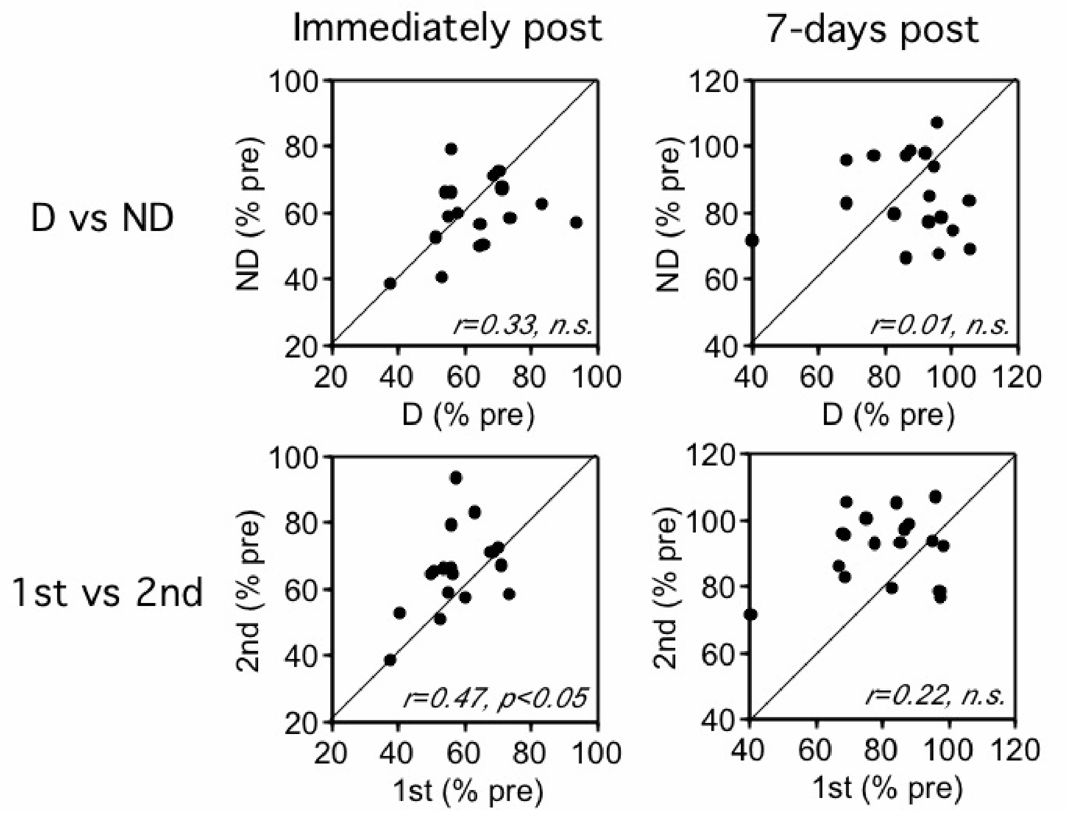

*Figure 11*. Maximum isometric torque compared to the pre-exercise value immediately post exercise and 7 days post-exercise of each subject for the dominant (D) and non-dominant (ND) bouts (a, b) and the first (1$^{st}$) and second (2$^{nd}$) bouts (c, d). Pearson correlation coefficient (r) and its significance level are shown in each graph (n.s.: not significant). The line indicates that the two bout values are identical.

There were also no significant differences between the groups at any time following exercise for mean peak torque at a fixed elbow joint angle of 150$^o$ (Figure 12a). The decrements in torque immediately following exercise were similar to that reported for the 90$^o$ angle, however, both groups were not significantly different to pre-exercise levels (~46 Nm) by the final day of testing.

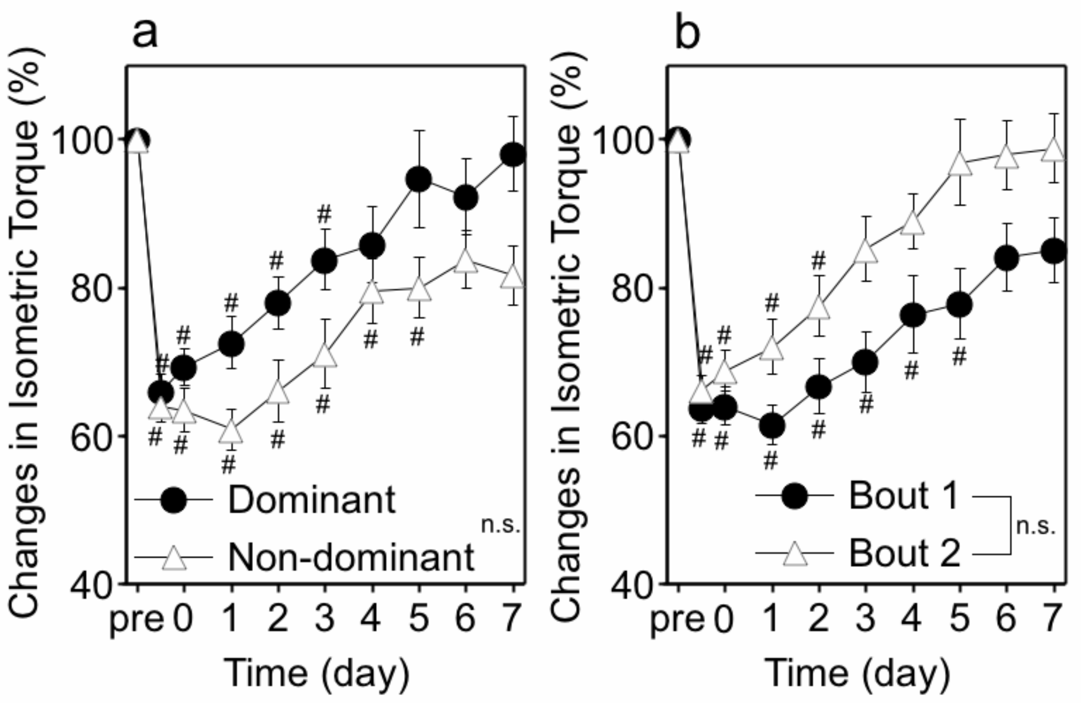

*Figure 12.* Comparison of changes in maximum isometric torque at 150° immediately (0) and 1-7 days following exercise from baseline (pre* 100%) between dominant and non-dominant arm bouts (a) and first and second bouts (b). Pre-exercise isometric torque (mean ± SEM) at 150$^o$ was 46.1 (0.8) Nm. n.s.: not significantly different between bouts, #: significantly different from the 1$^{st}$ set. *: a significant difference between bouts (over all: $p<0.05$, each time point: $p<0.006$).

Bout 1 versus Bout 2

In contrast to the dominant and non-dominant groups, there were significant differences ($p<0.05$) between bouts 1 and 2 for mean peak torque on several days following the eccentric exercise intervention at an elbow joint angle of 90$^o$ (Figure 10b). The pattern of recovery of torque was different between the bouts and is reflected by a significant time by group interaction ($p<0.05$). Mean peak torque immediately following exercise decreased by approximately 45% and 35% in bouts 1 and 2, respectively. By the final day of testing the only group to remain significantly below pre-exercise levels was bout 1 ($p<0.05$).

Scatter plots and correlation coefficients for immediately following, and 7 days after eccentric exercise show a poor relationship between the bouts for individual subjects (Figure 11c & d). The large number of data points lying above the line of equality indicates that the majority of individuals showed smaller peak torque decrements following exercise in bout 2.

In contrast to the findings at an elbow joint angle of $90^o$, there were no significant differences between bouts 1 and 2 for mean peak torque at any time following eccentric exercise at the larger elbow joint angle of $150^o$ (Figure 12b). Both groups showed decrements in mean peak torque immediately following exercise of approximately 35%, however, by the final day of testing there was a divergence of the groups with bouts 1 and 2 approximately 15% and 1% below pre-exercise levels, respectively. Despite the 14% difference between bouts 1 and 2 at day 7 following exercise, the mean peak torque of both groups were not significantly below pre-exercise levels.

There was a noticeable difference in standard error of the mean between the elbow joint angles with both groups producing appreciably larger readings at the greater angle of $150^o$ than the smaller angle of $90^o$.

### *4.3.5 Isokinetic Torque*

Dominant versus Non-dominant

Table 2 reveals that there were no significant differences between the dominant and non-dominant groups for any of the testing sessions at any of the concentric velocities following the eccentric exercise intervention. Both groups produced their greatest decrements in isokinetic torque of between ~33 – 40% either immediately following, or 30 minutes after, eccentric exercise ($p<0.05$). Torque at all velocities, and for both groups, remained significantly below pre-exercise levels for several days ($p<0.05$) but had recovered to non-significant levels by the final day of testing.

Table 2.

*Changes in Normalised Isokinetic Torque at Five Different Velocities from Pre-exercise (100%) over 7 days Following Eccentric Exercise for Dominant and Non-dominant Conditions. Mean and Standard Error of the Mean (SEM) are Shown*

|  |  |  |  | Percentage of pre-exercise torque |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | Time following eccentric exercise |  |  |  |  |  |  |  |  |
| Velocity | Arm | n |  | Imm Post | 30 min Post | Day1 | Day2 | Day3 | Day4 | Day5 | Day6 | Day7 |
| $30^{o}\cdot s^{-1}$ | Dominant | 18 | Mean | 63.5# | 63.4# | 68.5# | 73.5# | 79.5# | 80.8# | 84.5 | 89.5 | 90.1 |
|  |  |  | SEM | 2.9 | 2.1 | 2.8 | 3.7 | 3.6 | 3.9 | 4.5 | 3.9 | 4.3 |
|  | Non-dominant | 18 | Mean | 62.1# | 62.6# | 63.3# | 66.7# | 70.7# | 75.6# | 81.2# | 83.7# | 86.4 |
|  |  |  | SEM | 3.4 | 3.1 | 2.8 | 3.3 | 3.1 | 4.6 | 4.0 | 3.8 | 4.5 |
| $90\ ^{o}\cdot s^{-1}$ | Dominant | 18 | Mean | 65.0# | 63.0# | 65.0# | 69.6# | 79.5# | 81.8# | 85.3 | 85.5 | 89.9 |
|  |  |  | SEM | 2.9 | 3.2 | 3.8 | 3.9 | 3.7 | 5.0 | 4.5 | 4.4 | 5.1 |
|  | Non-dominant | 18 | Mean | 62.3# | 61.9# | 62.3# | 69.2# | 72.7# | 79.4# | 80.5 | 82.4# | 84.7 |
|  |  |  | SEM | 3.7 | 3.2 | 2.9 | 3.9 | 4.0 | 4.3 | 4.6 | 4.1 | 4.1 |
| $150^{o}\cdot s^{-1}$ | Dominant | 18 | Mean | 63.5# | 63.8# | 67.0# | 70.5# | 76.1# | 79.2# | 84.3# | 86.0 | 87.8 |
|  |  |  | SEM | 3.1 | 3.0 | 4.0 | 4.2 | 4.0 | 4.3 | 4.7 | 4.6 | 4.8 |
|  | Non-dominant | 18 | Mean | 60.6# | 63.0# | 63.4# | 73.8# | 74.0# | 82.8 | 84.2 | 83.1# | 87.0 |
|  |  |  | SEM | 2.2 | 3.3 | 3.1 | 4.6 | 3.8 | 4.7 | 4.2 | 3.9 | 4.5 |
| $210^{o}\cdot s^{-1}$ | Dominant | 18 | Mean | 66.4# | 67.3# | 70.7# | 71.6# | 78.3# | 80.1# | 85.9 | 86.3 | 87.6 |
|  |  |  | SEM | 3.8 | 2.5 | 4.1 | 3.2 | 3.5 | 3.5 | 3.8 | 3.8 | 4.3 |
|  | Non-dominant | 18 | Mean | 63.4# | 67.3# | 66.5# | 74.0# | 78.0# | 86.4 | 86.9 | 85.4 | 85.4 |
|  |  |  | SEM | 2.7 | 3.3 | 3.5 | 4.5 | 3.9 | 4.0 | 4.3 | 4.4 | 4.2 |
| $300^{o}\cdot s^{-1}$ | Dominant | 18 | Mean | 64.7# | 69.0# | 71.5# | 73.2# | 79.3# | 82.1# | 84.3 | 88.1 | 86.9 |
|  |  |  | SEM | 3.9 | 4.0 | 4.1 | 4.0 | 3.9 | 3.9 | 5.1 | 4.2 | 4.7 |
|  | Non-dominant | 18 | Mean | 65.5# | 68.9# | 71.9# | 75.3# | 81.0# | 86.0 | 91.0 | 90.9 | 88.4 |
|  |  |  | SEM | 2.9 | 3.3 | 3.4 | 4.6 | 3.5 | 3.8 | 4.7 | 4.4 | 4.0 |

Note. No significant difference between groups (Dominant versus Non-dominant) at any velocity after Bonferroni correction ($p>0.05$).
#: = significantly different from pre-exercise ($p<0.05$). Absolute values used for within group comparisons.
Imm Post: = Immediately following eccentric exercise.

Bout 1 versus Bout 2

Table 3 shows that there were also no significant differences between bouts 1 and 2 for any of the testing sessions at any of the concentric velocities following the exercise intervention. The nadir in isokinetic torque for both groups was also between ~33 – 40% below pre-exercise levels and, with one exception, was temporally similar to that reported for the dominant and non-dominant groups. At a concentric testing velocity of $90^{o} \cdot sec^{-1}$ bout 1 was the exception producing its nadir on day 1. Although both groups produced significant decrements in torque at all velocities for several days following eccentric exercise ($p<0.05$), by day 7 they no longer exhibited declines that differed significantly from pre-exercise levels.

### *4.3.6 Range of Motion (ROM)*

Dominant versus Non-dominant

There were no significant differences between the groups for changes in ROM at any time point following eccentric exercise (Figure 13a). Immediately following exercise dominant and non-dominant groups decreased ROM by $10.92^{o}$ and $10.38^{o}$ from pre-exercise values, respectively. The nadir in ROM was separated temporally between the groups with the greatest decrement occurring at day 1 for the non-dominant group and day 4 for the dominant. By day 7 the ROM of both groups was separated by less than $0.5^{o}$ and had recovered to within $3.5^{o}$ of pre-exercise levels. For several days of testing the SEM of the dominant group was more than twice that of the non-dominant (Figure 13a).

Table 3

*Changes in Normalised Isokinetic Torque at Five Different Velocities from Pre-exercise (100%) over 7 days Following Eccentric Exercise for Bout 1 and Bout 2 Conditions. Mean and Standard Error of the Mean (SEM) are Shown*

| | | | | Percentage of pre-exercise torque | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Time following eccentric exercise | | | | | | | | |
| Velocity | Arm | n | | Imm Post | 30 min Post | Day1 | Day2 | Day3 | Day4 | Day5 | Day6 | Day7 |
| $30^{o}\cdot s^{-1}$ | Bout 1 | 18 | Mean | 61.3# | 59.6# | 62.4# | 65.7# | 71.4# | 74.0# | 77.9# | 82.1# | 83.6 |
| | | | SEM | 3.3 | 2.2 | 2.9 | 3.4 | 3.1 | 4.2 | 4.3 | 3.6 | 4.5 |
| | Bout 2 | 18 | Mean | 64.3# | 66.5# | 69.3# | 74.5# | 78.8# | 82.5# | 87.8 | 91.1 | 93.0 |
| | | | SEM | 3.0 | 2.8 | 2.6 | 3.5 | 3.7 | 4.2 | 3.9 | 3.9 | 4.1 |
| $90\ ^{o}\cdot s^{-1}$ | Bout 1 | 18 | Mean | 64.2# | 61.2# | 60.8# | 65.4# | 73.3# | 75.1# | 77.1# | 80.2# | 83.4 |
| | | | SEM | 3.7 | 3.3 | 3.4 | 3.4 | 3.5 | 4.7 | 4.3 | 4.6 | 4.8 |
| | Bout 2 | 18 | Mean | 63.1# | 63.7# | 66.5# | 73.4# | 78.9# | 86.0 | 88.7 | 87.7 | 91.1 |
| | | | SEM | 2.8 | 3.1 | 3.2 | 4.2 | 4.2 | 4.2 | 4.5 | 3.7 | 4.4 |
| $150^{o}\cdot s^{-1}$ | Bout 1 | 18 | Mean | 59.2# | 62.9# | 63.2# | 68.0# | 72.9# | 76.3# | 80.2# | 81.3# | 85.0 |
| | | | SEM | 2.6 | 3.4 | 3.8 | 4.4 | 4.1 | 4.6 | 4.3 | 4.6 | 5.0 |
| | Bout 2 | 18 | Mean | 64.8# | 63.9# | 67.3# | 76.3# | 77.2# | 85.6 | 88.3 | 87.9 | 89.7 |
| | | | SEM | 2.6 | 2.9 | 3.4 | 4.1 | 3.7 | 4.2 | 4.4 | 3.9 | 4.2 |
| $210^{o}\cdot s^{-1}$ | Bout 1 | 18 | Mean | 64.3# | 67.6# | 68.5# | 70.3# | 76.1# | 80.8# | 85.4 | 84.6 | 85.3 |
| | | | SEM | 3.6 | 3.6 | 4.6 | 4.2 | 4.1 | 4.7 | 4.6 | 4.6 | 4.5 |
| | Bout 2 | 18 | Mean | 65.5# | 67.0# | 68.7# | 75.2# | 80.3# | 85.7# | 87.3 | 87.1 | 87.8 |
| | | | SEM | 3.0 | 2.1 | 3.0 | 3.5 | 3.2 | 2.6 | 3.4 | 3.4 | 4.0 |
| $300^{o}\cdot s^{-1}$ | Bout 1 | 18 | Mean | 63.0# | 66.4# | 68.5# | 71.2# | 77.1# | 80.8# | 82.5 | 89.5 | 85.9 |
| | | | SEM | 3.4 | 3.8 | 3.7 | 4.3 | 3.6 | 4.3 | 5.3 | 4.6 | 4.8 |
| | Bout 2 | 18 | Mean | 67.2# | 71.6# | 74.9# | 77.4# | 83.2# | 87.4 | 92.9 | 89.4 | 89.5 |
| | | | SEM | 3.3 | 3.4 | 3.7 | 4.3 | 3.7 | 3.2 | 4.2 | 4.1 | 3.8 |

Note. No significant difference between groups (Bout 1 versus Bout 2) at any velocity after Bonferroni correction ($p>0.05$).
#: = significantly different from pre-exercise ($p<0.05$). Absolute values used for within group comparisons.
Imm Post: = Immediately following eccentric exercise.

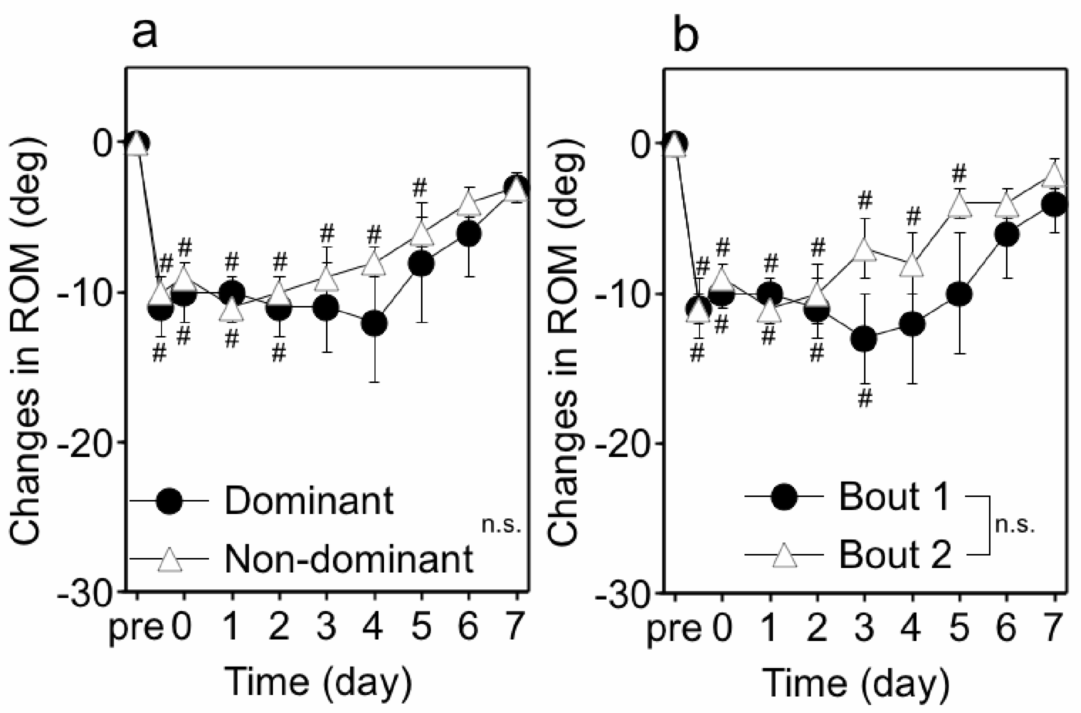

Figure 13. Comparison of changes in ROM immediately (0) and 1-7 days following exercise from the baseline (pre: 0) between dominant and non-dominant arm bouts (a) and first and second bouts (b). n.s.: not significantly different between bouts, #: significantly different from the 1st set.

Figure 14 (a & b) shows scatter plots and associated correlation coefficients for changes in ROM immediately following exercise, and 4 days later. Immediately following eccentric exercise there was a significant but low correlation between the dominant and non-dominant groups ($p<0.05$). When viewing the individual data points in relation to the line of equality, the variance between dominant and non-dominant arms for several subjects is appreciable. At day 4 the correlation coefficient was not significant and extremely low at 0.11 indicating a poor relationship between the groups. One subject’s data showed extreme variance between the dominant and non-dominant conditions, however, even when this data point was removed the correlation coefficient remained extremely low and non-significant.

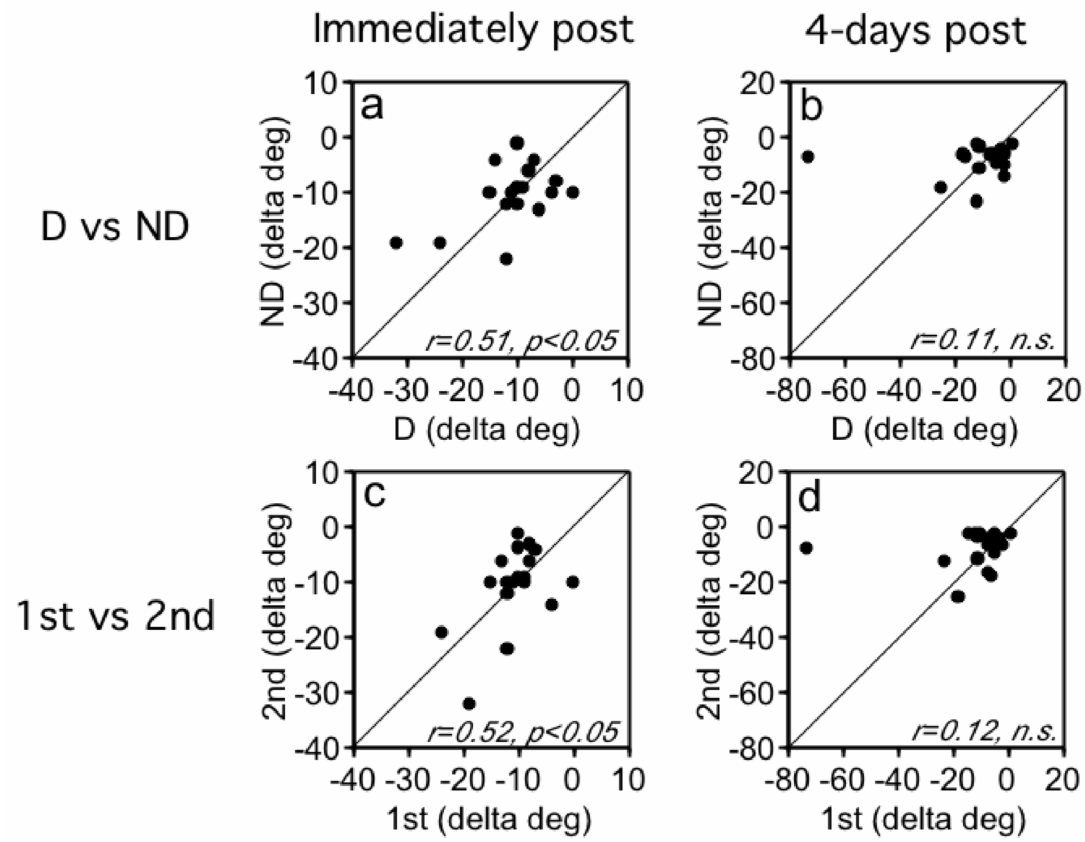

*Figure 14*. Changes in ROM from the pre-exercise value immediately post exercise and 4 days post-exercise of each subject for the dominant (D) and non-dominant (ND) bouts (a, b) and the first ($1^{st}$) and second ($2^{nd}$) bouts (c, d). Pearson correlation coefficient (r) and its significance level are shown in each graph (n.s.: not significant). The line indicates that the two bout values are identical.

### Bout 1 versus Bout 2

Figure 13b indicates that although the mean values for changes in ROM in bouts 1 and 2 were separated by approximately $5^{o}$ at days 3, 4, and 5 following exercise, in statistical terms there were no significant differences between the groups. The finding of no significant difference between bouts 1 and 2 extended to all other time points over the 7 days. The nadir in ROM occurred two days earlier and was over $1^{o}$ less following the second bout of eccentric exercise. On days 3, 4, 5, and 6 following the eccentric intervention the SEM of bout 1 was over double that recorded in bout 2.

The scatter plots and correlation coefficients for immediately following, and 4 days after, the eccentric exercise are shown in Figure 14 (c & d). The significant correlation coefficient of 0.52 immediately following exercise was low suggesting a poor relationship between the bouts. Inspection of the scatter plot reveals a number of data points sitting above the line of equality showing smaller decrements in ROM for these subjects following bout 2, however, there were also four points located well below the line indicating the opposite in these individuals.

Four days following eccentric exercise the correlation coefficient of 0.12 between the two bouts was very low and not significant (Figure 14d). Even with the obvious outlier removed the correlation coefficient remained low at 0.38. The scatter plot shows that the majority of the data points were located away from the line of equality indicating appreciable individual differences between the bouts for changes in ROM.

### *4.3.7 Upper Arm Circumference*

Dominant versus Non-dominant

Changes in circumference between the dominant and non-dominant groups were not significant for any of the testing sessions. This is illustrated clearly in Figure 15a. There were, however, significant changes in circumference within the groups over the eight days of testing. Both dominant and non-dominant groups recorded significant increases in circumference of approximately 4 mm from pre-exercise levels immediately following the eccentric intervention ($p<0.05$). Thirty minutes later the circumference in both groups had decreased such that they were no longer significantly larger than pre-exercise values. By day 1 following the eccentric intervention the circumference in both groups had increased again and were significantly elevated above pre-exercise levels ($p<0.05$). The change in circumference from pre-exercise levels continued to increase over the next few days peaking on days 4 and 5 for the dominant and non-dominant groups, respectively. By day 7 following eccentric exercise the upper arm circumference of both groups were still significantly larger than pre-exercise values ($p<0.05$).

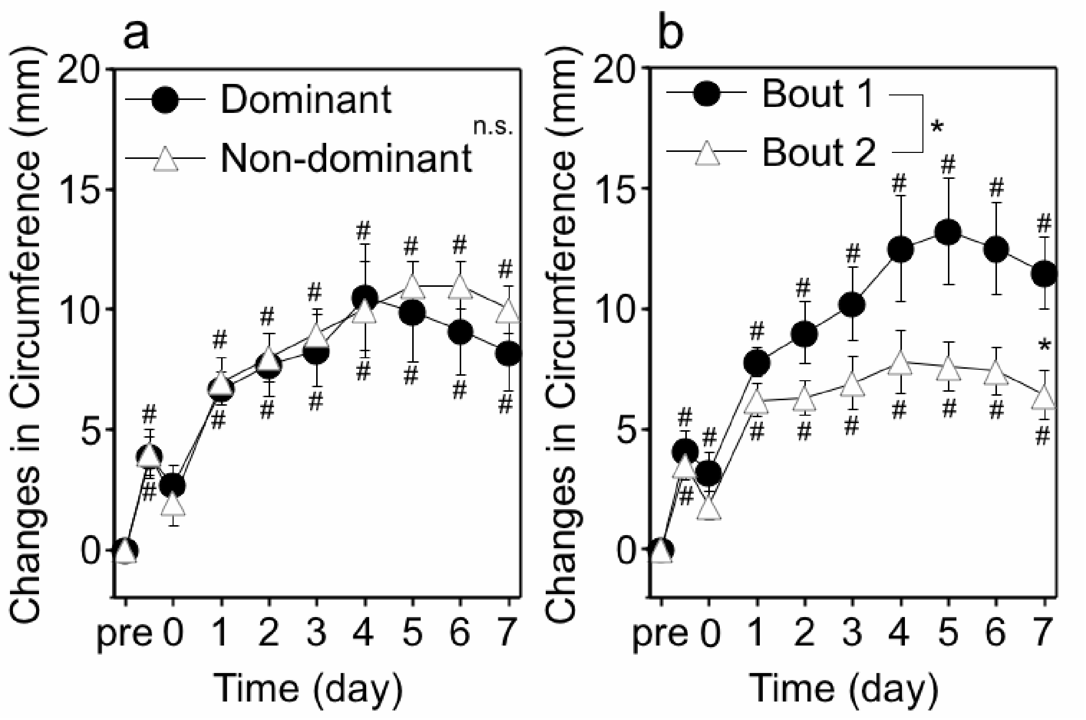

*Figure 15*. Comparison of changes in upper arm circumference immediately (0) and 1-7 days following exercise from baseline (pre: 0) between dominant and non-dominant arm bouts (a) and first and second bouts (b). n.s.: not significantly different between bouts, #: significantly different from the 1st set. *: a significant difference between bouts (over all: $p<0.05$, each time point: $p<0.006$).

The scatter plots of changes in circumference between dominant and non-dominant conditions show the sizeable spread of data points around the line of equality (Figure 16 a & b). The magnitude of this spread at 7 days following exercise is reflected in the extremely low correlation coefficient of -0.02. The correlation coefficient of 0.63 for immediately following eccentric exercise was significant ($p<0.01$), however, it was not strong due to many data points straying from the line of equality.

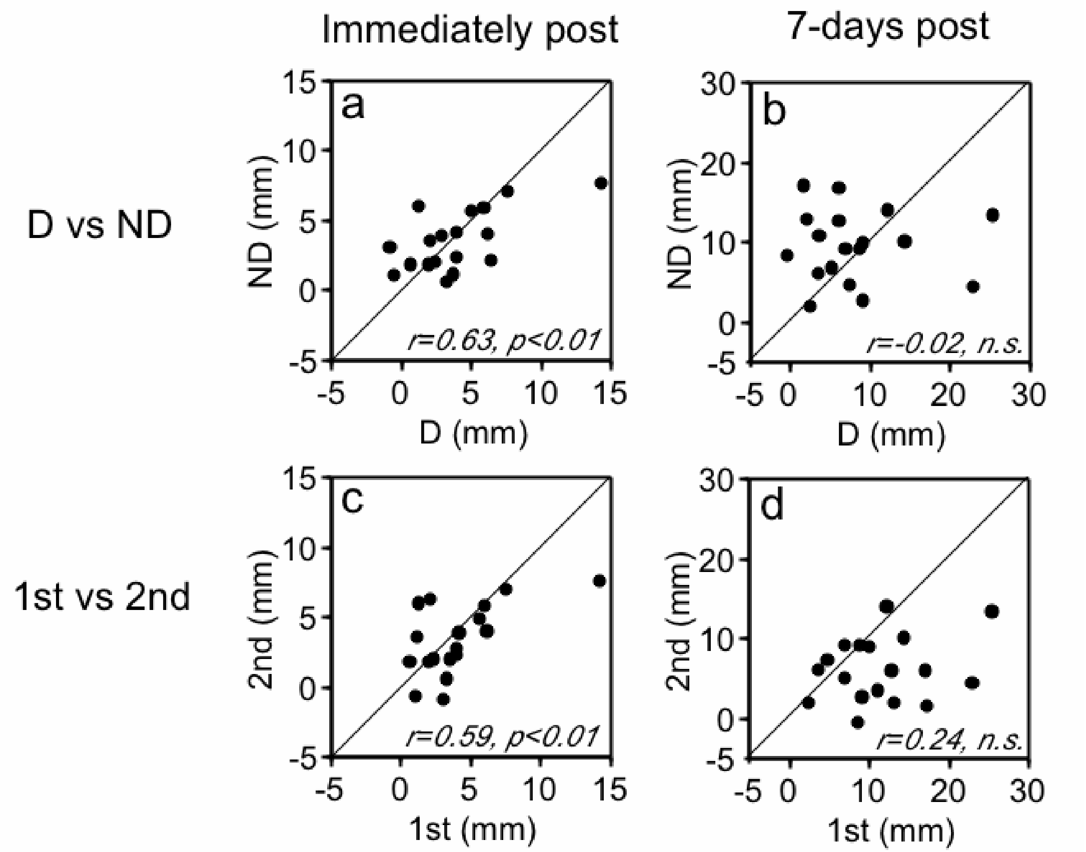

*Figure 16.* Changes in upper arm circumference from the pre-exercise value immediately post exercise and 7 days post-exercise of each subject for the dominant (D) and non-dominant (ND) bouts (a, b) and the first ($1^{st}$) and second ($2^{nd}$) bouts (c, d). Pearson correlation coefficient (r) and its significance level are shown in each graph (n.s.: not significant). The line indicates that the two bout values are identical.

### Bout 1 versus Bout 2

In contrast to the dominant and non-dominant data, there were significant differences between bouts 1 and 2 in terms of changes in upper arm circumference ($p<0.05$). There was a significant time by group interaction which is clearly illustrated in Figure 15b by the divergence of the groups over several days of testing ($p<0.05$). There were noticeably large standard error of the means on many of the testing days for bout 1 which were not seen at corresponding time points in bout 2. Both bouts recorded significant main effects for within group comparisons. This can be seen in Figure 15b where significant increases in circumference from pre-exercise levels are evident at all but one testing session ($p<0.05$). The greatest change in circumference for bouts 1 and 2 occurred one day apart at days 5 and 4, respectively.

The scatter plots of individual change in circumference responses to both bouts of eccentric exercise are shown in Figure 16c and d. As seen in the dominant and non-dominant results above, there was a significant but low correlation for bouts 1 and 2 immediately following exercise. At day 7, when circumference measures were much larger, the correlation between bouts 1 and 2 was extremely low and non-significant at 0.24.

Scatter plots at both time points show appreciable straying of data points from the line of equality. The day 7 data is most striking, revealing that the majority of subjects produced smaller changes in circumference following the second bout of eccentric exercise.

### *4.3.8 Plasma Creatine Kinase (CK) Activity*

#### Dominant versus Non-dominant

There were no significant differences between the dominant and non-dominant groups for plasma CK activity either before (pre) or at any time following exercise (Figure 17a). Both groups recorded CK values that were within the normal reference range for healthy adult males prior to performing the eccentric intervention. Figure 17a shows that following eccentric exercise CK activity in both groups increased progressively over the first several days, peaking at day 5 with values approximately 12 times greater than pre-exercise measures. The SEM of both groups was large over many of the testing days, however, it was markedly so for the dominant group which recorded values approximately 25% greater than the non-dominant.

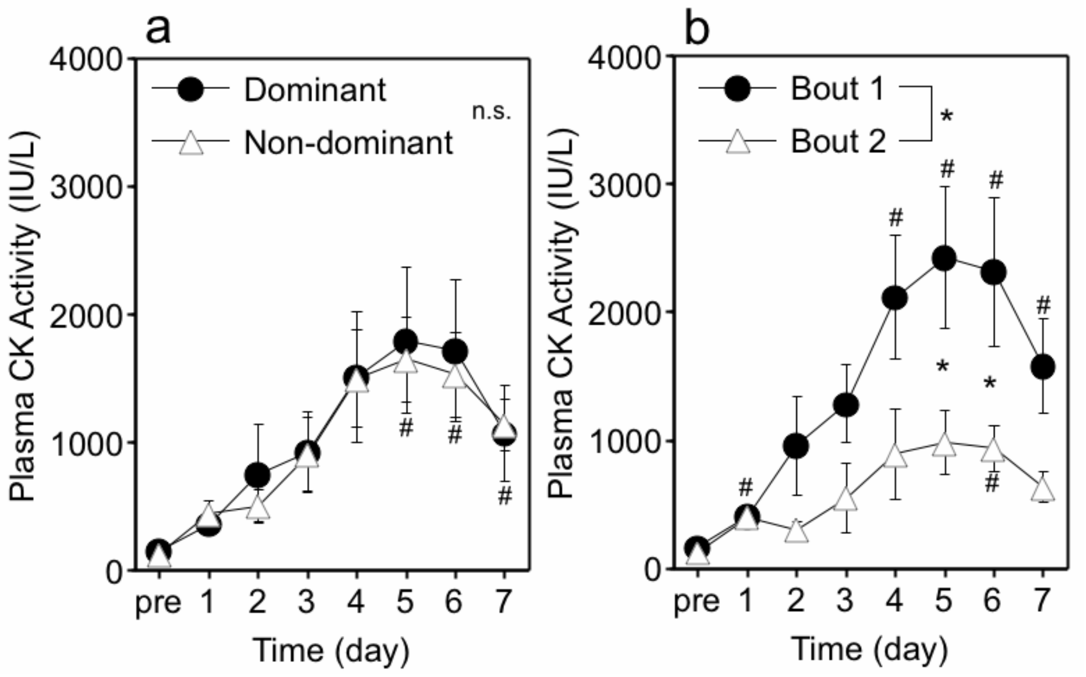

*Figure 17*. Comparison of changes in plasma CK activity before (pre) and 1-7 days following exercise between dominant and non-dominant arm bouts (a) and first and second bouts (b). n.s.: not significantly different between bouts, #: significantly different from pre-exercise value. *: a significant difference between bouts (over all: p<0.05, each time point: p<0.006).

The scatter plots of 1 day post and peak values show striking contrasts (Figure 18a & b). At day 1 following the eccentric intervention, when CK activity was only beginning to rise, the correlation between the groups was significant and relatively strong with many of the data points located fairly close to the line of equality (p<0.05). However, as shown in Figure 18b the correlation between the groups is very low and statistically non-significant at the time peak CK activity values were recorded. When viewing the peak CK values for each individual it is clear that dominant and non-dominant arms produced disparate responses that were relatively balanced on either side of the line of equality.

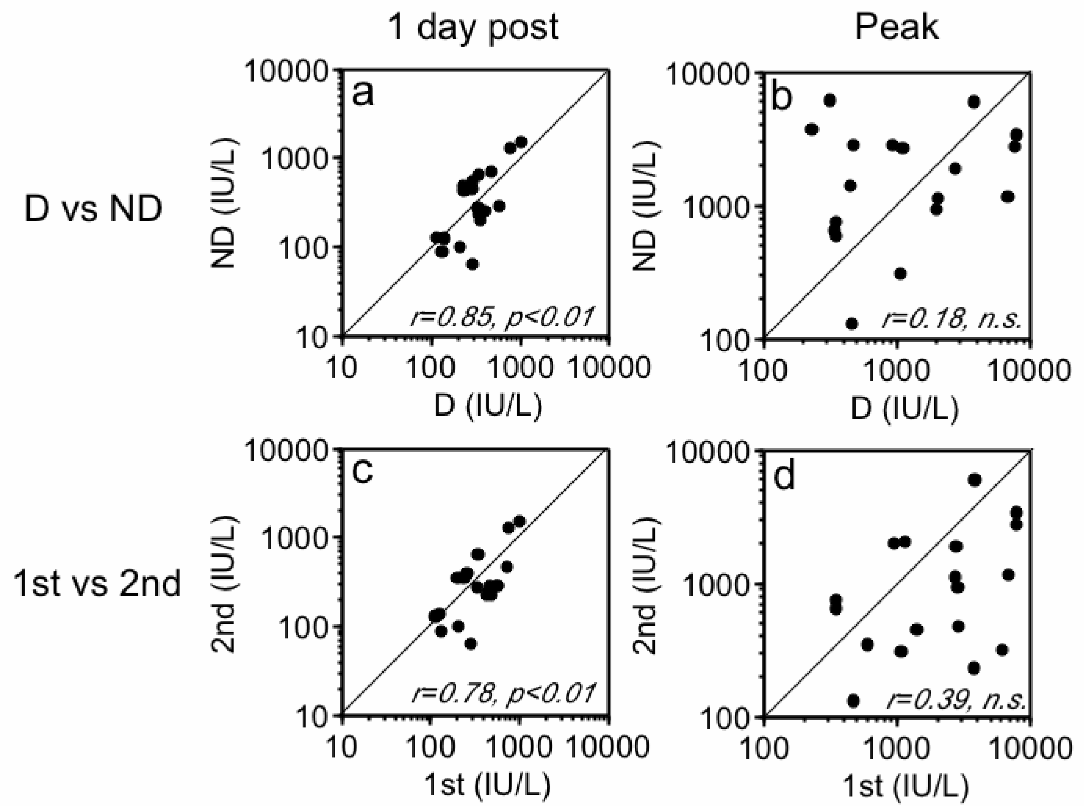

*Figure 18*. Plasma CK activity at 1 day post-exercise and its peak value of each subject for the dominant (D) and non-dominant (ND) bouts (a, b) and the first ($1^{st}$) and second ($2^{nd}$) bouts (c, d). Pearson correlation coefficient (r) and its significance level are shown in each graph (n.s.: not significant). The line indicates that the two bout values are identical.

### Bout 1 versus Bout 2

In contrast to the dominant and non-dominant groups, the patterns of CK response differed between bouts 1 and 2 following eccentric exercise (Figure 17b). This was reflected by a significant time by group interaction and a significant main effect for between group comparisons ($p<0.05$). Bout 2 produced lower CK activity than bout 1 at all time points following eccentric exercise, although only days 5 and 6 were statistically significant ($p<0.05$).

CK activity increased following both bouts of eccentric exercise with approximately 12 and 8 fold increases over pre-exercise levels in bouts 1 and 2, respectively. Large SEM values were also noticeable for both bouts on many of the days following the eccentric intervention (Figure 17b).

The scatter plot for 1 day following eccentric exercise shows a relatively linear pattern of data points with many located in close proximity to the line of equality (Figure 18c). This is supported statistically with a significant correlation coefficient of 0.78 indicating a moderate relationship between the bouts (Vincent, 1999).

The scatter plot of CK activity measured at its peak following the eccentric intervention (Figure 18d) shows many data points located in the lower section of the plot remote from the line of equality. This pattern reinforces that shown in Figure 17b and indicates that many subjects produced appreciably larger CK activity following the first bout of eccentric exercise.

### *4.3.9 Soreness*

Dominant versus Non-dominant

There were no significant differences between the groups for any soreness class for the duration of the study (Table 4). However, within groups differences were evident with both groups recording significant increases in soreness from pre-exercise levels for several days following the eccentric intervention ($p<0.05$). Peak soreness levels occurred in both groups for all of the soreness classes on day 2, however, the VAS scores varied between the classes with extension producing the highest mean values and flexion the least.

Table 4 shows that recovery of soreness for all classes in both groups was nearly complete by day 7 following the eccentric intervention with no value being significantly elevated above pre-exercise levels.

Scatterplots of peak soreness values for upper arm palpation and extension soreness show marked differences for dominant and non-dominant arms of the individual subjects (Figure 19a & b). There are numerous deviations from the line of equality in both scatterplots and the correlation coefficients are small.

Table 4

*Changes in Upper Arm, Forearm, Extension and Flexion Soreness over 7 Days Following Eccentric Exercise of the Forearm Flexors for Dominant and Non-dominant Conditions (Peak Soreness also Shown). Mean and Standard Error of the Mean (SEM) are Shown*

| | | | | Visual Analog Scale soreness (mm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Time following eccentric exercise and peak reading | | | | | | | |
| Soreness class | Arm | n | | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 | Peak |
| Upper Arm | Dominant | 18 | Mean | 27.8# | 33.8# | 28.6# | 17.6 | 9.6 | 5.2 | 2.3 | 39.2 |
| | | 18 | SEM | 4.9 | 4.7 | 5.0 | 4.9 | 3.8 | 3.0 | 1.4 | 5.1 |
| | Non-Dominant | 18 | Mean | 28.9# | 38.2# | 33.7# | 22.1# | 10.1 | 4.4 | 3.2 | 41.1 |
| | | 18 | SEM | 4.7 | 4.8 | 4.7 | 3.7 | 3.1 | 2.1 | 1.9 | 4.7 |
| Forearm | Dominant | 18 | Mean | 16.7# | 23.9# | 19.6# | 12.6 | 6.9 | 3.1 | 1.0 | 28.4 |
| | | 18 | SEM | 4.2 | 4.5 | 4.1 | 3.6 | 3.0 | 1.9 | 0.8 | 4.7 |
| | Non-Dominant | 18 | Mean | 18.2# | 21.1# | 19.8# | 11.7# | 7.2 | 2.6 | 1.3 | 29.7 |
| | | 18 | SEM | 3.9 | 3.8 | 3.8 | 3.0 | 2.6 | 1.2 | 0.7 | 4.0 |
| Extension | Dominant | 18 | Mean | 27.6# | 40.1# | 30.8# | 18.6 | 8.8 | 3.9 | 2.7 | 46.8 |
| | | 18 | SEM | 4.5 | 4.8 | 5.4 | 5.4 | 3.8 | 2.9 | 2.4 | 5.4 |
| | Non-Dominant | 18 | Mean | 28.1# | 39.1# | 28.2# | 18.5# | 12.0 | 6.3 | 2.4 | 42.8 |
| | | 18 | SEM | 5.4 | 4.9 | 5.2 | 4.4 | 4.7 | 3.4 | 1.5 | 5.3 |
| Flexion | Dominant | 18 | Mean | 11.6# | 16.5# | 13.1 | 9.0 | 2.9 | 0.9 | 0.7 | 22.1 |
| | | 18 | SEM | 2.5 | 3.7 | 4.2 | 4.7 | 2.4 | 0.8 | 0.6 | 5.3 |
| | Non-Dominant | 18 | Mean | 14.4# | 19.1# | 11.8# | 7.8# | 1.8 | 0.8 | 0.7 | 21.7 |
| | | 18 | SEM | 3.4 | 4.3 | 3.1 | 1.9 | 0.9 | 0.7 | 0.6 | 4.2 |

Note. No significant difference between groups (Dominant versus Non-dominant) for all soreness classes after Bonferroni correction ($p>0.05$).

#: = significantly different from pre-exercise ($p<0.05$). Pre-exercise soreness was zero for all soreness classes and conditions.

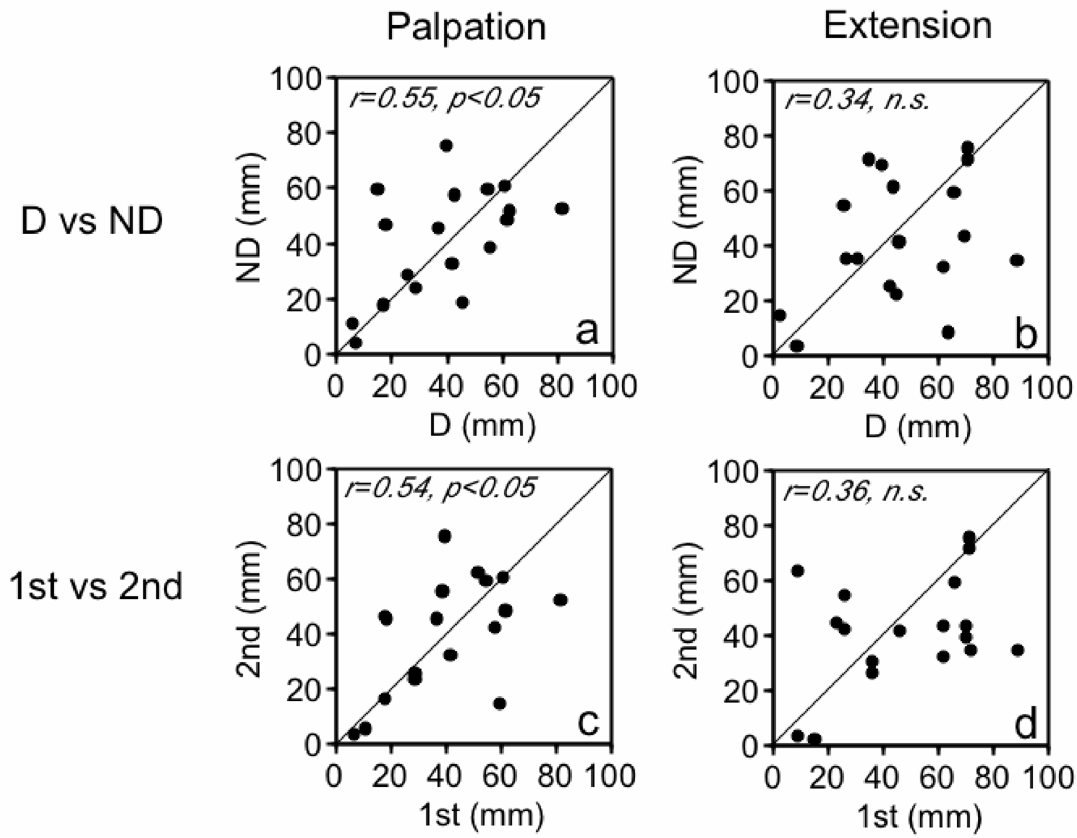

*Figure 19.* Peak muscle soreness upon palpation and extension of each subject for the dominant (D) and non-dominant (ND) bouts (a, b) and the first ($1^{st}$) and second ($2^{nd}$) bouts (c, d). Pearson correlation coefficient (r) and its significance level are shown in each graph (n.s.: not significant). The line indicates that the two bout values are identical.

### Bout 1 versus Bout 2

Bouts 1 and 2 showed a similar pattern of soreness responses to that of the dominant and non-dominant groups. Table 5 shows that throughout the study there were no significant differences evident between the groups for any soreness class. However, bouts 1 and 2 also produced within group differences with all soreness classes recording significant increases from pre-exercise levels ($p<0.05$). In parallel with the dominant and non-dominant data, peak soreness for all classes was recorded at day 2 in both groups and the extension and flexion classes produced the highest and lowest VAS scores, respectively (Table 5).

In similar fashion to the dominant and non-dominant groups, by the final day of the study recovery of soreness in both groups was nearly complete for all classes with no value being significantly different from pre-exercise measures.

Scatterplots for upper arm palpation and extension soreness show that few data points were located on the line of equality revealing that there were marked differences between the bouts for individual subjects (Figure 19c & d). Correlation coefficients for both upper arm palpation and extension soreness were small indicating low relationships between bouts for these measures.

Table 5

*Changes in Upper Arm, Forearm, Extension and Flexion Soreness over 7 Days Following Eccentric Exercise of the Forearm Flexors for Bout 1 and Bout 2 Conditions (Peak Soreness also Shown). Mean and Standard Error of the Mean (SEM) are Shown*

| | | | | Visual Analog Scale soreness (mm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Time following eccentric exercise and peak reading | | | | | | | |
| Soreness class | Arm | n | | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 | Peak |
| Upper Arm | Bout 1 | 18 | Mean | 23.3# | 36.2# | 33.2# | 21.4# | 11.9 | 5.7 | 2.8 | 39.9 |
| | | 18 | SEM | 4.2 | 4.7 | 5.0 | 4.9 | 3.9 | 3.0 | 1.6 | 4.9 |
| | Bout 2 | 18 | Mean | 33.4# | 35.8# | 29.2# | 18.3# | 7.7 | 3.9 | 2.7 | 40.3 |
| | | 18 | SEM | 5.0 | 4.8 | 4.8 | 3.7 | 2.9 | 2.1 | 1.7 | 4.9 |
| Forearm | Bout 1 | 18 | Mean | 16.1# | 23.4# | 21.1# | 16.9# | 10.3 | 4.5 | 1.7 | 31.4 |
| | | 18 | SEM | 4.1 | 4.6 | 3.7 | 4.2 | 3.7 | 2.1 | 0.9 | 4.6 |
| | Bout 2 | 18 | Mean | 18.8# | 21.6# | 18.4# | 7.4# | 3.7# | 1.2 | 0.7 | 26.7 |
| | | 18 | SEM | 4.0 | 3.7 | 4.2 | 1.5 | 1.0 | 0.6 | 0.5 | 3.9 |
| Extension | Bout 1 | 18 | Mean | 23.2# | 42.2# | 35.9# | 20.9 | 15.4 | 7.7 | 3.7 | 47.7 |
| | | 18 | SEM | 4.1 | 5.3 | 5.9 | 5.8 | 5.4 | 3.9 | 2.5 | 6.0 |
| | Bout 2 | 18 | Mean | 32.4# | 36.9# | 23.1# | 16.2# | 5.4 | 2.4 | 1.4 | 41.8 |
| | | 18 | SEM | 5.5 | 4.3 | 4.2 | 3.8 | 2.0 | 1.9 | 1.2 | 4.6 |
| Flexion | Bout 1 | 18 | Mean | 12.3# | 20.7# | 15.7# | 11.8 | 3.4 | 1.1 | 0.8 | 25.6 |
| | | 18 | SEM | 2.4 | 4.4 | 4.2 | 4.7 | 2.4 | 0.8 | 0.6 | 5.6 |
| | Bout 2 | 18 | Mean | 13.7# | 14.9# | 9.2 | 5.0 | 1.3 | 0.7 | 0.6 | 18.2 |
| | | 18 | SEM | 3.5 | 3.4 | 2.9 | 1.6 | 0.9 | 0.7 | 0.6 | 3.5 |

Note. No significant difference between groups (Bout 1 versus Bout 2) for all soreness classes after Bonferroni correction ($p>0.05$).

#: = significantly different from pre-exercise ($p<0.05$). Pre-exercise soreness was zero for all soreness classes and conditions.

## 4.4 Discussion

The primary focus of the present study was to determine whether changes in markers of muscle damage and soreness (criterion measures) differed between arms when exposed to identical maximal eccentric exercise of the elbow flexors. The findings of the present investigation revealed that for some of the criterion measures there were significant differences between contralateral arms of the first and second eccentric exercise bouts, suggesting that order of exercise plays an important role. This was despite no significant difference in any of the pre-exercise values of the criterion measures and similar performance in terms of work during both eccentric exercise bouts (Figures 9b). When dominant and non-dominant arms were compared, however, there were no significant differences evident in any of the criterion measures.

Considering the results of the current study, it would seem prudent to counterbalance the exercise bouts by arm dominance and then analyse the results using groups based on dominance. The suggestion presented above stems from the results of the present study showing similarities with those that have investigated the repeated bout effect using an ipsilateral limb model (Clarkson et al., 1992; Clarkson & Tremblay, 1988; Nosaka, Newton, & Sacco, 2005). In the present work, where there were significant differences between arms (Figures 10b**,** 15b, and 17b), the group of arms that was exercised second produced smaller changes in criterion measures. This was despite the torque changes and work showing almost no variance between bouts during the eccentric intervention (Figures 8b and 9b), suggesting that the exercise stress to the elbow flexors of contralateral arms was similar. In research that has focused on repeated exercise of an ipsilateral limb, lower levels of disruption have been reported following a second bout of eccentric exercise (Clarkson et al., 1987; Clarkson & Tremblay, 1988; Nosaka et al., 1991; Nosaka & Sakamoto, 2001). These reductions in the markers of muscle damage and soreness (criterion measures) are referred to in the literature as a “protective” or “repeated bout” effect.

The protective effect conferred by the initial eccentric exercise bout in ipsilateral limb studies is appreciably greater in magnitude than that of the present contralateral arm study. Although the protective effect conferred to the second bout in the present study was minor, it was significant enough to warrant further consideration.

A possible explanation for how a repeated bout type effect could be evident in some of the criterion measures of the present study may lie in the phenomenon of cross education. Research on cross education presents convincing evidence that the exercise training of one limb can induce improvements in the untrained contralateral limb (Cannon & Cafarelli, 1987; Farthing & Chilibeck, 2003; Hortobagyi, J. et al., 1997; Hortobagyi, Lambert, & Hill, 1997; Housh, Housh, Johnson, & Chu, 1992; Shima et al., 2002). The contralateral transfer of strength is believed by some to be solely of neural origin (central adaptation) and not related to local adaptations such as increases in cross sectional area or modifications to intrinsic fibre characteristics of the contralateral muscle (Hortobagyi, Lambert et al., 1997; Zhou, 2000), although two previous studies have shown a small amount of hypertrophy of the untrained limb as a whole (Housh et al., 1992) or type II fibres within the limb (Brown, McCartney, & Sale, 1990). In a review of several studies examining cross transfer of strength, Zhou (2000) notes that the contralateral limb achieved approximately 60 percent of the ipsilateral strength gain. This translated to strength increases in the contralateral arm of between 3 and 77 percent depending upon the nature of the training and the mode of testing employed (Zhou, 2000). Hortobagyi et al. (1997) showed that compared with concentric exercise significantly greater eccentric and isometric strength cross education occurred if the training included eccentric contractions.

In contrast to the present study where the eccentric exercise consisted of a single bout, the duration of training in the aforementioned studies ranged from six to twelve weeks. The effect that a single bout of maximal eccentric exercise would have on cross education remains to be elucidated. Cross education was not evaluated in the present study, however, if it were to occur whether it would have been of a large enough magnitude to confer a protective effect is unclear. This could be put forward as a possible explanation for why a protective, or repeated bout effect, was not conferred to the criterion measures of concentric isokinetic torque, isometric torque at $150^{o}$, range of motion at the elbow joint, and soreness. It may be that certain criterion measures require greater cross education than others in order to be afforded a degree of protection from muscle damage and soreness. Future studies addressing this topic may be wise to assess the criterion measures of the limb to be exercised second prior to the eccentric intervention of the first limb, and then again in the usual manner immediately prior to its own eccentric intervention. This would inform the investigators whether the eccentric exercise on the first limb had exerted any effect on the contralateral limb prior to its own intervention. In hindsight this would have been an improvement in the current study design.

It is important to note that evidence of damage and soreness was manifest in all of the criterion measures following both bouts of eccentric exercise. Therefore, protection that appears to have been afforded to the criterion measures of isometric torque at $90^o$, circumference, and CK activity following the second bout was significant but not complete (Figures 10b, 15b & 17b). In terms of isometric torque this is a similarity shared by many studies that have investigated the repeated bout effect using an ipsilateral limb model. Following a second bout of eccentric exercise on the same limb, strength loss immediately after exercise is usually similar or slightly lower than what was reported following the initial bout, but the rate of recovery is often appreciably faster after the subsequent bout (Clarkson & Tremblay, 1988; McHugh & Tetro, 2003; Newham et al., 1987). In terms of CK activity a different response is usually evident following a repeated bout. In many cases it is not significantly elevated following a subsequent bout of eccentric exercise of the ipsilateral limb suggesting a complete protection for this criterion measure (Clarkson et al., 1992; Clarkson & Tremblay, 1988; Newham et al., 1987; Nosaka et al., 1991). Using an ipsilateral design Clarkson and Tremblay (1988) showed that even when the first maximal eccentric bout was approximately one third the volume of the second, full protection was conferred to the subsequent bout in terms of CK response. Why full CK protection was not conferred to the second bout involving the contralateral arm is unclear but it may be due to lack of sufficient neural and peripheral crossover.

In contrast to the present study, Clarkson et al. (1987) and Connolly et al. (2002) reported no protective or repeated bout type effect using a contralateral limb model. The Clarkson et al. (1987) investigation used subjects of the same gender as those employed in the present study, however, three quarters of the subjects used by Connolly et al. (2002) were female. Connolly et al. (2002) considered it appropriate that males and females were recruited due to there being no conclusive evidence suggesting that there is a gender effect. In the Connolly et al. (2002) study pain was significantly lower following the second bout of exercise, however, the authors attributed this to a tolerance effect rather than a protective adaptation. In both the present study and that of Clarkson et al. (1987), soreness was no different between contralateral limbs suggesting the absence of a tolerance effect.

Both Clarkson et al. (1987) and Connolly et al. (2002) studies employed designs that eccentrically exercised the leg musculature at lower intensities than the arm model of the present study and therefore care should be employed when making comparisons. Arm musculature was chosen for the present study due to the claim of Thompson et al. (2004) that arms are used less in modern society than are legs. Thompson et al. (2004) suggest that use of the arm musculature reduces some of the baseline strength differences that would be evident in the legs due to daily activities such as walking and climbing stairs. Whether the differences between these and the present study were due to the choice of limb model and / or the intensity of eccentric exercise remains to be elucidated. Future studies could attempt to address this problem by employing one group of subjects that exercised contralateral arms and legs using the same relative intensity of eccentric exercise for each limb. One potential drawback of such a study would be the time requirement of each participant due to the need to allow complete recovery between each limb.

In the present study, when the elbow flexors were separated into groups based upon arm dominance and the criterion measures were analysed using this criteria, there were no significant differences evident between the groups for any of the testing sessions. This was also reflected in the dominant and non-dominant torque and work measures recorded during the eccentric interventions with no significant differences evident between the groups. Due to the design of the present study, arm dominance was counterbalanced between the first and second bouts in order to avoid any possible bias due to the dominant arm when assessing the effect of exercise order. However, as there were significant interactions between exercise bouts for some of the criterion measures it raises the possibility of a bias being introduced to the dominant versus non-dominant comparison caused by conferred protection to some of the dominant and non-dominant elbow flexors. In order to control for this possibility it would be necessary to include a protracted period between bouts to eliminate any protective effect. Nosaka et al.

(2001a) demonstrated that the repeated bout effect lasts at least six months for most criterion measures with some still exhibiting a protective effect at nine months. By twelve months following the initial bout of maximal eccentric exercise no protection was evident for any of the examined criterion measures. Unfortunately a study model that delays a subsequent bout by at least nine months is not a desirable option for most investigations and would probably be deemed unusable.

The dominant versus non-dominant results, though, support the findings of Clarkson et al. (1987) and Connolly et al. (2002) who reported no evidence of protection due to a contralateral crossover effect. The results of the present investigation appear to suggest that an intra-subject contralateral arm model is a viable alternative to the inter-subject design if the order of exercise is counterbalanced by arm dominance. It is unclear though whether Clarkson et al. (1987) and Connolly et al. (2002) employed a counterbalanced design based upon leg dominance. Connolly et al. (2002) made no mention of the specific assignment of legs to exercise bouts and Clarkson et al. (1987) noted that right and left legs were balanced over subjects and across days but made no reference to dominance.

There are two primary benefits proposed for employing a contralateral limb model when assessing muscle damage and soreness. The first suggests that there is an optimal matching of limbs due to both being associated with the same subject, and the second is linked to the reduced number of subjects required to complete a study. By using both limbs of each subject it essentially means that half as many participants need to be recruited to maintain the same statistical power. Whether this model is any better than an inter-subject design is questionable based on the individual scatterplots of the criterion measures. With the exception of CK activity one day following the eccentric interventions (Figure 18 a & c) all of the other criterion measures for both conditions (exercise order and dominance) produced correlations that Vincent (1999) considers to be low. It is not surprising that the correlations between arms were high for CK activity one day following the interventions as this measure does not usually peak until approximately day 5 (Figure 17 a & b). At 24 hours following the exercise intervention CK activity would remain close to baseline for most subjects. However, by the time CK activity peaked the correlations were extremely low and non-significant.

In the present study it is contended that of higher importance than the correlation coefficients is the variation of points from the line of identity. As opposed to high proximity to the line of identity, large correlation coefficients approaching 1.0 do not necessarily indicate that the criterion measures of the contralateral arms were similar. Perusal of most of the scatterplots in the results section reveals that despite identical eccentric interventions the contralateral arms deviated appreciably from each other at times when damage and soreness were high, even when the arms were grouped according to dominance. Thus, even though criterion measures of the dominant and non-dominant groups were not significantly different, responses of the contralateral arms of individuals often varied. This may well be due to a protective effect conferred to the contralateral arm by the previously exercised arm. This suggests that any small but ‘real’ differences due to an intervention may not be detected by the model. However, the same criticism can apply to the inter-subject model where the variances between matched individuals may be no smaller than any supposed crossover protection in the contralateral design.

It is unknown how resistance trained individuals would respond to an intra-subject contralateral limb model similar in nature to the present study. In chapter 5 it is shown that following identical maximal eccentric exercise to that used in the present study, resistance trained individuals produced changes in criterion measures which contrasted those found in untrained subjects. In future work it would be interesting to replicate the present study in a group that had substantial resistance training experience.

In conclusion, findings from the present investigation reveal that comparison of contralateral elbow flexors following maximal eccentric exercise results in significant differences of some criterion measures when analysis focuses on the effect of exercise order. However, when dominant and non-dominant elbow flexors were compared, resulting in exercise order being counterbalanced, no significant differences were evident for any of the criterion measures. Such findings have implications for the design of eccentric exercise studies when the goal is to use one of the contralateral limbs as a control. In such situations it would seem sagacious to counterbalance the exercise bouts by arm dominance and then analyse the results using groups based on dominance.

# CHAPTER 5

## 5.1 Introduction

Resistance training provides a unique stimulus to the neuromuscular system culminating in alterations to neural (Aagaard, 2003; Gabriel et al., 2006), muscular (Higbie, Cureton, Warren, & Prior, 1996; Jones et al., 1989; Staron et al., 1994) and connective tissue (Stone, 1988). Depending upon the structure of the training regimen adaptations such as increased muscular strength, power, and hypertrophy may be attained. Resistance training typically incorporates a mixture of concentric, eccentric and isometric actions. Individuals employing this form of training to increase maximum strength spend significant time exercising at high intensity with resistances in the vicinity of their concentric one repetition maximum (e.g., 1 to 6 RM) (Kraemer, Duncan, & Volek, 1998). Although these resistances usually correspond to 80% or greater of the weight that could be lifted only once through the concentric phase of the movement (1 RM), they may represent appreciably less of an individual’s eccentric maximum. This suggests that during traditional resistance training the majority of the eccentric work may be performed at a sub-maximal level.

Following chronic high intensity resistance training, individuals usually exhibit striking contrasts to their previously untrained state in terms of muscle function. They are generally capable of lifting greater weights in the specific movements used in training and are able to generate appreciably higher rates of force development and power outputs (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002; Deschenes & Kraemer, 2002). How chronically resistance trained individuals respond to maximal voluntary eccentric exercise is not well described. This is noted in a recent review by Falvo and Bloomer (2006) where they report that there is a dearth of research that has investigated the response of “trained” individuals to exercise-induced muscle damage. The majority of research examining exercise-induced muscle damage has employed either untrained individuals or those who have not been involved in chronic resistance training. The small number of studies that have explored the response of trained individuals to eccentric exercise did not examine how the criterion measures changed following a bout of maximal eccentric exercise (Bourgeois et al., 1999; Dolezal et al., 2000; Gibala et al., 2000; Semark et al., 1999; Vincent & Vincent, 1997).

Five studies have had previously untrained subjects exercise for periods of time ranging from one session to nine weeks using only concentric actions, following which they were exercised eccentrically and changes in various criterion measures were recorded (Gleeson et al., 2003; Nosaka & Clarkson, 1997; Nosaka & Newton, 2002a; Ploutz-Snyder, Tesch, & Dudley, 1998; Whitehead, Allen, Morgan, & Proske, 1998). Three of the studies (Gleeson et al., 2003; Ploutz-Snyder et al., 1998; Whitehead et al., 1998) reported that prior concentric training caused greater changes in some of the criterion measures suggesting an increased vulnerability to eccentric exercise-induced dysfunction and muscle injury. Ploutz-Snyder et al. (1998) suggested that the increased susceptibility may have been the result of training-induced elevation of the concentric 1 RM allowing the subjects to handle greater eccentric loading. In contrast, Nosaka & Newton (2002a) found that prior concentric training did not exacerbate eccentric exercise-induced muscle damage and Nosaka & Clarkson (1997) showed that muscle dysfunction was actually attenuated if eccentric exercise was preceded immediately by a bout of concentric contractions. Differences in the exercise protocols between the studies, and training status of the individuals, make it difficult to predict how chronically resistance trained subjects would respond to the same eccentric interventions.

It is also well established that previously untrained individuals who are exposed to a single bout of either maximal or sub-maximal eccentric exercise exhibit less muscle dysfunction and injury when exposed to a subsequent bout of maximal eccentric exercise 1 to 10 weeks after the initial bout (Brown, Child, Day, & Donnelly, 1997; Newham et al., 1987; Nosaka et al., 2001b). This prophylactic effect of an initial bout of eccentric exercise on a subsequent bout is a phenomenon referred to as the “repeated bout effect”. If the initial bout of eccentric exercise is considered a resistance training session, then based upon the available research literature it could be argued that resistance training incorporating entirely eccentric contractions confers protection against the effects of subsequent maximal voluntary eccentric exercise.

In contrast to the period between exercise bouts in the above mentioned studies, typical resistance training regimens incorporate a second bout of eccentric and concentric contractions for the same muscle group, usually within 72 hours. The effect of repeated eccentric exercise within short periods on muscle dysfunction and injury has been investigated by several groups who had previously untrained subjects perform identical bouts of eccentric exercise separated by a period of 72 hours or less (Chen & Hsieh, 2000; Paddon-Jones, Muthalib, & Jenkins, 2000; Smith, Fulmer et al., 1994). The primary findings of these studies were that the time course of recovery of criterion measures were not altered and damage was not exacerbated following the subsequent bout(s), even though they were undertaken prior to complete recovery from the initial bout.

Chen and Hsieh (2001) and Nosaka and Newton (2002a) had previously untrained subjects exercise repeatedly for 7 days and 8 weeks, respectively, using the same bouts of eccentric training. Chen and Hsieh (2001) trained their subjects daily for 7 days whilst Nosaka and Newton (2002a) had their group exercise weekly for 8 weeks. Both studies found that muscle damage was not exacerbated following a bout of maximal eccentric exercise undertaken at the end of the training programs.

Whether experienced resistance trained individuals respond similarly, following maximal voluntary eccentric exercise, to the repeated bout response of untrained subjects is unclear. Furthermore, whether individuals with a significant resistance training history, including high intensity concentric contractions and non-maximal eccentric actions, respond differently to untrained subjects in terms of changes in criterion measures following maximal voluntary eccentric exercise remains to be elucidated. Therefore, the purpose of the present study was to determine whether changes in markers of exercise-induced muscle damage and soreness differed between untrained and resistance-trained (trained) males following maximal voluntary eccentric exercise of the elbow flexors.

## 5.2 Methods

### *5.2.1 Experimental Design*

The study utilised two groups of subjects who performed the eccentric exercise intervention using one arm. A 2x8 factorial design was used to investigate the effect of manipulation of the independent variable on dependent variables. The independent variable was training status (resistance-trained or untrained), and the dependent variables were the criterion measures described in chapter 3 (section 3.6). The main experimental period consisted of a block of 6 consecutive days of measurement preceded by two familiarization sessions. The time course of the testing sessions is described in section 5.2.4 below.

A counterbalanced design was employed for assigning which arm would be used for the eccentric exercise intervention resulting in both groups having the same number (50%) of dominant and non-dominant arms exercised.

### *5.2.2 Subjects*

Thirty male subjects, 15 resistance trained and 15 untrained, volunteered to take part in the study. The mean ± SEM age, height, and weight of the 15 resistance trained subjects were 28.2 ± 1.9, 175.0 ± 1.6, and 77.6 ± 1.9, respectively. The corresponding data for the untrained subjects were 30.0 ± 1.5, 169.8 ± 7.4, and 79.9 ± 4.4, respectively. All subjects completed informed consent forms and a medical questionnaire and were free of any disease or injuries that would contraindicate their inclusion in the study. The inclusion criteria for the trained subjects required a minimum of one year of resistance training with a frequency of at least three sessions per week including exercises involving the elbow flexor musculature. None of the trained subjects performed any pure negative (maximal voluntary eccentric) exercise as part of their resistance training program. The mean ± SEM years of resistance training of the trained group was 7.7 ± 1.4 years. The untrained subjects were not currently undertaking any form of vigorous exercise and had not performed any resistance training for at least one year.

### *5.2.3 Eccentric Exercise Bout*

The exercise intervention consisted of 10 sets of 6 maximal voluntary eccentric actions of the elbow flexors against the lever arm of the isokinetic dynamometer (Cybex 6000, Ronkonkoma, NY, USA.) moving at constant velocity of $90°\cdot s^{-1}$. A detailed explanation of the protocol was described in chapter 3 (section 3.5).

### *5.2.4 Timetable of Criterion Measures*

All of the criterion measures were recorded during the two familiarisation sessions which were completed in the week preceding the eccentric exercise intervention. Table 6 shows the other testing sessions during which the criterion measures were evaluated. During each testing session the order in which the criterion measures were taken remained consistent commencing with CK followed by muscle soreness, ROM, upper arm circumference, and concluding with MVC torques (isometric preceding isokinetic). The criterion measures that were collected in this study employed the techniques described in chapter 3 (section 3.6).

Table 6

*Timetable of Criterion Measure Testing Prior to and Following the Eccentric Exercise Intervention*

| Criterion measure | Testing session in relation to the eccentric exercise intervention | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Pre | Post | | Day following eccentric exercise | | | | |
| | Pre-ex | Imm | 30 min | 1 | 2 | 3 | 4 | 5 |
| MVC torque | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ROM | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Circumference | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| CK activity | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| Soreness | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ |

Note. A tick "✓" indicates that testing has taken place at this time point. "Circumference" refers to upper arm circumference. "Pre-ex" and "Imm" refer to immediately preceding and immediately following the eccentric exercise intervention, respectively.

A full description of the methods used to analyse the data of the present study is outlined in chapter 3 (section 3.8).

## 5.3 Results

### *5.3.1 Subject Characteristics and Pre-exercise Criterion Measures*

No significant differences between the groups were evident for age, height, weight, or any of the pre-exercise criterion measures (Table 7).

Table 7

*Pre-exercise values (mean ± SEM) of maximum isometric torque at 90° (ISO-90) and 150° (ISO-150), isokinetic torque at 30°·s$^{-1}$ (IK-30), 90°·s$^{-1}$ (IK-90), 150°·s$^{-1}$ (IK-150), 210°·s$^{-1}$ (IK-210) and 300°·s$^{-1}$ (IK-300), ROM, upper arm circumference (CIR: mean of the five sites), and plasma CK activity for the trained (T) and untrained (UT) groups*

| Group | ISO90 (Nm) | ISO150 (Nm) | IK30 (Nm) | IK90 (Nm) | IK150 (Nm) | IK210 (Nm) | IK300 (Nm) | ROM (°) | CIR (mm) | CK (IU·L$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| T | 72.8<br>±4.2 | 52.9<br>±2.7 | 50.4<br>±2.8 | 49.6<br>±2.6 | 44.6<br>±2.5 | 40.0<br>±2.5 | 35.1<br>±2.2 | 128.3<br>±1.8 | 299.5<br>±6.4 | 370<br>±73 |
| UT | 68.4<br>±3.2 | 47.3<br>±3.4 | 48.6<br>±3.2 | 42.6<br>±2.7 | 38.1<br>±2.5 | 35.1<br>±2.4 | 31.6<br>±2.5 | 132.1<br>±2.1 | 283.1<br>±5.8 | 144<br>±16 |

### *5.3.2 Peak Torque During Eccentric Exercise*

Peak eccentric torque progressively declined for both groups over the ten sets of eccentric exercise. When evaluated in terms of mean torque per set, Figure 20 shows that for both groups the last seven sets produced significantly lower torque than set one ($p<0.05$). Over the course of the ten sets of eccentric exercise the mean torque per set for the untrained and trained groups decreased approximately 33% and 22%, respectively. Despite the apparent contrast, there was no significant difference between the groups in terms of mean torque over the ten sets.

When the torque of the first and last of the 60 eccentric contractions were expressed as a ratio of the pre-exercise isometric torque, it is noteworthy that the resulting ratios were less than unity (Figure 20 inset). Even when the peak eccentric torque for each group was considered, regardless of where it occurred during the 60 contractions, the ratio to pre-exercise isometric torque was exactly one (unity). Therefore, neither group was able to generate eccentric torque with the elbow flexors that was greater than that produced isometrically. Independent t-tests revealed that the untrained group produced a significantly greater decline in eccentric torque than the trained group over the sixty contractions when expressed as a ratio of pre-exercise isometric torque (Figure 20 inset).

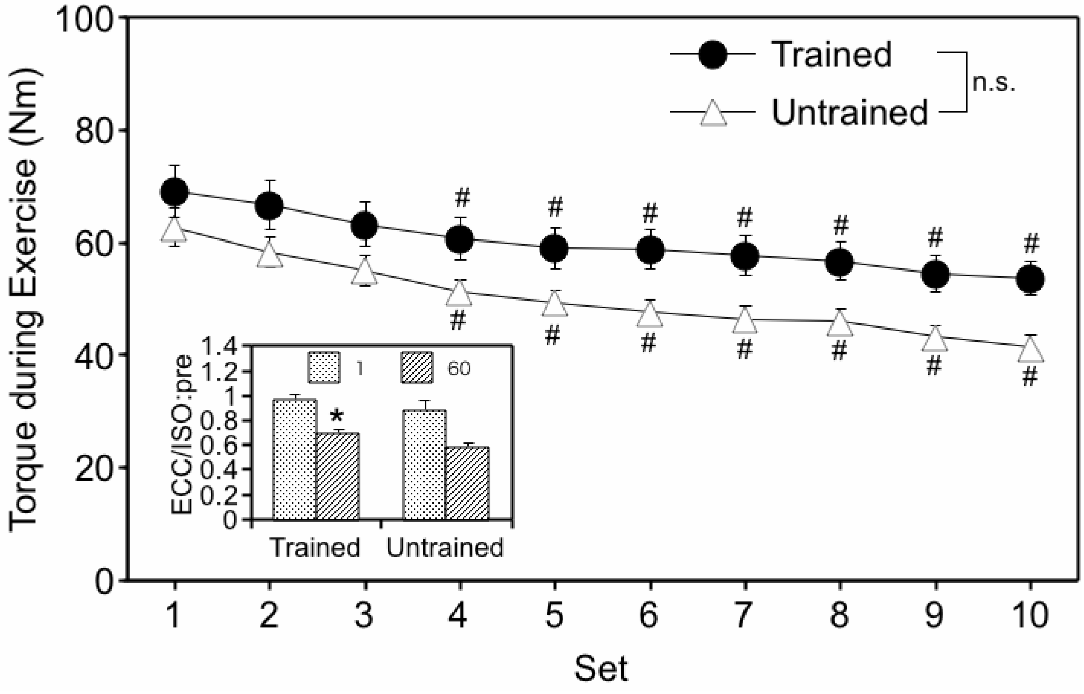

*Figure 20*. Changes in mean peak torque of 6 eccentric actions over 10 sets of eccentric exercise for the trained and untrained groups. n.s.: not significantly different between groups, #: significantly different from the 1st set. In the inset graph, a ratio between pre-exercise maximum isometric torque and peak torque during the 1st (1) and 60th (60) eccentric actions for the trained and untrained groups is shown. *: significantly different from the corresponding untrained group value.

### 5.3.3 Work During Eccentric Exercise

A similar pattern to torque was evident when considering the work production during the eccentric exercise. The work produced by both groups progressively decreased during each successive set of exercise. In percentage terms, both groups produced declines in work over the ten sets that were identical to that shown in the previous section for torque production (i.e., 33% for untrained and 22% for trained). The total work per set was significantly lower than baseline (set 1) by the third set for the trained group, but not until the ninth set for the untrained (Figure 21). Despite the within group contrast, there were no significant differences between the groups for work production during any of the ten sets or for total work (Figure 21 and inset).

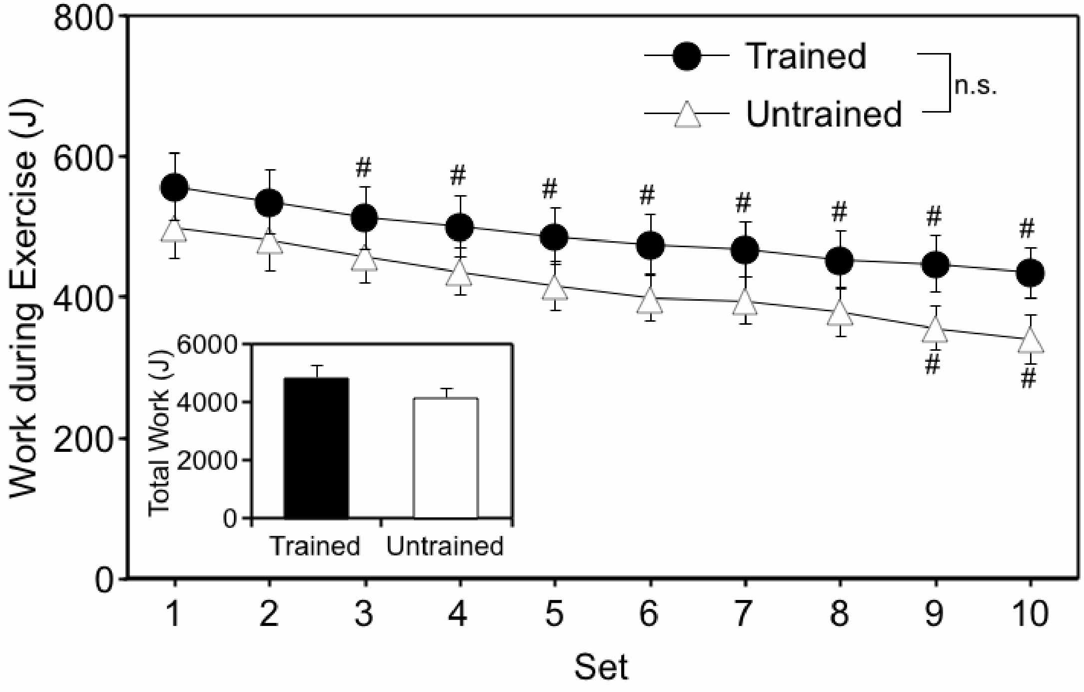

*Figure 21*. Changes in the total work per set over 10 sets of eccentric exercise for the trained and untrained groups. n.s.: not significantly different between groups, #: significantly different from the 1st set. In the inset graph, the total work of 10 sets for the trained and untrained groups is shown.

### *5.3.4 Isometric Torque*

Isometric torque responses at fixed angles of 90 and 150 degrees of elbow extension for both groups showed similar patterns of strength loss and subsequent recovery following the eccentric exercise intervention (Figures 22 & 23). Immediately following the 60 eccentric contractions the maximum isometric torque of both groups had declined significantly at 90 and 150 degrees of elbow extension ($p<0.05$). At this time point following exercise there were significant differences between the groups with the trained group exhibiting a decline of approximately 25% for both angles whereas the untrained group decreased approximately 40% and 47% at elbow extension angles of 150 and 90 degrees, respectively ($p<0.05$). The differences between the groups remained significant for all subsequent tests through day 5 ($p<0.05$). By day 3 ($90^o$) and 2 ($150^o$) following exercise the isometric torque of the trained group was not significantly different from pre-exercise (baseline) levels, and had returned to 90% of baseline by day 5 of testing (Figures 22 & 23). In contrast, the torque of the untrained group remained significantly lower than baseline at both angles throughout the study and was still depressed by approximately 30% at day 5.

The significant time by group interactions for both joint angles, which is evident upon inspection of the diverging lines for trained and untrained groups in Figures 22 and 23, demonstrate that the rates of recovery of isometric torque were dissimilar ($p<0.05$).

When recovery of isometric torque was calculated from the nadir to the final day of testing, the trained group recovered by approximately 20% at a fixed angle of $90^o$. In contrast, the untrained group produced a smaller recovery of approximately 15%. A similar pattern was evident for the groups at an angle of $150^o$.

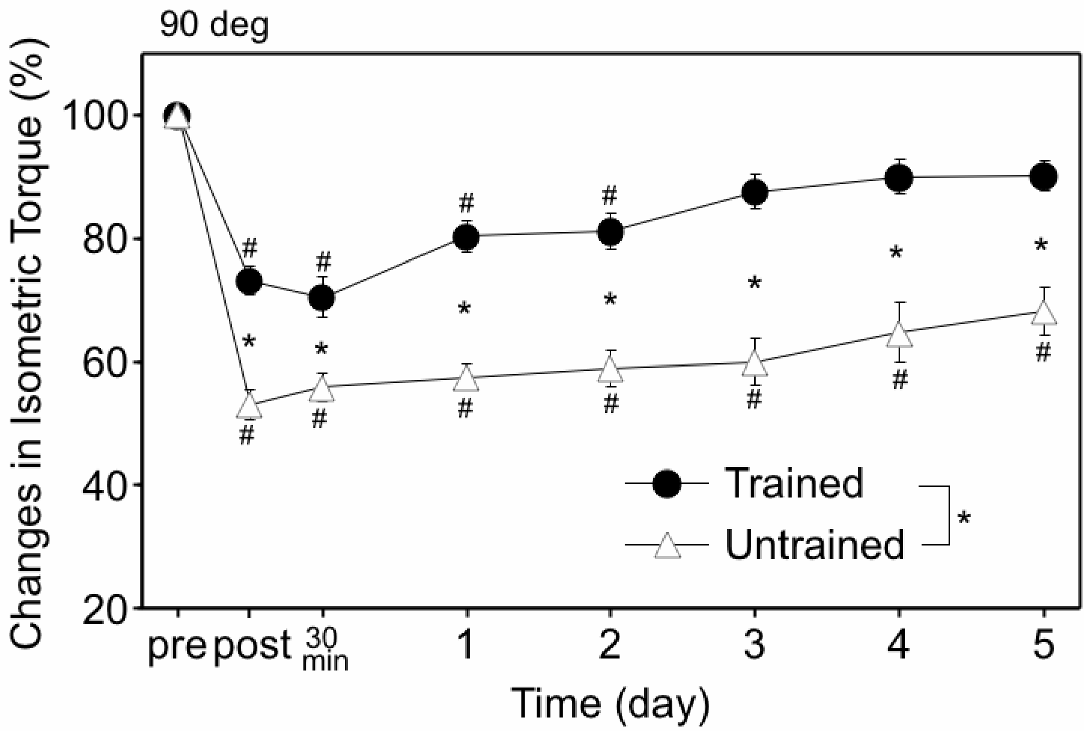

*Figure 22.* Changes in maximum isometric torque measured at 90° from baseline (pre: 100%) immediately (post) and 30 minutes after exercise, and 1-5 days following exercise for the trained and untrained groups. *: significantly different between groups (over all: $p<0.05$, each time point: $p<0.007$), #: significantly different from pre-exercise value.

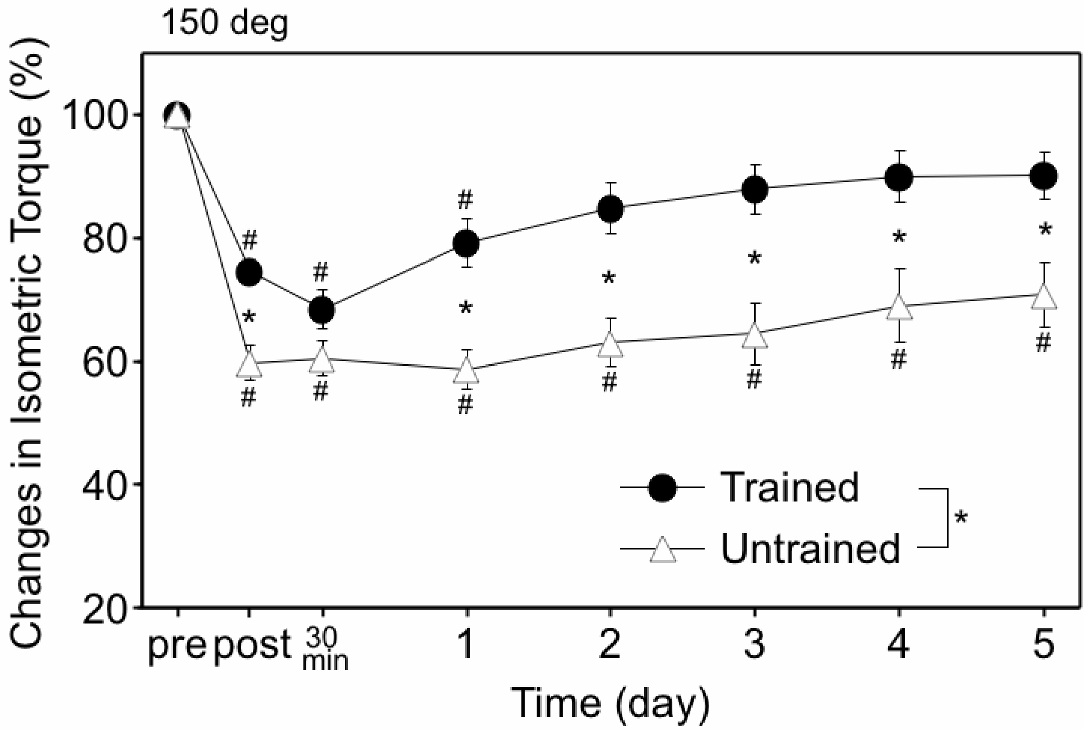

*Figure 23*. Changes in maximum isometric torque measured at 150° from baseline (pre: 100%) immediately (post) and 30 minutes after exercise, and 1-5 days following exercise for the trained and untrained groups. *: significantly different between groups (over all: $p<0.05$, each time point: $p<0.007$), #: significantly different from pre-exercise value.

### 5.3.5 *Isokinetic Concentric Torque at 30, 90, 150 , 210 and 300$^{o}\cdot s^{-1}$*

Table 8 shows changes in isokinetic concentric torque following exercise. Torque at all concentric velocities decreased significantly from pre-exercise levels for both groups immediately following the eccentric exercise treatment ($p<0.05$). Torque at the concentric velocities for the untrained group was 14% – 20% lower at this time point than that recorded by the trained, and was significantly different between the groups at 30, 150, and 210$^{o}.s^{-1}$ (Table 8). These concentric torque decrements were similar to the isometric values recorded at angles of 90$^{o}$ and 150$^{o}$. Both groups produced nadirs in concentric torque by day 1 following the eccentric exercise treatment for all tested velocities (Table 8).

Table 8.

*Changes in Normalised Isokinetic Torque at Five Different Velocities from Pre-exercise (100%) over 5 days Following Eccentric Exercise for Untrained and Trained Conditions. Mean and Standard Error of the Mean (SEM) are Shown*

| | | | | Percentage of pre-exercise torque | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Time following eccentric exercise | | | | | | |
| Velocity | Group | n | | Imm Post | 30 min Post | Day1 | Day2 | Day3 | Day4 | Day5 |
| $30^{o}\cdot s^{-1}$ | Untrained | 15 | Mean | 58.5*# | 57.5*# | 58.3*# | 60.4*# | 66.2*# | 66.7*# | 71.8*# |
| | | | SEM | 4.0 | 2.6 | 2.7 | 2.9 | 2.8 | 4.3 | 4.5 |
| | Trained | 15 | Mean | 79.5# | 77.1# | 83.7# | 86.5 | 90.4 | 94.5 | 94.1 |
| | | | SEM | 2.8 | 4.0 | 3.6 | 3.7 | 4.2 | 4.2 | 3.6 |
| $90\ ^{o}\cdot s^{-1}$ | Untrained | 15 | Mean | 60.4# | 58.1# | 55.0*# | 60.9*# | 65.9*# | 66.5*# | 69.2*# |
| | | | SEM | 4.8 | 3.7 | 3.2 | 3.7 | 3.4 | 4.5 | 4.8 |
| | Trained | 15 | Mean | 74.4# | 68.9# | 78.7# | 82.6 | 89.0 | 89.7 | 92.0 |
| | | | SEM | 3.5 | 2.9 | 4.3 | 4.9 | 5.3 | 5.5 | 5.4 |
| $150^{o}\cdot s^{-1}$ | Untrained | 15 | Mean | 56.8*# | 59.3# | 57.3*# | 64.7*# | 66.8*# | 69.8# | 72.7# |
| | | | SEM | 3.0 | 3.8 | 3.3 | 4.1 | 3.7 | 4.8 | 4.6 |
| | Trained | 15 | Mean | 76.2# | 72.3# | 80.7# | 82.8 | 91.3 | 89.4 | 92.0 |
| | | | SEM | 3.5 | 3.3 | 4.3 | 4.3 | 4.3 | 4.9 | 5.2 |
| $210^{o}\cdot s^{-1}$ | Untrained | 15 | Mean | 59.9*# | 64.2# | 63.8*# | 62.7*# | 70.0*# | 72.5# | 77.0 |
| | | | SEM | 3.9 | 4.2 | 4.4 | 3.4 | 4.8 | 5.1 | 5.6 |
| | Trained | 15 | Mean | 78.2# | 73.2# | 84.7 | 87.7 | 90.8 | 90.7 | 94.8 |
| | | | SEM | 3.3 | 2.8 | 4.0 | 4.6 | 4.3 | 4.1 | 5.5 |
| $300^{o}\cdot s^{-1}$ | Untrained | 15 | Mean | 60.1# | 62.8# | 63.5*# | 64.5*# | 72.2*# | 74.2# | 77.7# |
| | | | SEM | 4.5 | 4.5 | 3.6 | 4.0 | 4.4 | 5.1 | 5.7 |
| | Trained | 15 | Mean | 75.3# | 73.5# | 85.3 | 86.5 | 91.7 | 92.0 | 95.9 |
| | | | SEM | 3.6 | 2.8 | 3.6 | 3.3 | 5.1 | 4.6 | 6.2 |

Note. *: = significantly different between conditions after Bonferroni correction ($p<0.05$).
#: = significantly different from pre-exercise ($p<0.05$). Absolute values used for within group comparisons.
Imm Post: = Immediately following eccentric exercise.

Recovery of concentric torque progressed over the subsequent testing days for both groups at all velocities, and had returned to over 90% of pre-exercise levels in the trained group by day 5. By day 2 of recovery all concentric torque measures of the trained group were no longer significantly different from pre-exercise levels ($p<0.05$). In contrast, the concentric torques at all velocities in the untrained group remained significantly below pre-exercise levels on day 4 of testing. Table 8 reveals that torque at all velocities remained over 20% below pre-exercise levels in the untrained group at day 5 following exercise.

### *5.3.6 Range of Motion (ROM)*

Figure 24 reveals that the change in upper arm ROM from pre-exercise levels was significant for both the untrained and trained groups following the 60 maximal eccentric contractions ($p<0.05$). The largest decrease in ROM for the trained group occurred immediately following exercise, after which it recovered to pre-exercise levels by the final day of testing. In contrast, the untrained group showed a continuing decrease in ROM reaching a nadir of just over $-18^{o}$ degrees on day 3 following exercise before recovering slightly over the final two days of testing. ROM in this group was significantly lower than pre-exercise levels at all points following the eccentric exercise intervention, with the exception of the final day of testing ($p<0.05$).

The changes in ROM between the groups was appreciable with the untrained group decreasing significantly more than the trained group at all time points following the maximal eccentric exercise ($p<0.05$). Immediately following eccentric exercise the ROM of the untrained group was approximately $6^{o}$ lower than the trained group with the margin increasing to a maximum difference between the groups of $17^{o}$ at day 4 before recovering slightly by the final day of testing.

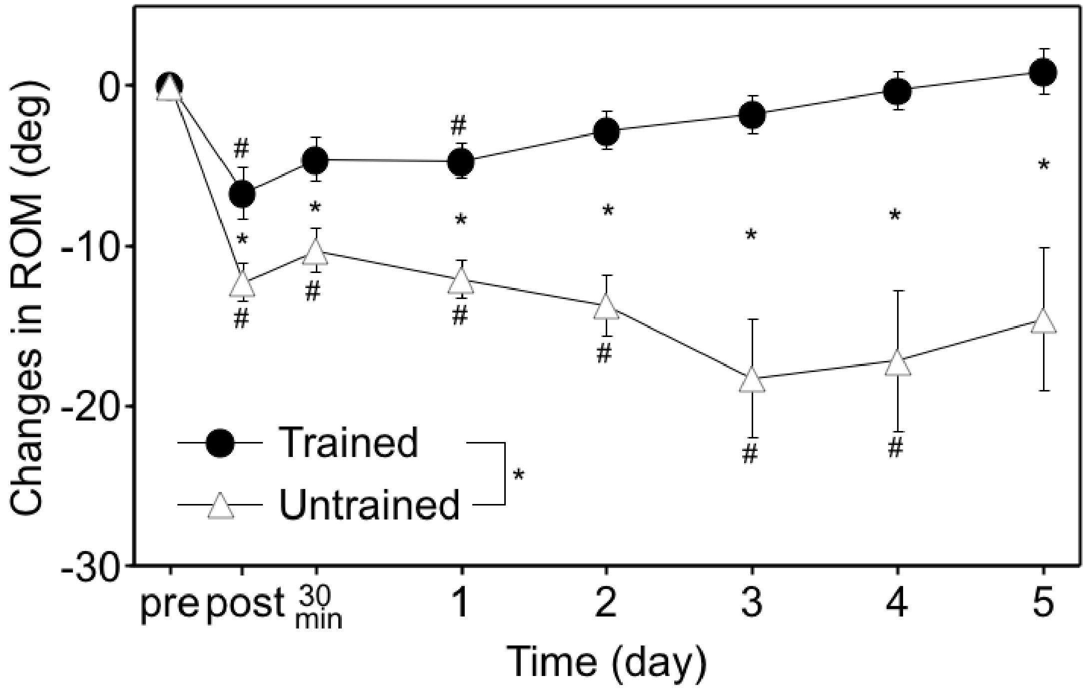

*Figure 24.* Changes in ROM from baseline (pre: 0) immediately (post) and 30 minutes after exercise, and 1-5 days following exercise for the trained and untrained groups. *: significantly different between groups (over all: $p<0.05$, each time point: $p<0.007$), #: significantly different from pre-exercise value.

### *5.3.7 Upper Arm Circumference*

Upper arm circumference increased in both groups following the exercise treatment with the untrained group displaying the greatest response (Figure 25). The increase in circumference was apparent immediately after eccentric exercise in both groups, with the peak increase of approximately 5 mm in the trained group occurring 1 day following exercise while the largest circumference of 16 mm was recorded on day 5 in the untrained group.

In contrast to the trained group which first recorded a significant increase in circumference over pre-exercise levels at day 1, the larger response of the untrained group resulted in significance immediately following the eccentric exercise treatment which remained through day 5 ($p<0.05$).

As illustrated in Figure 25, the disparity in trained and untrained circumference responses resulted in significant differences between the groups for the final three days of testing ($p<0.05$). By the final day of testing the increase in circumference of the untrained group was over 3 times greater than that of the trained.

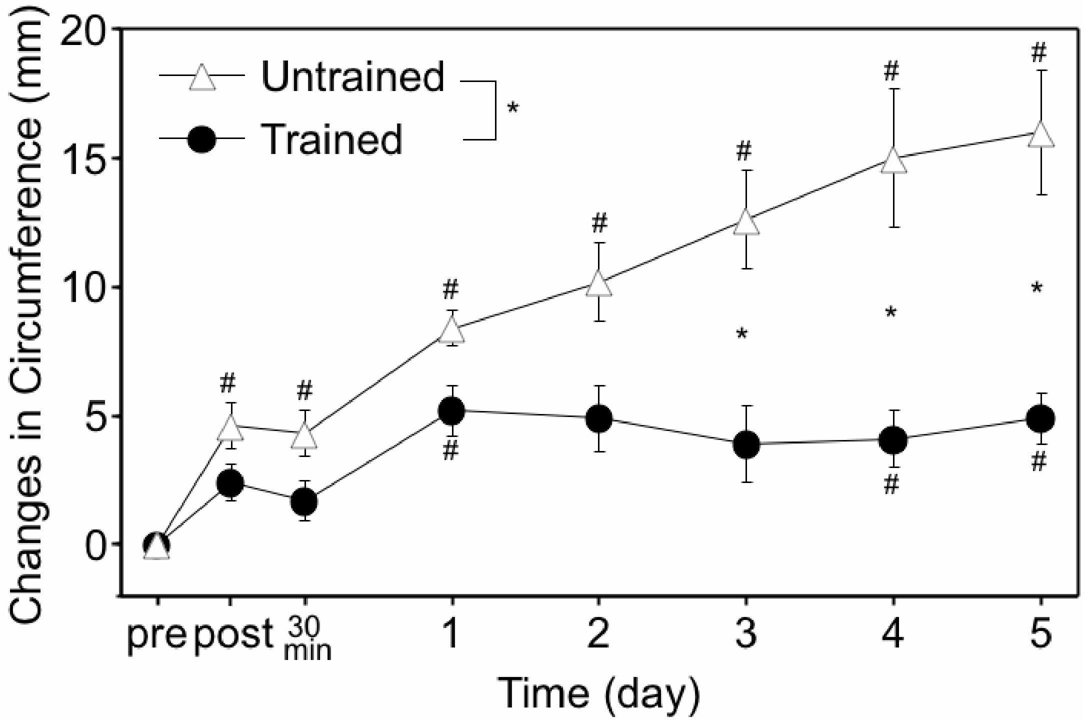

*Figure 25*. Changes in upper arm circumference from baseline (pre: 0) immediately (post) and 30 minutes after exercise, and 1-5 days following exercise for the trained and untrained groups. *: significantly different between groups (over all: $p<0.05$, each time point: $p<0.007$), #: significantly different from pre-exercise value.

### *5.3.8 Plasma Creatine Kinase (CK) Activity*

Figure 26 indicates that mean plasma CK activity was not significantly different between the groups prior to performing the 60 maximal eccentric contractions, however, it is noteworthy that the mean reading of the trained group (370 $IU \cdot L^{-1}$) was above the upper limit of the normal reference range of 220 $IU \cdot L^{-1}$ for healthy adult males.

In the days following the eccentric exercise session mean CK activity was elevated, reaching a peak in both groups on the final day of testing (day 5). There was a stark contrast in the response of CK between the groups following the exercise treatment with the trained group not quite doubling the activity to 735 $IU{\cdot}L^{-1}$ by day 5, whereas the untrained group recorded slightly over a 20 fold increase from its pre-exercise value of 164 $IU{\cdot}L^{-1}$. Although CK activity was not significantly elevated above pre-exercise levels at any point following eccentric exercise in the trained group, it did reach significance in the untrained group at days 4 and 5 ($p<0.05$). These final two days of testing were also marked by significant differences between the two groups for CK activity ($p<0.05$). Peak CK activity did not occur in all of the subjects on the final day of testing resulting in a mean peak CK that was slightly higher in both groups than that recorded on day 5 (Figure 26 inset). Significant differences were evident between the groups for this measure ($p<0.05$).

The inter subject variability in CK response was high for both groups across all testing days resulting in relatively large standard errors of the mean.

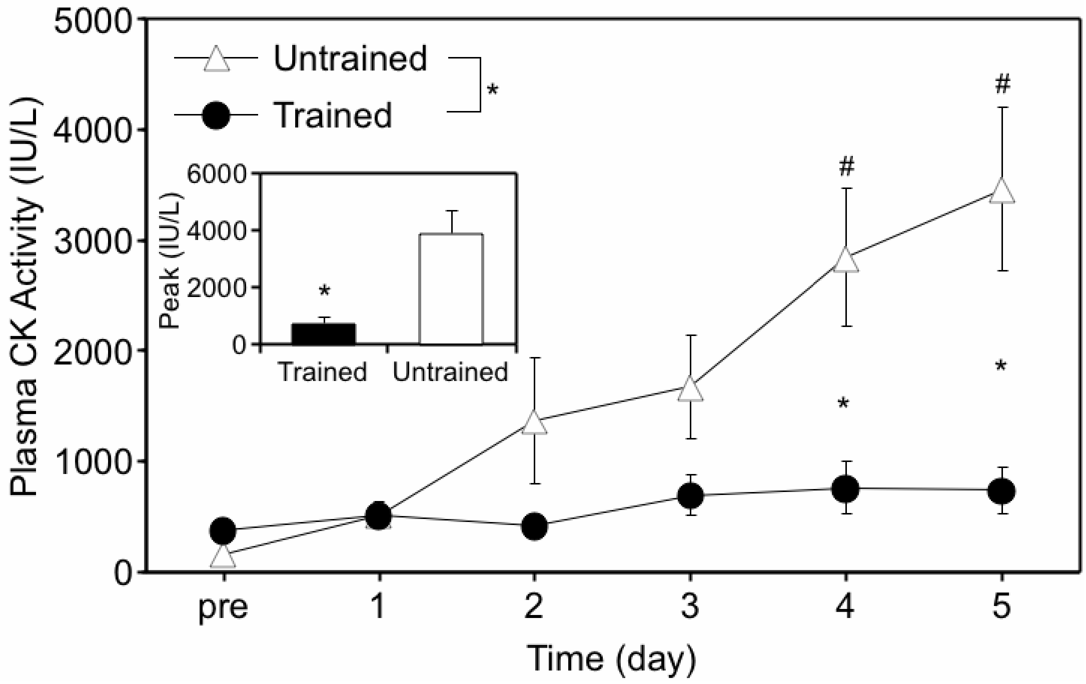

*Figure 26*. Changes in plasma CK activity before (pre), and 1-5 days following exercise for the trained and untrained groups. *: significantly different between groups (over all: p<0.05, each time point: p<0.007), #: significantly different from pre-exercise value. In the inset graph, comparison of peak CK activity between groups is shown. *: significantly different from the untrained group.

### *5.3.9 Muscle Soreness*

On the VAS scale of zero to 100, muscle soreness for forearm, upper arm palpation, extension and flexion was rated at zero prior to eccentric exercise which represented a subjective representation of no pain at all. Following the performance of 60 maximal eccentric contractions of the elbow flexors both groups reported muscle soreness that was significantly greater than pre-exercise levels (p<0.05). Table 9 indicates that with the exception of flexion in the trained group, all other soreness classes of both groups resulted in significant increases from pre-exercise levels one day following the eccentric contractions (p<0.05). Extension and flexion soreness was similar between the groups at this time point, however, for upper arm and forearm measures the trained group recorded VAS scores slightly under double and approximately triple that of the untrained, respectively. A significant increase from baseline occurred at day 2 in the trained group for soreness during passive flexion of the upper arm ($p<0.05$).

Table 9 shows that upper arm peak soreness was approximately 14% higher for the trained group and occurred one day earlier than in the untrained. By day 5 the soreness had subsided in both groups and was no longer significantly different to pre-exercise levels. The trained group also peaked earlier and recorded a VAS score of approximately 21% higher for forearm soreness. In this soreness measure both groups were also no longer significantly elevated above pre-exercise levels on the final day of testing.

For extension and flexion soreness both groups peaked on day 2 following the eccentric intervention. Although there were no significant differences in soreness between the groups at this time the untrained group recorded VAS scores of just under double those of the trained group for extension soreness, and approximately 30% higher for the flexion measure (Table 9).

Table 9

*Changes in Upper Arm, Forearm, Extension and Flexion Soreness over 5 Days Following Eccentric Exercise of the Forearm Flexors for Untrained and Trained Conditions (Peak Soreness also Shown). Mean and Standard Error of the Mean (SEM) are Shown*

| | | | | Visual Analog Scale soreness (mm) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Time following eccentric exercise and peak reading | | | | | |
| Soreness class | Group | n | | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Peak |
| Upper Arm | Untrained | 15 | Mean | 17.1# | 32.8# | 33.3# | 22.3# | 13.2 | 37.7 |
| | | 15 | SEM | 3.4 | 5.6 | 6.2 | 5.9 | 4.6 | 5.9 |
| | Trained | 15 | Mean | 33.4# | 38.1# | 28.5# | 15.3 | 8.3 | 42.8 |
| | | 15 | SEM | 5.4 | 5.5 | 4.9 | 4.5 | 2.6 | 5.7 |
| Forearm | Untrained | 15 | Mean | 8.5# | 20.8# | 21.4# | 17.3 | 12.9 | 27.3 |
| | | 15 | SEM | 2.5 | 4.3 | 4.5 | 4.8 | 4.3 | 5.1 |
| | Trained | 15 | Mean | 25.9# | 20.3# | 11.4# | 6.5 | 3.1 | 28.0 |
| | | 15 | SEM | 5.1 | 5.2 | 2.5 | 2.4 | 1.4 | 5.3 |
| Extension | Untrained | 15 | Mean | 22.5# | 43.1# | 39.9# | 26.7# | 20.5 | 49.2 |
| | | 15 | SEM | 4.1 | 5.4 | 6.3 | 7.0 | 6.2 | 6.5 |
| | Trained | 15 | Mean | 21.3# | 23.3# | 13.1 | 7.5 | 3.5 | 27.0 |
| | | 15 | SEM | 5.8 | 6.1 | 4.1 | 3.3 | 2.2 | 5.8 |
| Flexion | Untrained | 15 | Mean | 13.0# | 20.7# | 18.3 | 14.8 | 5.7 | 26.1 |
| | | 15 | SEM | 3.4 | 5.4 | 5.3 | 5.9 | 3.1 | 6.7 |
| | Trained | 15 | Mean | 13.5 | 15.9# | 10.1 | 4.5 | 2.6 | 19.0 |
| | | 15 | SEM | 3.9 | 4.3 | 3.2 | 2.3 | 1.5 | 4.4 |

Note. #: = significantly different from pre-exercise level ($p<0.05$). Pre-exercise soreness was zero for all soreness classes and conditions.

## 5.4 Discussion

The purpose of the present study was to determine whether the criterion measures differed between untrained and trained males following maximal voluntary eccentric exercise of the elbow flexors. The results revealed that there were significant differences evident between the untrained and trained subjects for all of the criterion measures, with the exception of muscle soreness (Figures 22, 23, 24, 25, 26 and Table 9). Despite both groups performing similarly in terms of torque and total work during the eccentric exercise intervention (Figures 20 and 21), the trained group produced smaller changes in muscle function (torque and ROM) and other damage markers of upper arm circumference and CK activity. Such a response is consistent with the "repeated bout effect" in which an initial bout of eccentric exercise provides varying degrees of protection against muscle damage in a subsequent bout performed some time later (Ebbeling & Clarkson, 1989; McHugh et al., 1999). The degree of protection appears to be dependent upon the criterion measure in question, the intensity and / or volume of the initial and subsequent bouts of eccentric exercise, and the intervening period between the bouts (Clarkson et al., 1992; Clarkson & Tremblay, 1988; Nosaka et al., 1991; Nosaka et al., 2001a, 2001b).

In the present study, muscle soreness in the trained group did not show a response usually associated with the "repeated bout effect" (Table 9). This was unexpected considering that some degree of protection was evident for the other criterion measures. Repeated bout studies employing untrained subjects have shown that an initial bout of maximal eccentric exercise conferred a protective effect against a subsequent eccentric bout that was complete (Brown et al., 1997; Chen & Hsieh, 2000; Newham et al., 1987; Nosaka et al., 2001a), and the full protective effect extended to muscle soreness.

Although statistically non-significant, the resistance-trained group reported peak muscle soreness of 14% and 21% higher than the untrained for upper arm and forearm palpation, respectively. This was despite showing smaller changes in the other criterion measures than the untrained group. In one of the few studies comparing the responses of chronically resistance-trained and untrained males to eccentric exercise, Vincent and Vincent (1997) also reported that, although not statistically significant, the trained group rated soreness higher than the untrained. In the present study the situation was reversed when considering the muscle soreness during extension and flexion with the untrained group reporting higher, but statistically non-significant, VAS readings (Table 9). An explanation for the differing results in regard to muscle soreness is not immediately clear, however, it may simply be a reflection of chance occurrence as none of the between group differences reached statistical significance. Despite the lack of significant differences in muscle soreness between the untrained and trained groups, both did experience soreness that was significantly greater than pre-exercise levels at various times following the eccentric intervention (Table 9). Although there is a scarcity of data relating to resistance-trained individuals, the soreness findings of the untrained group are consistent with those reported elsewhere for individuals of this training status (Chen & Hsieh, 2000; Clarkson et al., 1986; Smith, Keating et al., 1994).

A possible explanation for the trained groups' lack of protective effect in terms of soreness may lie in the principle of specificity. The administration of the eccentric exercise in the present study involved a Cybex dynamometer, the contraction type was isokinetic, and the eccentric intensity was maximal. The elbow flexor training routinely performed by the trained subjects involved significant free weight barbells and dumbbells, the contraction mode was concentric and eccentric dynamic constant external resistance (Fleck & Kraemer, 2004), and the eccentric contractions were not maximal in nature. Due to the novelty of the eccentric exercise intervention employed in the present study the trained subjects may not have adapted specifically to the unique stress applied to the elbow flexors.

It was interesting that muscle soreness was the only criterion measures not to show a "repeated bout" type effect in the trained group. Nosaka et al. (2002a) concluded that delayed onset muscle soreness is a poor reflector of eccentric exercise-induced muscle injury, and that changes in indirect markers of muscle damage are not necessarily associated with DOMS. Warren et al. (1999) also noted that soreness has shown poor correlations with changes in muscle function following eccentric exercise. It may be that soreness was not a sensitive enough marker of muscle damage to distinguish any differences between the groups. From a training standpoint, the present results suggest that individuals performing resistance training on a regular basis should exercise caution using the degree of soreness to indicate the magnitude of damage and loss of muscle function.

The criterion measure of CK activity demonstrated marked differences between the groups with the trained subjects exhibiting what could be referred to as complete protection in terms of “repeated bout” nomenclature (Figure 26). The magnitude and temporal nature of the CK response of the untrained group was similar to that reported in other studies, peaking at around 3500 $IU \cdot L^{-1}$ on day 5 following the eccentric intervention (Nosaka & Clarkson, 1992; Paddon-Jones et al., 2000; Smith, Fulmer et al., 1994). Vincent and Vincent (1997) reported a small rise in CK activity in their trained subjects following exercise which incorporated an eccentric component. In a similar response to the present study, their untrained group also showed significantly larger increases in CK activity than the trained subjects.

The trained group commenced the present study with CK activity that was higher than the reference range for healthy adult males, but not statistically different from that of the untrained subjects. The likely cause of the slightly higher CK activity in the trained group was the resistance training incorporating eccentric contractions undertaken just over a week prior to study commencement.

The lack of a rise in CK activity for the trained group following the eccentric intervention suggests that the large repeated mechanical stress placed on the exercised elbow flexor muscles did not lead to loss of integrity of the sarcolemma. When compared to the 20 fold increase in CK activity in the untrained group following eccentric exercise, there appears to be some adaptation associated with chronic resistance training that confers protection to the worked muscles of the trained subjects preventing efflux of CK into the lymph and blood.

There are a number of neuromuscular adaptations arising from chronic resistance training, some of which may be associated with the protective effect exhibited by the trained group for the criterion measures of torque, ROM, upper arm circumference and CK activity. These adaptations are also closely related to those put forward to explain the “repeated bout effect” experienced by untrained subjects following an initial bout of eccentric exercise.

Chronic high intensity resistance training has been shown to increase strength and lean muscle mass by a combination of neurological, endocrinological, and intramuscular adaptations (Fleck & Kraemer, 1988; Fry, 2004; Gonyea & Sale, 1982; Jones et al., 1989; Kraemer et al., 1998; Kraemer & Ratamess, 2005). It was, therefore, interesting that the untrained and trained groups did not differ in terms of isometric and isokinetic concentric torque or upper arm circumference at the commencement of the study. The absence of a strength difference between the groups may be attributable to the lack of specificity between the training and testing conditions. Rutherford and Jones (1986) note that “task specific methods of assessing strength, such as weight lifting, will obviously give larger changes than a less accustomed exercise.” They showed that dynamic resistance training produced increases in training weights of about 200% but much smaller isometric force improvements of only 15-20%. Therefore, if the groups of the present study were tested in terms of the weight they could lift in “traditional” resistance training exercises there may have been a statistically significant difference evident. It was not possible to determine if the untrained and trained groups differed with respect to lean muscle mass. Circumference measurements were not sensitive enough to provide the contribution of fat and muscle to upper arm volume. In hindsight it would have been sagacious to have included a more sensitive measure of upper arm muscle mass, however, the inclusion of dual energy x-ray absorptiometry (DEXA), computed axial tomography (CAT) or magnetic resonance imaging (MRI) scans were beyond the budgetary constraints of the study and the use of skinfold measurements was felt to introduce unacceptable error. However, based upon the circumference measurements, and the findings of no significant difference between the groups in terms of isometric and isokinetic concentric torque, it is unlikely that the groups differed in terms of absolute lean muscle mass.

If differences in strength (isometric and isokinetic concentric) and / or lean muscle mass are doubtful to explain the protective effect in this case, then other factors must play a role. Armstrong (1984) mentions that “training appears to be highly specific, not only for the particular muscle involved in the type of exercise, but for the type of contractions performed. Thus, the DOMS that results from eccentric exercise is reduced specifically by training that involves eccentric contractions.” This is definitely applicable to the trained group of the present study as their typical training regimens incorporated regular performance of eccentric contractions.

Armstrong (1984) also suggests that in order for a muscle to produce a given force, a smaller number of motor units are activated during an eccentric contraction. Therefore in eccentric contractions the force is spread over a smaller cross-sectional area of muscle, meaning that the specific tension is greater. This greater specific tension could potentially give rise to mechanical damage to any number of activated fibres leading to focal necrosis, immune cell infiltration and subsequent repair of the injured area.

Armstrong, Ogilvie and Schwane (1983) put forward a theory to explain the repeated bout effect. They suggested that the fibres injured in the initial eccentric exercise bout represented a population of “susceptible fibres” which are eliminated during a novel bout of eccentric exercise, the remaining fibres being able to withstand subsequent eccentric exercise without further injury. If such a theory was shown to be correct then it may be one possible explanation for the findings of the present study. The eccentric exercise performed as part of the trained subjects regular training could lead to damage and subsequent removal of stress susceptible fibres rendering the muscles at least partially protected against injury during subsequent eccentric challenges. Newham et al. (1987) reported that the results of experiments conducted in their laboratory provided some evidence in favour of the possibility of the susceptible fibre theory. They had subjects perform maximal eccentric exercise of the elbow flexors on three occasions spaced two weeks apart. Their data demonstrated that the adaptation following the bouts did not result in any change in strength or contractile properties (20 / 100%) of the muscle tissue or the ability of it to resist fatigue. The recovery of force generation and 20/100% value was slower following the first bout of eccentric exercise than after the subsequent two bouts. The authors suggested it was possible that the force reduction and release of CK represented the removal of part or all of any irreparably damaged fibres, which were replaced during the recovery period. Doubt has been cast on this theory, however, by the originators themselves (Schwane & Armstrong, 1983) as well as Clarkson and Tremblay (1988) who showed that an initial bout of eccentric exercise that resulted in a very small magnitude of damage conferred protection against subsequent eccentric exercise known to normally produce much more severe injury.

Alternatively, an initial bout of eccentric exercise, or chronic resistance training, may cause sub-lethal stress to weakened myofibres which initiates structural reinforcement of the fibres themselves and / or connective tissue in the immediate vicinity (Clarkson & Tremblay, 1988; Lapier, Burton, Almon, & Cerny, 1995; McHugh et al., 1999; Morgan, 1990; Newham et al., 1987; Schwane & Armstrong, 1983). Stone (1988) states that "there is little doubt that physical training increases the maximum static strength of tendons and ligaments." (p.164) In later work (1992a) he notes that strength training may cause adaptations to tendons and ligaments causing them to become larger, stronger, and better able to resist injury. MacDougall and co-workers' (1984) research with resistance-trained individuals showed evidence of increased absolute, but not relative, amounts of connective tissue following chronic resistance training. This suggests that the body adapts to a resistance training challenge by increasing the amounts of both muscle and connective tissue, however, the ratio of connective tissue to muscle does not change.

It has also been speculated that strengthening of the cell membrane may be implicated in the protective effect (Clarkson & Tremblay, 1988; Vincent & Vincent, 1997). This suggestion has received some experimental support in recent times with Koskinen et al. (2001) reporting that downhill treadmill running in rats led to changes in synthesis of type IV collagen in the basement membrane at both mRNA and protein levels.

In the present study, the isometric and dynamic torque responses following the eccentric intervention produced a "repeated bout" type effect in the trained group (Figures 22 & 23 and Table 8). For both isometric angles ($90^{o}$ and $150^{o}$), and concentric velocities of $30^{o}\cdot sec^{-1}$, $150^{o}\cdot sec^{-1}$, and $210^{o}\cdot sec^{-1}$, the protective effect was evident immediately following eccentric exercise which is a finding not reported in all human repeated bout studies (Clarkson et al., 1992; Clarkson & Tremblay, 1988; Newham et al., 1987). Protection immediately following the eccentric intervention did not appear to extend to the concentric test velocities of $90^{o}\cdot s^{-1}$ and $300^{o}\cdot s^{-1}$ in the trained group. However it should be noted that the number of testing sessions included in the ANOVA reduced the corrected alpha level appreciably below the single test level of 0.05 decreasing the likelihood of locating significant differences. These velocities ($90^{o}\cdot s^{-1}$ and $300^{o}\cdot s^{-1}$), though, showed trends toward significant differences between the groups and therefore further explanation for the lack of apparent protection at these velocities will not be explored.

The significant differences between the untrained and trained groups in isometric and dynamic torque immediately following the eccentric exercise intervention suggests that the protective effect conferred by chronic resistance training may be due in part to adaptations at the level of the dihydropyridine (DHP) channels in the T-tubules and ryanodine receptors in the sarcoplasmic reticulum. From data collected in mouse and rat studies researchers have suggested that the majority of the pronounced decrement in normalized maximum isometric force production following eccentric exercise is likely the result of E-C failure (Balnave & Allen, 1995; Ingalls, Warren et al., 1998b; Warren, Ingalls, Shah, & Armstrong, 1999; Warren et al., 1993). Ingalls et al. (1998a) determined that E-C uncoupling could account for at least 75% of the reduction in maximum isometric force production immediately following the eccentric exercise and at least 57% of the decrement following 5 days of recovery. Warren et al. (1999) believe that the main site for E-C uncoupling is "localized between the t-tubular voltage sensor and the SR $Ca^{2+}$ release channel" (p. 618). They believe that the failure may be associated with sensing the membrane depolarization by the voltage sensor (DHP) and / or transduction of the signal to the SR $Ca^{2+}$ release channel. It is possible that the high mechanical forces produced during the early stages of an intense resistance training program cause disruption to these structures and adaptation occurs to the structures themselves, or their supporting cellular framework, allowing for improved signal transduction and calcium handling, resulting in lower torque decrements when exposed again to the same or similar exercise stress.

Another adaptation that has been suggested to occur within the muscle fibre as a response to eccentric activity is the addition of sarcomeres in series (Morgan, 1990; Morgan & Allen, 1999). In a study involving incline and decline treadmill running by rats, Lynn and Morgan (1994) showed evidence of such a change, lending support to Morgan's earlier hypothesis. The effect of such an adaptation would be for the subsequent active lengthening of the sarcomere to occur on the ascending limb of the length tension curve thus avoiding the more damaging descending limb. Lynn et al. (1998) performed a further experiment involving treadmill running with rats and suggested that the observed repeated bout effect may be due to a greater number of sarcomeres in series. If this effect is evident in humans then it is a possible contributor to the protective effect shown in the present study for the trained subjects. However, the effect of the concentric exercise of the trained subjects on sarcomere numbers in series is unknown and, in theory, could negate the lengthening effect of the eccentric component of the training regimens. Sarcomere shortening during concentric training has been suggested by Morgan (1990) and Lynn et al. (1998).

Resistance training has been shown to induce heat shock protein expression and mitogen-activated protein kinase (MAPK) activation, and it has been suggested that these molecules may play an important role during subsequent muscle adaptation (Thompson, Maynard, Morales, & Scordilis, 2003). Willoughby et al. (2003) showed that it is the eccentric contractions that produce the largest response in terms of heat shock protein-72 (HSP-72) and activity of the apoptotic protease caspase-3 and the ubiquitin proteolytic pathway. Thompson et al. (2003) also reported that high-force eccentric contractions of the elbow flexors in untrained subjects elicited significant increases in HSP27 and HSP70 protein and mRNA, and activation of intramuscular MAPK through elevation of JNK and ERK phosphorylation.

Koh (2002) put forward the hypothesis that muscle cells may be protected by the induction of heat shock proteins following mechanical loading caused by exercise. He suggested that the protection of muscle may be mediated by the heat shock proteins interacting with cytoskeletal elements and / or the glutathione system. Work by Thompson et al. (2002) suggests that the heat shock protein system may adapt in such a way as to protect muscle during exposure to repeated bouts of exercise. As the trained subjects in the present study were exposed to repeated bouts of eccentric and concentric resistance training over a protracted period (i.e., years), it is tempting to speculate that adaptation to the heat shock system may be responsible, in part, for the attenuated responses in damage markers compared to the untrained group.

Although not investigated in the present study, neural adaptations due to the chronic resistance exercise performed by the trained subjects may be partly responsible for the attenuated responses in many of the criterion measures in this group following the eccentric intervention. Such adaptations could take the form of increased motor unit activation for a given torque, alterations to motor unit recruitment, or increased synchronisation of motor unit activation (McHugh, Connolly, Eston, Gartman, & Gleim, 2001). Warren et al. (2000) demonstrated some evidence for an increased recruitment of slow motor units and a concomitant decrease in fast unit activation following a repeated bout of maximal voluntary eccentric exercise. In terms of the present study, the work of Warren et al. (2000) could be taken to suggest that, through incorporation of eccentric contractions during exercise, trained subjects “learned” to switch off significant numbers of the more damage susceptible fast twitch fibres while concurrently recruiting the hardy slow twitch fibres to bear the load during subsequent training. Although such a prospect seems attractive, McHugh et al. (2001) reported research which showed no change in EMG per unit torque or median frequency between novel and repeated bouts of submaximal isokinetic eccentric exercise. The conclusion drawn by these researchers was that there was no evidence of any neural adaptation accompanying the repeated bout effect. Whether the disparity between these two recent studies was due to the intensity of the eccentric contractions is unclear, however, future research focusing on neural mechanisms should shed more light on the aetiology of the repeated bout effect.

Despite the trained group exhibiting protection against decrements in muscle function and other criterion measures when exposed to the eccentric exercise intervention, the magnitude of the effect was not complete for most of the criterion measures. This is with the notable exception of CK activity. As discussed above, soreness did not show any evidence of a protective effect when compared to the responses of the untrained group. Thus far, the focus of the discussion has been on the differences between the groups and what may have contributed to the apparent protective effect in the trained subjects. Another question that warrants attention is, what factors may have inhibited a full protective effect in the trained subjects?

The first potential factor to be considered involves the trained subjects performing resistance training too close to the beginning of the study and somehow affecting the response to the eccentric exercise intervention. This was very unlikely as subjects in the trained group were instructed to refrain from performing their personal resistance training regimen for the week prior to the commencement of the study. There is always the possibility of some detraining effect due to the requested one week abstinence from training, however, the likelihood of this occurring was probably offset to some degree by the two familiarisation sessions that the subjects were required to attend during this week. These sessions required the subjects to perform sets of low volume but high intensity maximal voluntary isometric and isokinetic concentric arm curl exercise.

There is support for the utility of performing high intensity resistance training when maintenance of previously established gains is the goal (Berger, 1962). It has also been shown that strength levels can be maintained for many weeks or months in the face of significant reductions in volume of training if the intensity of maintenance sessions remain high (Berger, 1962; Graves et al., 1988). Further support for the lack of a detraining effect in the present study is found in a recent study of Nosaka and Newton (2002a) who showed that following 8 weeks of either concentric (con) or eccentric (ecc) resistance training of the elbow flexors, with a dumbbell set at approximately 50% of maximum isometric force, the gains achieved in strength were maintained when assessed following four (con) and six (ecc) weeks of detraining (absolutely no training).

The second factor to be considered relates to whether the performance of concentric exercise as part of the trained subjects resistance training regimen could have limited the impact of the protective effect compared to a program in which only eccentric exercise was performed. All subjects reported that high-intensity concentric exercise formed a major component of their regular resistance training. Due to the use of traditional barbell, dumbbell and variable resistance weight stack machines this contraction mode was combined with an eccentric phase during their training.

Research focusing on whether prior concentric contractions (exercise) affect the magnitude of decrements in muscle function and other indirect markers of muscle damage following eccentric exercise has produced contradictory findings. Work by Gleeson et al. (2003), Ploutz-Snyder et al. (1998) and Whitehead et al. (1998) suggest that the inclusion of concentric training for a period (days or weeks) prior to an eccentric intervention increases the susceptibility of muscle to changes in the criterion markers associated with damage. They suggest that this probably occurred due to the concentric 1 repetition maximum being increased by training, possibly allowing the muscle to be exposed to a larger eccentric load. In contrast, Nosaka and Clarkson (1997) and Nosaka and Newton (2002a) reported that an acute bout and short term concentric training, respectively, did not exacerbate muscle damage as measured by changes in the criterion markers. In the Nosaka and Newton (2002a) study the criterion measures were no different to those of the eccentric-only training group following the maximal eccentric exercise despite the concentric-only group increasing both isometric and maximal isokinetic concentric strength following the training program.

The present study differed from those presented above in two respects. First, the subjects in the cited studies were not chronically trained. All studies recruited previously untrained subjects and had them perform concentric exercise for periods ranging from one bout to nine weeks prior to the eccentric intervention. The second difference related to the mode of training. In the present study the subjects combined concentric and eccentric contractions as part of their regular training regimen, which contrasted with the concentric-only training performed in the studies cited above. The design of the present study does not allow for an answer to the question of whether the inclusion of concentric contractions in the trained groups exercise regimen could have inhibited the protective effect compared to an eccentric-only program. Future research employing a slightly modified design to that used in the present study could shed light on this question.

The final factor to be considered relates to whether the absence of maximal voluntary eccentric contractions in the trained groups exercise regimen inhibited the protective effect compared to a program that incorporated regular maximal eccentric exercise. All the subjects in the trained group reported that they did not perform any pure “negative” (i.e., maximal eccentric) training due to the inconvenience associated with this kind of training. A few of the subjects were also of the opinion that this type of training increased the likelihood of sustaining an injury.

There is currently a lack of research comparing the responses of criterion measures to maximal eccentric exercise between groups who had previously performed chronic training incorporating either maximal voluntary eccentric exercise or submaximal eccentric contractions. Nosaka and Newton (2002a) had a group of subjects train using only sub-maximal eccentric contractions for a period of 8 weeks and then exposed them to a bout of maximal voluntary eccentric exercise 6 weeks later. Following the maximal eccentric exercise subjects produced only a slight attenuation in the markers of muscle damage when compared to a previous study. The previous study used the same eccentric intervention but was investigating the repeated bout effect of maximal voluntary eccentric contractions. Using this cross study comparison Nosaka and Newton (2002a) concluded that short-term submaximal eccentric-only training was not as effective as a single bout of maximal voluntary eccentric exercise in conferring protection against subsequent maximal eccentric exercise.

In light of the Nosaka and Newton (2002a) conclusion, the results of the trained group in the present study are interesting as the protective effect seemed to be similar to that shown in other studies investigating the “repeated bout” phenomenon and employing bouts of maximal eccentric exercise. In fact, the torque loss experienced by the trained group immediately following the exercise intervention showed a greater magnitude of protection compared to some of the “repeated bout” studies using maximal eccentric exercise in each bout (Clarkson et al., 1992; Clarkson & Tremblay, 1988; Newham et al., 1987). It is possible that several years of lower level mechanical stress caused by the sub-maximal eccentric training in the trained group produces neuromuscular adaptations similar to that experienced following acute maximal voluntary eccentric exercise. Whether chronic resistance training incorporating maximal voluntary eccentric exercise would confer additional protection is unclear and will make for interesting future research.

In conclusion, the results of the present study show that chronically resistance trained males experienced smaller changes in muscle function, limb circumference, and CK activity following maximal eccentric exercise than untrained males despite similar performances in the eccentric exercise task. The aetiology of the protective effect in the trained individuals was not able to be determined in the present study but may relate to neuromuscular adaptations not directly related to increased strength or muscle mass. Future research could be directed at elucidating the physiological mechanisms responsible for the adaptations in resistance trained athletes that results in smaller changes in most markers of exercise-induced muscle damage compared to untrained individuals.

It also appears that the degree of muscle soreness is not a sensitive indicator of the magnitude of damage and loss of muscle function in both resistance-trained and untrained males.

# CHAPTER 6

## 6.1 Introduction

In the previous chapter I explored the variation in responses to eccentric exercise associated with training status. One obvious source of difference between individuals is that based on racial background, however, there is presently a dearth of research addressing this factor with regard to changes in criterion measures following eccentric exercise. In a study evaluating the efficacy of an analgesic to treat muscle pain, Clarkson et al. (2005) subjected individuals of varying racial backgrounds to a bout of maximal eccentric exercise of the elbow flexors. DNA testing of the subjects showed that there were a disproportionate number of Asian subjects who were homozygous for the MLCK 49T rare allele of the gene coding for the myofibrillar protein myosin light chain kinase (MLCK). When compared with the remainder of the group, subjects homozygous for this rare allele produced significantly elevated CK and Mb activity following the maximal eccentric exercise.

In our laboratory it has been noted that subjects with a Japanese heritage often produced larger CK activity following eccentric exercise than those of Caucasian subjects. In a number of studies mean peak CK activity of between 15,000 – 20,000 $\mathrm{IU \cdot L^{-1}}$ was recorded for the untrained male Japanese subjects (Nosaka & Newton, 2002c; Nosaka, Newton et al., 2002a; Nosaka & Sakamoto, 2001; Nosaka et al., 2001b) following 24 maximal eccentric actions of the elbow flexors, which contrasted with values of under 10,000 $\mathrm{IU \cdot L^{-1}}$ for exercise of the same muscle groups in untrained Caucasians (Clarkson et al., 1992; Evans, Knight, Draper, & Parcell, 2002; Jones et al., 1987; Paddon-Jones et al., 2000; Saxton et al., 1995; Smith, Keating et al., 1994). In all bar one of the cited Caucasian studies maximal eccentric exercise consisted of appreciably more than 24 actions, however, the majority included both male and female subjects which may have impacted on the mean peak CK activity.

Studies involving other Asian populations have not shown the same magnitude of peak CK activity as seen in the Japanese groups following maximal eccentric exercise of the elbow flexors. Chen and Hsieh (2000) reported that untrained male Taiwanese subjects produced mean peak CK activity of approximately 4000 IU·L$^{-1}$ following performance of 3 sets of 10 maximal eccentric contractions of the elbow flexors. In a subsequent study administering the same eccentric exercise protocol to 22 untrained Taiwanese males, mean peak CK activity of slightly over 10,000 IU·L$^{-1}$ was recorded (Chen & Hsieh, 2001). When Chen (2003) had 9 untrained Taiwanese males perform 30 maximal eccentric contractions of the elbow flexors peak CK activity of approximately 13,000 IU·L$^{-1}$ was recorded 5 days following the exercise intervention. Zainuddin et al. (2005; , 2005) and (2006) subjected untrained male and female Malaysian individuals to 10 sets of 6 maximal eccentric actions of the elbow flexors and recorded peak CK activity of less than 4,000 IU·L$^{-1}$ following exercise for each of the three studies.

In terms of other criterion measures, differences also seemed to be evident between studies of Japanese and other races, with the Japanese subjects recording changes of slightly greater magnitude. It is difficult, though, to make definitive comparisons between the experiments due to differences in some of the exercise protocols and the method of determining certain criterion measures, as well as the inclusion of both genders in several of the studies. In order to provide a more controlled comparison between Japanese and Caucasians, an environment needed to be established where both groups comprised the same gender, received identical maximal voluntary eccentric exercise, and had equivalent criterion measures evaluated using the same method before and following the exercise intervention.

Therefore, the purpose of the present study was to compare the changes in criterion measures between untrained Caucasian and Japanese males following maximal voluntary eccentric exercise of the elbow flexors.

## 6.2 Methods

### *6.2.1 Experimental Design*

The Caucasian versus Japanese study included two groups of subjects who performed the eccentric exercise intervention on the non-dominant arm. A 2x5 factorial design was employed to investigate the effect manipulation of the independent variable had on the dependent variables. The independent variable was racial background (Caucasian or

Japanese), and the dependent variables were the criterion measures described below (section 6.2.4) and in chapter 3 (section 3.6). The main experimental period consisted of a block of 5 consecutive days of measurement preceded by two familiarization sessions. The time course of the testing sessions is described in section 6.2.4 below.

### *6.2.2 Subjects*

Thirty male subjects, 15 Caucasian and 15 Japanese, volunteered to take part in the study, however, one subject of each racial background withdrew prior to all of the data being collected. The mean ± SEM age, height, and weight of the remaining 28 subjects is shown in Table 11 below (section 6.3.1). All subjects completed informed consent forms and a medical questionnaire and were free of any disease or injuries that would contraindicate their inclusion in the study.

### *6.2.3 Eccentric Exercise Bout*

The exercise intervention consisted of 10 sets of 6 maximal voluntary eccentric actions of the elbow flexors against the lever arm of the isokinetic dynamometer (Cybex 6000, Ronkonkoma, NY, USA.) moving at constant velocity of $90^{o}\cdot s^{-1}$. A detailed explanation of the protocol is provided in chapter 3 (section 3.4).

### *6.2.4 Timetable of Criterion Measures*

The criterion measures evaluated in the present study included MVC torque (isometric $90^{o}$ only), ROM, upper arm circumference, CK activity and muscle soreness. All of the criterion measures were recorded during the two familiarisation sessions which were completed in the week preceding the eccentric exercise intervention. Table 10 shows the other testing sessions during which the criterion measures were evaluated. During each testing session the order in which the criterion measures were taken remained consistent commencing with CK followed by muscle soreness, ROM, upper arm circumference, and concluding with MVC torque. The criterion measures that were collected in this study employed the techniques described in chapter 3 (section 3.6).

Table 10

*Timetable of Criterion Measure Testing Prior to and Following the Eccentric Exercise Intervention*

| Criterion measure | Testing session in relation to the eccentric exercise intervention | | | | | |
|---|---|---|---|---|---|---|
| | Pre | Post | Day following eccentric exercise | | | |
| | Pre-ex | Imm | 1 | 2 | 3 | 4 |
| MVC torque | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ROM | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Circumference | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| CK activity | ✓ | | ✓ | ✓ | ✓ | ✓ |
| Soreness | ✓ | | ✓ | ✓ | ✓ | ✓ |

Note. A tick "✓" indicates that testing has taken place at this time point. "Circumference" refers to upper arm circumference. "Pre-ex" and "Imm" refer to immediately preceding and immediately following the eccentric exercise intervention, respectively.

A full description of the methods used to analyse the data of the present study is outlined in chapter 3 (section 3.8).

## 6.3 Results

### *6.3.1 Subject Characteristics and Pre-exercise Criterion Measures*

Table 11 displays a comparison of subject characteristics and selected pre-exercise criterion measures of isometric torque, upper arm circumference, ROM, and CK activity between the Caucasian and Japanese groups.

The Caucasian group was on average 10 years older, five centimetres taller, and 15 kilograms heavier than the Japanese ($p<0.05$). There were also significantly greater pre-exercise measures in the Caucasian group for isometric torque (~22 Nm) and upper arm circumference (~4 cm), however, ROM was $9^o$ less than the Japanese group ($p<0.05$).

Although not statistically significant, pre-exercise CK activity was approximately 29 IU·L$^{-1}$ higher in the Japanese group.

All subjects in both groups reported VAS scores of zero for upper arm palpation, extension, and flexion soreness.

Table 21

*Comparison of Subject Characteristics and Selected Pre-exercise Criterion Measures Between Caucasian and Japanese Groups. Mean and Standard Error of the Mean (SEM) of 14 Subjects are Shown*

| Measure | Caucasian | | Japanese | |
|---|---|---|---|---|
| | Mean | SEM | Mean | SEM |
| Age (yr) | 30.1 * | 1.9 | 20.5 | 0.4 |
| Height (cm) | 177.8 * | 1.4 | 172.6 | 1.1 |
| Weight (kg) | 76.8 * | 1.9 | 61.9 | 1.1 |
| Isometric Torque 90$^{o}$ (Nm) | 65.9 * | 3.9 | 43.6 | 0.9 |
| Circumference Upper Arm (mm) | 282.2 * | 5.2 | 242.7 | 3.3 |
| Range of Motion (degrees) | 132.4 * | 1.1 | 141.4 | 1.9 |
| Creatine Kinase Activity (IU·L$^{-1}$) | 117 | 18 | 146 | 23 |

Note: * denotes that the groups are significantly different at $p<0.05$. Independent t-tests with Bonferroni correction were used for the analyses.

### *6.3.2 Isometric Torque*

Figure 27 (a & b) shows both absolute and normalized (% of pre-exercise) isometric torque for the Caucasian and Japanese groups, respectively, at a fixed angle of 90 degrees of elbow extension. The Caucasian group commenced the study with a mean isometric torque that was approximately 22 Nm greater than that of their Japanese counterparts (Figure 27a). Immediately following the bout of maximal eccentric exercise both groups recorded significant decreases in isometric torque production ($p<0.05$). When normalized to pre-exercise levels (Figure 27b), it is clear that the decrement in isometric torque at this time point was significantly greater for the Japanese group (~59%) than the Caucasian (~37%). Both groups showed continual increases in torque over the subsequent days of testing with the Caucasian and Japanese groups recovering to approximately 82% and 60% of pre-exercise levels, respectively by day 4.

It is evident from Figure 27b that the decrement in normalized torque was significantly greater for the Japanese group at all time points following exercise ($p<0.05$). In percentage terms, however, the rate of recovery in isometric torque from immediately following exercise to the final day of testing was similar with both groups increasing by approximately 19% over this time. Examination of Figure 27 (a & b) indicates that although the recovery over the four days was similar in terms of percentage, the pattern of recovery within the four days varied between the groups. This is supported by the significant time by group interactions ($p<0.05$).

Figure 28 (a & b) show plots of the normalized isometric torque of individual subjects from both the Caucasian and Japanese groups immediately following eccentric exercise and four days later. Inspection of the plots reveals that although the mean values vary significantly, the spread of values in both groups is similar. The coefficient of variation for the Caucasian and Japanese groups immediately following exercise was 14.5% and 15.5%, respectively. Four days after exercise the coefficients of variation were slightly more divergent at 16% for the Caucasian and 20% for the Japanese group.

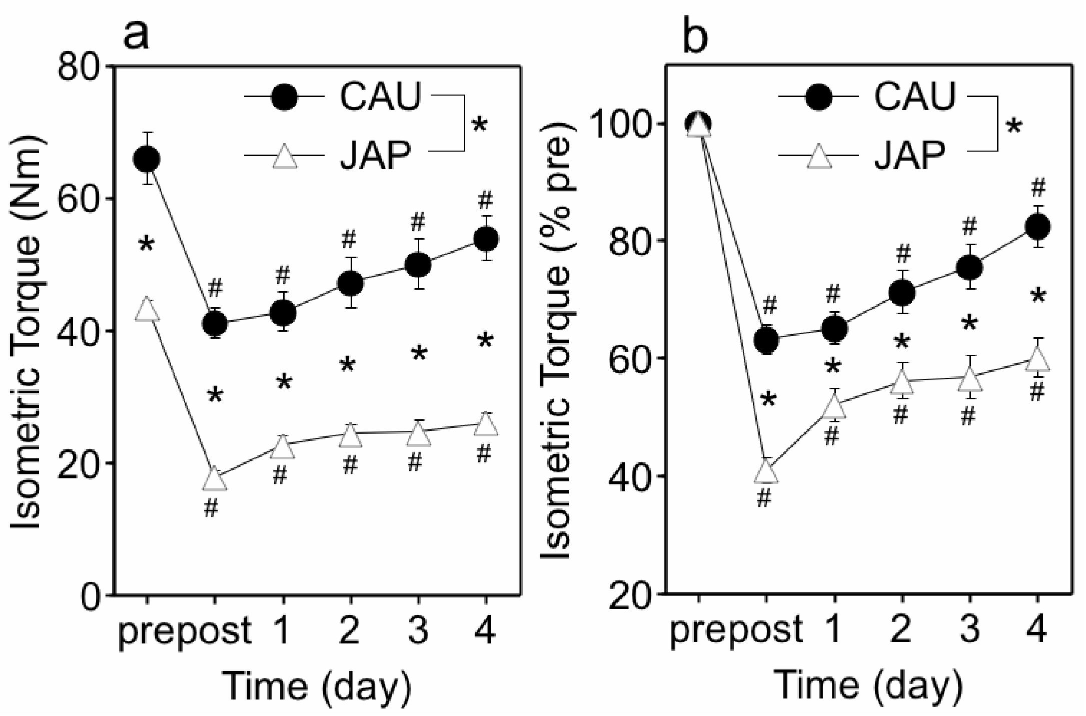

*Figure 27.* Comparison between Caucasian (CAU) and Japanese (JAP) groups for changes in maximum isometric torque (a) and normalised changes in the torque (b) before (pre), immediately after (post), and 1-4 days following exercise. *: significantly different between groups (over all: $p<0.05$, each time point: $p<0.008$), #: significantly different from pre-exercise value.

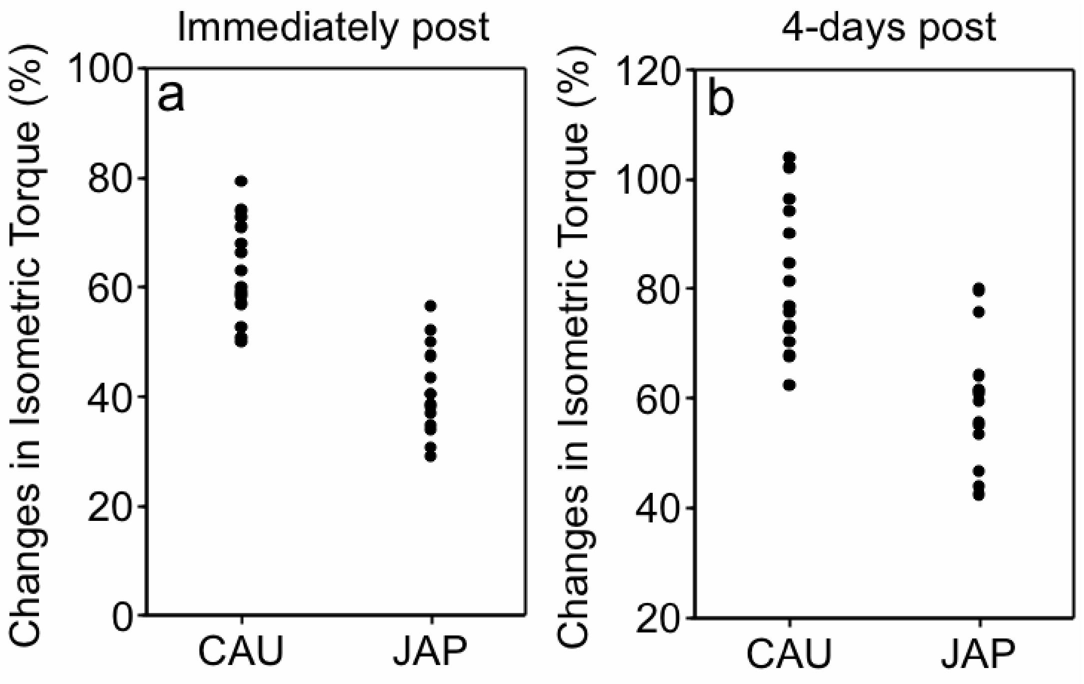

*Figure 28*. Maximum isometric torque level (% pre-exercise value) immediately post-exercise (a) and 4 days post-exercise (b) for each subject in the Caucasian (CAU) and Japanese (JAP) groups.

### *6.3.3 Range of Motion (ROM)*

Figure 29 (a & b) displays absolute ROM and changes in ROM from pre-exercise levels, respectively. Immediately following the eccentric intervention it can be seen that both groups produced significant decreases in ROM ($p<0.05$). It is at this time point that the Japanese group produced their largest decrease in ROM of slightly over 25°. Although in absolute terms (Figure 29 a) the difference is not significant between the groups, when considered in terms of changes in ROM from pre-exercise levels (Figure 29 b) they differed significantly ($p<0.05$). This pattern continues over the subsequent days of testing with no significant differences evident between the groups in absolute terms, however, when considered as changes from pre-exercise levels the groups differed at every testing session ($p<0.05$).

The groups also differed temporally in terms of when they produced their largest change from pre-exercise levels. The Caucasian group recorded their greatest decrease in ROM one day later than the Japanese group.

The contrasts between the groups extended to the magnitude of the change in ROM with the Japanese group producing a decrease of $25.6^{o}$, over double that recorded by the Caucasians ($11.3^{o}$). This difference of approximately $14^{o}$ between the groups was still evident during the final testing session on day 4 following eccentric exercise. The significant time by group interaction reveals that the pattern of changes in ROM over the recovery period were different for each group ($p<0.05$).

Figure 29b shows that although contrasting in terms of magnitude, both groups recorded significant changes in ROM from pre-exercise levels during every testing session ($p<0.05$). By day 4 following exercise both groups had recovered less than $4^{o}$ from their lowest recorded ROM with the Japanese group still experiencing a loss of approximately $22^{o}$.

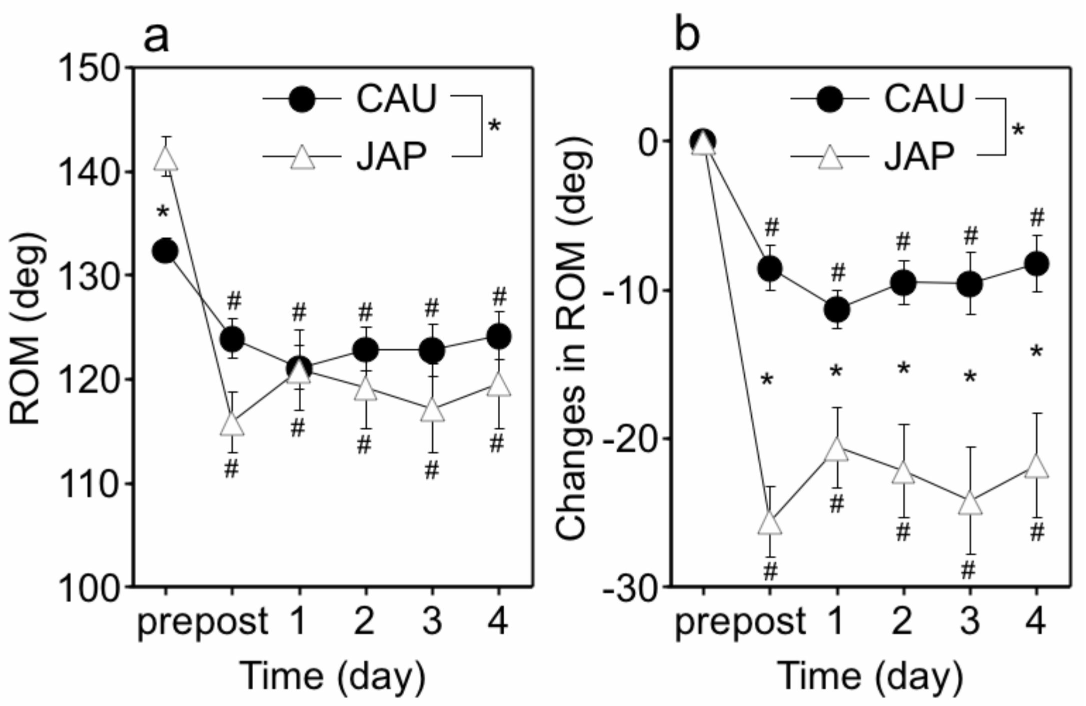

*Figure 29.* Comparison between Caucasian (CAU) and Japanese (JAP) groups for changes in absolute ROM (a) and changes in normalized ROM from the pre-value (b) before (pre), immediately after (post), and 1-4 days following exercise. *: significantly different between groups (over all: $p<0.05$, each time point: $p<0.008$), #: significantly different from pre-exercise value.

### *6.3.4 Upper Arm Circumference*

Significant changes in upper arm circumference from pre-exercise levels were evident following maximal eccentric exercise (Figure 30 a & b). The Caucasian group commenced the study with an average upper arm circumference approximately four centimetres larger than that of the Japanese (Figure 30 a). The circumference of both groups increased significantly from pre-exercise levels immediately following the eccentric exercise intervention ($p<0.05$). The Japanese group recorded a significantly larger increase at this time point with the change in circumference from pre-exercise levels being slightly over three times greater than that of the Caucasian group ($p<0.05$).

Figure 30 (a & b) shows that there was a trend for circumference measures to continue increasing over the subsequent days of the study with each time point following the eccentric treatment significantly greater than pre-exercise values for both groups ($p<0.05$). Although absolute upper arm circumference was significantly different between the groups at all testing time points (Figure 30 a), when the data is treated in terms of change from pre-exercise values (Figure 30 b) the Caucasian and Japanese groups recorded significant differences immediately following exercise, and at days 3 and 4 ($p<0.05$). The significant main effect for time by group interaction is evident upon inspection of Figure 30b where it can be seen that the patterns of increase in circumference are different between the groups ($p<0.05$). From immediately following eccentric exercise to the final day of testing, the upper arm circumference of the Japanese group increased by approximately nine percent which was slightly over two and a half times that of the Caucasian group.

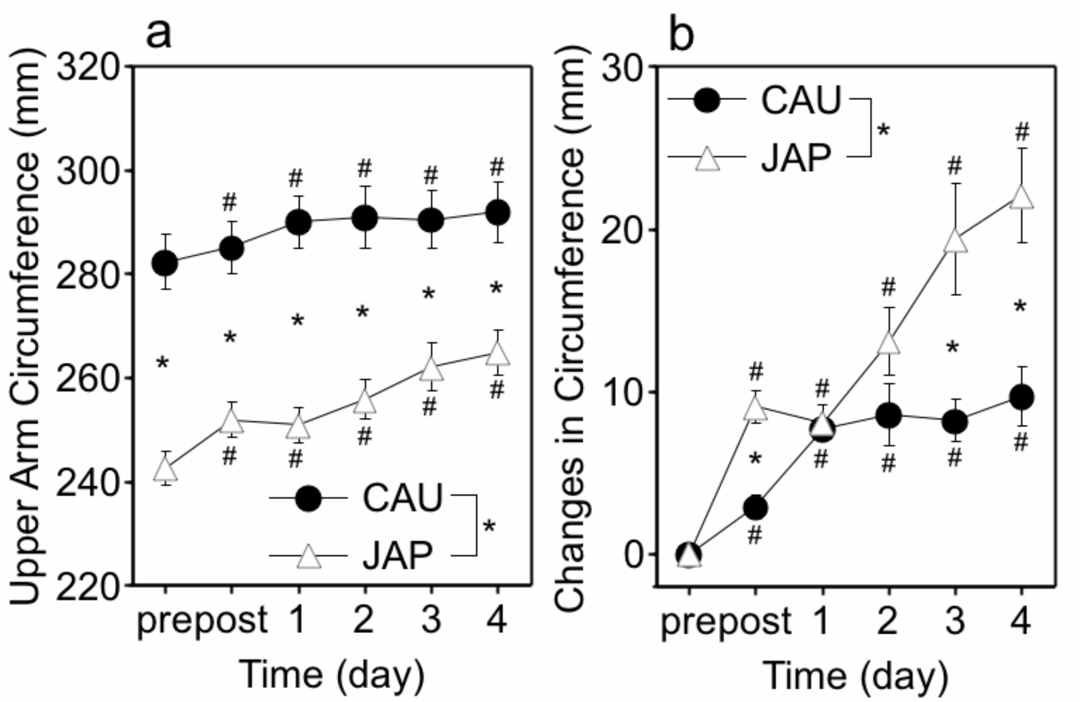

*Figure 30.* Comparison between Caucasian (CAU) and Japanese (JAP) groups for changes in absolute upper arm circumference (a) and changes in the normalised circumference from the pre-value (b) before (pre), immediately after (post), and 1-4 days following exercise. *: significantly different between groups (over all: $p<0.05$, each time point: $p<0.008$), #: significantly different from pre-exercise value.

### *6.3.5 Plasma Creatine Kinase (CK) Activity*

There were striking contrasts between the groups in terms of plasma CK activity following the 60 maximal eccentric actions of the elbow flexors. Figure 31 illustrates the differing pattern of response between the groups over the days of testing. Both groups commenced the study (pre) with mean values in the normal reference range for healthy adults and did not differ significantly in terms of CK activity. By day 4 following eccentric exercise the Caucasian group had increased their CK activity slightly over 12 fold, however due to the intra-group variability of this criterion measure the mean value was not significantly different from the pre-exercise measure. In contrast, the mean CK activity of the Japanese group increased approximately 108 fold over pre-exercise levels and was significantly elevated over baseline at days 3 and 4 ($p<0.05$).

Differences between the groups were significant at days 3 and 4 with the mean value of the Japanese group at day 4 of 15,795 $IU \cdot L^{-1}$ being about 11 times greater than the Caucasian group at the same time ($p<0.05$). Figure 32 shows the CK activity of individuals in the Caucasian and Japanese groups at day 4. Not all 14 data points of each group are visible due to very similar measures in a number of subjects. The highest recorded CK activity by an individual subject in the Caucasian group was 6080 $IU \cdot L^{-1}$. In contrast, 78.5% of the Japanese subjects recorded CK readings that exceeded this value. The largest CK activity measured on a Japanese subject was 33,700 IU $L^{-1}$ (Figure 32).

The pattern of increase in CK activity over the four days following the eccentric exercise treatment was also different between the groups and is reflected by the significant time by group interaction ($p<0.05$).

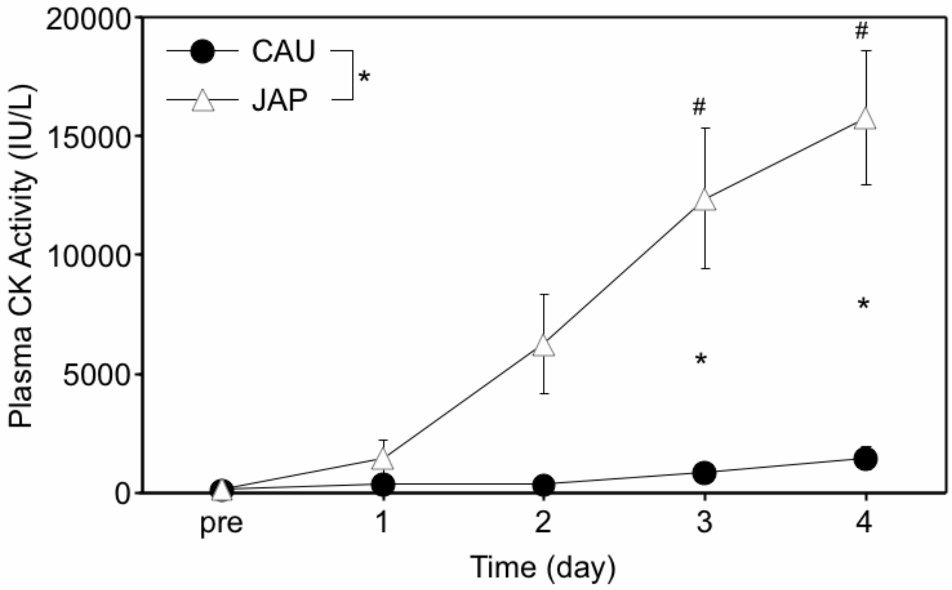

*Figure 31*. Comparison between Caucasian (CAU) and Japanese (JAP) groups for changes in plasma CK activity before (pre), and 1-4 days following exercise. *: significantly different between groups (over all: p<0.05, each time point: p<0.008), #: significantly different from pre-exercise value.

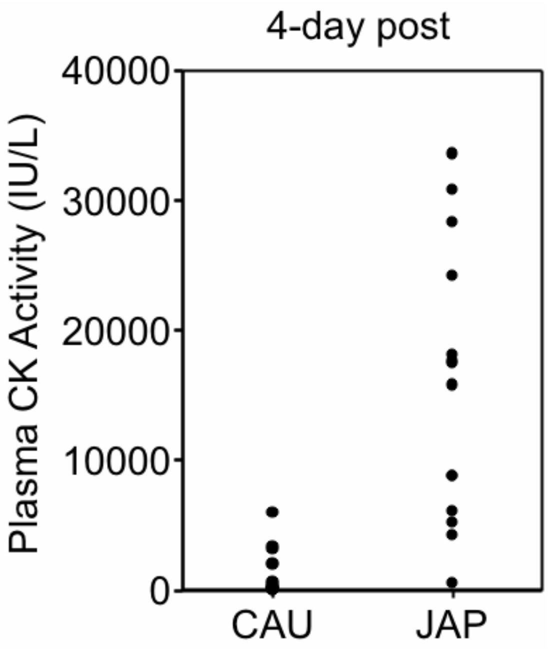

*Figure 32*. Plasma CK activity at 4 days post-exercise for each subject in the Caucasian (CAU) and Japanese (JAP) groups.

### *6.3.6 Soreness*

All subjects from both groups recorded zero (no pain at all) on the visual analog scale for upper arm palpation, extension, and flexion soreness during the pre-exercise testing session (Figure 33 a, b, & c). With the exception of flexion soreness for the Caucasians both groups recorded significant increases in soreness at the first testing session following the eccentric exercise intervention for palpation, extension and flexion ($p<0.05$). The soreness for all measures continued to increase and peaked for both groups at day 2, after which it began to subside.

Upper arm palpation soreness was significantly elevated above pre-exercise levels at all time points following the eccentric intervention for both groups ($p<0.05$), however, at no time was there any significant difference between the groups (Figure 33 a).

Flexion soreness (Figure 33 c) was perceived as being the least sore of the three measures following exercise, however, at specific time points after the eccentric intervention it was elevated significantly above pre-exercise levels by both groups ($p<0.05$). As with upper arm palpation soreness, there was no significant difference between the groups for any of the testing sessions.

In contrast, there were significant differences between the Caucasian and Japanese groups for extension soreness at days 1, 2, and 3 following eccentric exercise. Although the Japanese group was still recording a soreness score in mm double that of the Caucasian's during the final testing session (day 4), the difference was not statistically significant.

The highest mean reading for the Caucasian group of 43.1 mm was recorded for upper arm palpation soreness, whereas the Japanese group perceived the extension measure to be the most uncomfortable with a peak score of 57.4 mm out of a possible 100.

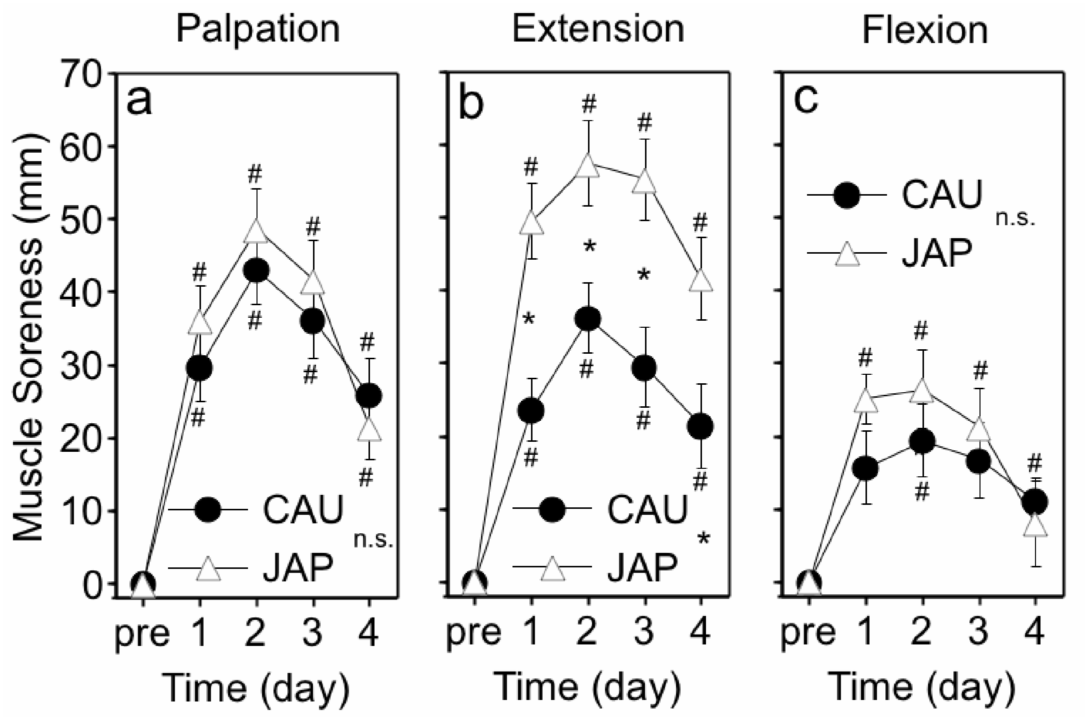

*Figure 33*. Comparison between Caucasian (CAU) and Japanese (JAP) groups for changes in muscle soreness upon palpation (a), extension (b), and flexion (c) before (pre) and 1-4 days following exercise. *: significantly different between groups (over all: $p<0.05$, each time point: $p<0.008$), #: significantly different from pre-exercise value.

## 6.4 Discussion

The purpose of the present study was to determine whether the criterion measures differed between untrained Caucasian and Japanese males following maximal voluntary eccentric exercise of the elbow flexors. To the best of the author's knowledge, this is the first study to compare a number of the more common criterion measures between Caucasian and Japanese subjects subjected to maximal eccentric exercise. The results revealed that there were significant differences evident between the Caucasian and Japanese subjects for all of the criterion measures, however, in terms of soreness this was restricted to only extension scores.

In our laboratories it had previously been noted that untrained Japanese subjects appeared to respond differently to untrained Caucasians. It was, however, difficult to directly compare studies dealing with these two populations due to the differing eccentric exercise interventions employed. In the present study the independent (exercise intervention) and dependent (criterion measures) variables were identical for both groups allowing for direct comparisons to be made.

Maximal voluntary contraction (MVC) torque is a commonly measured variable in exercise muscle damage studies and is considered by Warren et al. (1999) to provide the best measure of muscle injury resulting from eccentric contractions. In terms of isometric torque decrement following the exercise intervention both groups responded in a similar manner to that reported in previous studies (Chapman et al., 2005; Newham et al., 1987; Nosaka & Clarkson, 1994; Nosaka & Newton, 2002b; Nosaka & Sakamoto, 2001; Philippou et al., 2004; Rinard et al., 2000). The nadir occurred immediately following the eccentric intervention and maximum isometric torque progressively recovered over the subsequent four days (Figure 27 a & b). Although the general pattern of isometric torque loss and subsequent recovery was similar for both groups, the magnitude of loss differed with the Japanese group recording significantly greater decrements during each testing session following the intervention.

In order to account for the significant difference in baseline (pre) isometric torque between the groups (Figure 27a) the torque data from each testing session was normalized to pre-exercise values (Figure 27b). The appreciable loss of torque (~59%) recorded by the Japanese group immediately following the eccentric intervention is not unique to this study (Figure 27b). Previous work employing untrained Japanese subjects produced similar decrements in this muscle group immediately following exercise despite the subjects performing only 12 (Nosaka, Newton et al., 2002b) or 24 maximal eccentric actions (Murayama, Nosaka, Yoneda, & Minamitani, 2000; Nosaka & Newton, 2002c; Nosaka et al., 2001b). In these studies, however, the lower volume of eccentric exercise was administered by an apparatus operated manually by the experimenter, and not an isokinetic dynamometer. From previous experience using both types of devices it appears that the manually operated device, commonly employed in the laboratories of Clarkson and Nosaka, produces greater decrements in isometric torque for a given number of maximal eccentric actions.

In previous Caucasian studies the greatest isometric torque decrements following maximal eccentric exercise have varied in magnitude from less than 20% to slightly over 70% (Chapman et al., 2005; Evans et al., 2002; Gleeson et al., 2003; Lee & Clarkson, 2003; Lee et al., 2002; Paddon-Jones et al., 2000; Philippou et al., 2004; Rinard et al., 2000; Saxton et al., 1995; Sayers & Clarkson, 2003; Sayers et al., 2000a; Sayers et al., 2000b). The large variability in isometric torque decrements among these studies may be the result of the gender composition of the groups, the volume of repetitions performed, the velocity of the eccentric contractions, or the method employed to administer the exercise (e.g., isokinetic dynamometer or other). When the studies cited above were restricted to those that used isokinetic dynamometers to administer the exercise, performed no more than 60 repetitions, and employed contraction velocities of $120^{o}\cdot sec^{-1}$ or less (5 studies), then the average decrement in isometric torque was approximately 40%. This figure is within a few percent of that recorded by the Caucasian group of the present study immediately following the eccentric exercise intervention (~37%).

By day 4 of recovery the isometric torque of the Japanese group was still significantly below that recorded by the Caucasians, despite the rate of recovery being similar for both groups. This difference was likely due to the significantly greater decrement in isometric torque of the Japanese group immediately following the eccentric intervention. Studies conducted using a rodent model (Ingalls, Warren et al., 1998a; Ingalls, Warren, Zhang, Hamilton, & Armstrong, 2004) have provided evidence that a major proportion of the decrement in isometric torque in the short-term following eccentric exercise is due to E-C uncoupling. These authors continue to suspect that the cause of this disruption lies at the interface between the dihydropyridine and ryanodine receptors (Ingalls et al., 2004). In a study incorporating untrained men, Deschenes et al. (2000) suggested that the disturbance following exercise containing an eccentric component was probably due to dysfunction within the E-C coupling mechanism. Therefore, it is possible that, following maximal eccentric exercise, the Japanese group was more susceptible than the Caucasians to disruption at the interface described by Ingalls et al. (2004).

The criterion measures of range of motion, upper arm circumference, CK activity, and extension soreness (Figures 29, 30, 31, and 33b, respectively) were also significantly different between the two groups at various time points following the eccentric intervention. In fact, it could be argued that all of the criterion measures in the

Caucasian group, with the exception of palpation and flexion soreness, exhibited a form of repeated bout effect. It is well established that when individuals are subjected to repeated bouts of eccentric exercise, the magnitude of the changes in criterion measures are diminished with respect to the initial novel bout (Clarkson & Tremblay, 1988; McHugh & Tetro, 2003; Nosaka et al., 1991; Nosaka, Newton, Sacco et al., 2005; Nosaka et al., 2001a). If the Japanese group were exposed to an identical bout of eccentric exercise at some time following the first, criterion measures similar to those produced by the Caucasian group could be expected. Nosaka and co-workers have previously reported that a repeated bout effect occurs with groups of Japanese subjects when exposed to an initial bout of full volume maximal (Nosaka, Newton, Sacco et al., 2005; Nosaka et al., 2001a), or reduced volume (Nosaka et al., 2001b) maximal eccentric exercise. Based upon previous repeated bout studies employing Japanese subjects, minor differences to those produced by the Caucasian group may be expected. For example, Nosaka et al. (2005) reported recovery of isometric torque and range of motion to be more rapid following a subsequent bout of identical eccentric exercise. However, in general, when exposed to the same eccentric exercise intervention the criterion measures of the Caucasian group exhibited what looks remarkably like a repeated bout type effect. This is exemplified by the response of creatine kinase activity between the groups. By the final day of testing mean CK activity had increased slightly over 12 fold in the Caucasian group compared to approximately 108 in the Japanese (Figure 31). Plots of individual subject responses during the final testing session (recovery day 4) reveal that all of the Caucasian subjects exhibited CK responses of less than 6500 IU·L$^{-1}$ which was in striking contrast to the Japanese group who had 71% of subjects exceed this value (Figure 32). In fact, 57% of the Japanese group produced CK values in excess of 15,000 IU·L$^{-1}$.

Palpation and flexion soreness were not statistically different between the groups during any of the post-intervention testing sessions (Figure 33a & b). Considering the between group contrasts with regard to the other criterion measures, including extension soreness, it is puzzling why palpation and flexion soreness were rated by the subjects as being similar. A possible explanation involves the subjective nature of rating soreness. Although the most commonly used marker of injury (Warren, Lowe et al., 1999), soreness measured by a visual analog scale is the most subjective criterion measure and is potentially open to larger error.

Although it was not the purpose of the present study to investigate the aetiology of the differences between the two groups, some mention is made concerning potential causes in the section below discussing future studies.

When considering the discussion presented above, the possibility exists that the differences in selected pre-exercise absolute criterion measures between the Caucasian and Japanese groups (Table 11) could account for some, or all, of the significant differences between the groups following the eccentric exercise intervention. Although this possibility cannot be totally discounted the likelihood is appreciably reduced due to the affected criterion measures of both groups being matched at the pre-exercise level by the application of normalizing procedures. Ideally, the groups would have been matched in absolute terms at the pre-exercise stage, however, although this was the intent during the design of the study it proved extremely difficult for a number of reasons. In the first instance, the study was conducted using volunteers and the average age of those that volunteered to complete the experiment was significantly higher for the Caucasian group. Although the contrast in age in the present study is undesirable some recent (2006) unpublished findings of Lavender and Nosaka showed that, with the exception of muscle soreness, young (19-25 yrs) and middle-aged (41-57 yrs) Japanese men did not differ in changes in criterion measures following eccentric exercise.

The second problem involved the size of the subjects in terms of height, weight, and arm circumference. The untrained Japanese subjects were of a smaller stature than their Caucasian counterparts and it was not possible to match them on any of these measures. In a study investigating the nutrient intakes of middle-aged individuals from China, Japan, the United Kingdom, and the United States it was noted that the average body mass index (BMI) was appreciably higher for the Western groups (Zhou et al., 2003). From the problem experienced matching the two groups in the present study, it would appear that a similar trend in BMI is also evident in the younger age groups of these populations.

Whether other Asian populations experience changes similar to those recorded for the Japanese group of the present study is unclear. In order to investigate this question studies would need to control for subject gender, eccentric exercise protocol and criterion measures.  In our laboratory we have recently exercised three groups of Malaysian subjects using an eccentric intervention and criterion measures that were identical to the current study (Zainuddin, Hope et al., 2005; Zainuddin, Newton et al., 2005; Zainuddin et al., 2006), however, a potential confounding variable was that the Malaysian groups were comprised of both genders.  For the criterion measures of isometric torque, arm circumference, and CK the Malaysian groups experienced changes similar to those shown by the Caucasian subjects of the current study.  For range of motion measures the Malaysian groups recorded changes similar to those of the Japanese subjects.  Extension soreness scores of two of the Malaysian groups were similar to the Japanese and one was appreciably higher.  In terms of flexion soreness the two Malaysian groups that had this measure recorded rated the discomfort as appreciably higher than both the Caucasian and Japanese groups.  Future studies could match Malaysian or other non-Japanese groups and investigate whether they differ from a similarly matched Japanese group in the responses of the criterion measures to an identical eccentric exercise protocol.

Prior to investigating the aetiology of any contrasting responses of Japanese and Caucasian populations, it was important to establish that the two population groups did in fact differ in at least one or more of the criterion measures.  Therefore, the design of the present study was not to examine any underlying causes but simply to investigate whether the two groups differed with regard to any of the criterion measures.  Having established that differences are apparent, future studies investigating the discrepant responses of Caucasian and Japanese populations to eccentric exercise could focus attention on a number of areas such as variations in genetics, diet, and daily activity between the groups.  It would also be interesting to examine whether female sub-groups from these populations differ in a similar manner to the males of the present study.

To date, there has been very little research focused on linking post eccentric exercise differences in criterion measures between subjects to genetic factors.  Clarkson et al. (2005) subjected individuals (78 men and 79 women) of varying racial backgrounds to a bout of maximal eccentric exercise of the elbow flexors.  They noted that some of the subjects produced CK and myoglobin activity that was significantly larger than others despite all individuals receiving the same eccentric exercise intervention.  DNA analysis of the subjects revealed that there were a disproportionate number of Asian subjects who were homozygous for the MLCK 49T rare allele of the gene coding for the MLCK. Subjects homozygous for this rare allele produced significantly elevated CK and Mb activity following the exercise. The Clarkson et al. (2005) study also revealed that although the release of CK & Mb from damaged muscle was strongly associated with MLCK C49T genotype, the protracted strength loss was not. On-going research such as that of Thompson et al. (2004), investigating functional polymorpisms associated with human muscle size and strength, may locate other genes and polymorphisms within those genes that are likely to be implicated with the deleterious effects induced by novel eccentric exercise. Chen et al. (2003) have also recently showed that damaging eccentric exercise in humans induced a series of genes involved with stress response, specific growth promotion, and anti-proliferation. As allele frequencies are known to vary as a function of ethnicity (Thompson et al., 2004), examination in this context of any candidate genes and their polymorphisms located from current research may shed light on the apparent contrasting responses of untrained Caucasian and Japanese groups.

Examination of dietary differences between the two ethnic groups may also reveal information that could form the basis of future research investigating the contrasting responses of the criterion measures to the eccentric intervention. It has been shown that the macro- and micro-nutrient composition of the traditional diet of 40-59 year old East Asians differs from that of their Western counterparts (Zhou et al., 2003). Western diets have been found to be higher in total fat, saturated and trans fatty acids, higher in simple sugars, and lower in total carbohydrate and starch (Zhou et al., 2003). A 2002 study by Andersson and colleagues (2002) reported that the fatty acid composition of muscle lipids in skeletal muscle reflects the dietary fatty acid composition of healthy men and women. It has also been shown that regular exercise training (Helge, Wu et al., 2001) or a single bout of eccentric exercise (Helge, Therkildsen et al., 2001) influences fatty acid composition of phospholipids in the muscle membrane. Zhou et al. (2003) reported that the Asian diet was higher in sodium and lower in potassium resulting in an elevated sodium / potassium ratio. Fish intake for all ages is known to be high in Japan (Arisawa et al., 2003), although when dietary fats were classified according to origin, Japanese males and females in their 30s were found to consume less oil of marine origin (Nakamura et al., 1995). Despite these findings the diet of young Japanese males appears to remain isoflavone rich. Lewis et al. (2005) compared 60 Japanese and 60 New Zealand males between 21 and 31 years of age who were consuming traditional diets and found plasma genistein and equol levels that were several times higher in the Japanese males. Their study also revealed that androstenedione, dehydroepiandrosterone, calculated free testosterone and markers of 5alpha-reductase, dihydrotestosterone, and the combined levels of androsterone sulfate and epiandrosterone sulfate were significantly higher in the Japanese males. Levels of the compounds measured by Lewis et al. (2005) were not determined in the subjects of the present study, however, if the Japanese group did possess greater steroidogenesis then it would be interesting to investigate whether this played a role in the contrasting criterion measures between the groups.

Monitoring daily activity of the Caucasian and Japanese subjects in the present study may have shed some light on the differences found between the groups in terms of pre-exercise anthropometric data and responses of the criterion measures to the eccentric intervention. In an attempt to establish whether the untrained Japanese subjects perform less daily activity involving contractions of an eccentric nature, future studies could consider monitoring both the volume and type of activity undertaken by the participants in a selected period prior to the eccentric intervention.

In conclusion, when untrained Caucasian and Japanese males were subjected to a bout of 60 maximal eccentric contractions of the elbow flexors, significantly greater changes in all criterion measures, with the exception of palpation and flexion soreness, were recorded in the Japanese group.

# CHAPTER 7

## SUMMARY AND RECOMMENDATIONS

Despite the substantial body of research accumulated on eccentric exercise-induced muscle damage, there remain several areas that warrant further investigation. In previous chapters it was reported that there are many factors with the potential to influence the magnitude of changes in markers of muscle damage following eccentric exercise. If eccentric exercise study designs incorporate groups with a mixture of these factors, there exists the potential for increased intra-group variability in the responses of the criterion measures leading to a lowered sensitivity for detecting significant inter-group differences.

Of the many factors that have been proposed to influence the magnitude of changes in markers of muscle damage following eccentric exercise, contralateral limb usage, resistance training status, and racial denomination have received limited research attention. In order to address the lack of experimental data relating to these factors, three studies were designed to investigate the following research questions. The first question focused on whether there would be changes in the markers of muscle damage and soreness between contralateral arms of untrained males following maximal eccentric exercise of the elbow flexors. The second question addressed whether the markers of exercise-induced muscle damage and soreness would differ between untrained and resistance-trained males following maximal voluntary eccentric exercise of the elbow flexors. The final question focused on whether there would be changes in the markers of muscle damage and soreness between untrained Caucasian and Japanese males following maximal voluntary eccentric exercise of the elbow flexor muscles.

The initial study incorporated an intra-subject design and examined the first research question by investigating two aspects of intra-subject variability in criterion measures following maximal voluntary eccentric exercise of contralateral elbow flexor musculature (i.e., arms). The first aspect that was addressed related to whether maximal eccentric exercise of the elbow flexors of one arm would influence the response of the same muscle group in the contralateral arm when exposed to a subsequent bout of identical eccentric exercise. In order to remove the effect of arm dominance from this question, the exercise bouts were counterbalanced with dominant and non-dominant arms. The second aspect related specifically to the issue of arm dominance and investigated whether the criterion measures would differ between the elbow flexors of dominant and non-dominant arms. In order to remove any possible effect of cross education protection, the dominant and non-dominant arms were counterbalanced between the two eccentric exercise bouts. Investigation of whether contralateral arms differ in their response to identical eccentric exercise is important as many studies have and will continue to use a model employing both arms to study various interventions. These studies work on the assumption that changes in the markers of exercise-induced muscle damage between contralateral arms do not differ following identical eccentric exercise.

The findings of the first study revealed that for some of the criterion measures there were significant differences between contralateral arms of the first and second eccentric exercise bouts, suggesting that order of exercise plays an important role. However, when dominant and non-dominant arms were compared, there were no significant differences in any of the criterion measures. Therefore, it is recommended that if an intra-subject design is employed using contralateral arms dominant and non-dominant comparisons should be made with arm dominance counterbalanced between the first and second exercise bouts. An important additional finding of the research, though, demonstrated that the correlation was low between dominant and non-dominant arms for changes in criterion measures following maximal eccentric exercise and that the responses of each arm deviated appreciably from the line of identity. This has led to the suggestion that although there was no statistically significant difference between dominant and non-dominant arms, the model may not be sensitive to any small but ‘real’ differences due to an intervention. It is unknown how contralateral arms of resistance trained subjects would respond to identical eccentric exercise. Whether the changes in markers of exercise-induced muscle damage would reflect that shown by untrained subjects remains to be elucidated and it was suggested in chapter 4 that this should be investigated in future work.

The second research question was investigated in study two where the responses of untrained and trained subjects were compared following identical maximal eccentric exercise of the elbow flexor muscles. This research is useful because it employed an identical exercise intervention for both groups, allowing the results to contribute toward our understanding of whether neuromuscular adaptations due to resistance training are effective in attenuating the decrements in muscle function previously shown in research involving untrained subjects exposed to the same exercise intervention. The findings showed that despite both groups performing similarly in terms of torque and total work during the eccentric exercise intervention, the trained subjects produced significantly smaller changes for all of the criterion measures, with the exception of muscle soreness. The responses of the trained subjects were attributed to adaptations consistent with the "repeated bout effect" previously reported in untrained subjects.

In light of the results of the second study three recommendations were made regarding future research. The first suggests that future work should investigate whether a group resistance trained in the traditional style incorporating concentric and eccentric contractions differs from another that employs eccentric only exercise. This suggestion stems from research in untrained subjects that have reported a greater magnitude of exercise-induced muscle damage if the eccentric exercise bout was preceded by concentric work on the same muscle group. The second recommendation for future research invites an investigation into whether chronic exercise training, incorporating significant maximal voluntary eccentric exercise, confers a greater protective effect on criterion measures compared to the traditional style resistance training that incorporates high-intensity concentric but submaximal eccentric loading. The final recommendation urges that there be investigation into uncovering the underlying mechanisms responsible for conferring the adaptations in resistance trained individuals that allows them to experience smaller changes in most markers of exercise-induced muscle damage compared to those that are untrained.

The final research question, designed to address racial differences, was examined in the third study where the responses of the criterion measures to maximal eccentric exercise were compared between Caucasian and Japanese subjects. The findings revealed that racial differences appear to exist as the Japanese subjects produced significantly greater changes in all of the criterion measures, with the exception of upper arm palpation and flexion soreness. The aetiology of the racial differences remain to be elucidated although it was suggested that they may be related to genetic differences in the Asian population as reported by Clarkson et al. (2005).

It was suggested that future studies investigating the differing responses between these two racial groups to eccentric exercise focus on areas such as variations in genetics, diet, and daily activity between the groups. It was also proposed that ensuing studies compare the responses of Caucasian and Japanese females to maximal voluntary eccentric exercise in order to determine whether the results of the male groups are reflected in the opposite gender.

All three studies comprising the present doctoral thesis share more than one common element. Firstly, as mentioned in the opening paragraph of this chapter, they each investigated factors that have been proposed to influence the magnitude of changes in markers of exercise-induced muscle damage and DOMS. However, they also share another commonality in that either directly or indirectly they are concerned with the variability of responses of the criterion measures to maximal voluntary eccentric exercise.

In order to design a model that is sensitive to small changes in the criterion measures following an eccentric exercise intervention, intra-group variability should be minimised. As such, the findings of each of the three presented studies provide information that can be of assistance when forming these types of subject groupings. If difficulty in subject recruitment is an issue and study duration is not as critical, then an intra-subject contralateral limb model may be an attractive option. However, the results of the first study suggest that due to the variability between contralateral arms this model may be no more sensitive than an inter-subject design in detecting small changes in criterion measures. If, however, an inter-subject model is adopted and sensitivity to small changes in criterion measures is important, then results from the final two studies suggest that from a variability standpoint it would not be wise to mix male resistance trained and untrained individuals, and / or Caucasian and Japanese men within a group. Whether the term 'Japanese' can be extended to other Asian populations is unclear and warrants further research. Future studies should also determine whether the findings of the present investigations extend to the female gender.

The studies comprising the present thesis have contributed to the body of knowledge by investigating three factors suspected of influencing the magnitude of changes in markers of exercise-induced muscle damage. The research has provided evidence that these factors do have the potential to impact the results of exercise related muscle damage investigations and as such provide information that could prove useful in future study design.

By way of some concluding remarks I feel that it has been a privilege to conduct research that hopefully contributes some small pieces to the complex jigsaw that is exercise-induced muscle damage. The experimental studies completed as part of the present doctoral work were important because they determined that differences do exist between individuals of different training status and race following maximal eccentric exercise. It was also shown that criterion measure responses of contralateral arms differ significantly if bout order is not counterbalanced across groups. However, the present studies simply described the changes due to the interventions, what is required of subsequent research is to elucidate the underlying mechanisms contributing to the observed differences. With emerging tools and techniques designed to probe such mechanisms, I look forward with anticipation and excitement to contributing to the future research effort.

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# APPENDIX A

# MEDICAL QUESTIONNAIRE

# Medical Questionnaire

The following questionnaire is designed to establish a background of your medical history, and identify any injury and/ or illness that may influence your testing and performance. Please answer all questions as accurately as possible, and if you are unsure about any thing please ask for clarification. All information provided is strictly confidential. If you answer "yes" to any non-exercise related question that may contraindicate you from completing this study a clearance from a qualified medical practitioner will be required prior to commencement of any exercise or testing.

Personal Details

Name:________________________________ ID number:_________________

Date of Birth (DD/MM/YYYY):__________________

**Medical History**

Have you ever had, or do you currently have any of the following?

If YES, please provide details

| | | | |
|---|---|---|---|
| High or abnormal blood pressure | Y | N | ___________________________ |
| High cholesterol | Y | N | ___________________________ |
| Rheumatic fever | Y | N | ___________________________ |
| Heart abnormalities | Y | N | ___________________________ |
| Asthma | Y | N | ___________________________ |
| Diabetes | Y | N | ___________________________ |
| Epilepsy | Y | N | ___________________________ |

Recurring back pain Y N ______________________________

Recurring neck pain Y N ______________________________

Severe allergies Y N ______________________________

Any infectious diseases Y N ______________________________

Any neurological disorders Y N ______________________________

Any neuromuscular disorders Y N ______________________________

Are you currently on any medications? Y N____________________________

Have you had a flu in the last two weeks? Y N____________________________

Have you recently injured yourself? Y N____________________________

Do you have any recurring muscle
or joint injuries? Y N____________________________

Have you had any elbow or
shoulder problems in the past? Y N____________________________

Have you participated in resistance
training in the last 12 months? Y N____________________________

Is there any other condition not previously
mentioned which may affect your upper
arm exercise? Y N____________________________

**Lifestyle Habits**

Do you exercise regularly? Y N

If YES, what do you do?

____________________________________________________________

How many hours per week?

____________________________________________________________

Do you smoke tobacco? Y N

If YES, how much per day?

____________________________________________________________

Do you consume alcohol? Y N

If YES, how much per week?

____________________________________________________________

Do you consume tea or coffee? Y N

If YES, how many cups per day?

____________________________________________________________

Declaration

I acknowledge that the information provided on this form, is to the best of my knowledge, a true and accurate indication of my current state of health.

Participant

Name:________________________________
Date (DD/MM/YYYY):_________________
Signature:_____________________________

Practitioner **(only if applicable)**

**I, Dr ________________________________________ have read the medical questionnaire and information/ consent form provided to my patient Mr_____________________________________, and clear him medically for involvement in the study entitled: (**specific study title was inserted here**).**

Date (DD/MM/YYYY):_________________________

# APPENDIX B

# INFORMED CONSENT FOR STUDY ONE

# Informed Consent Form

For the study

## *Comparison of selected measures of muscle function and soreness between contralateral elbow flexor muscles of subjects following high-intensity eccentric exercise*

Thank you for expressing interest in my research. The reason for providing you with the following information is to fully inform you of the purpose and the nature of the study.

### Purpose of the study

The objective of this study is to investigate whether the contralateral elbow flexor muscles of subjects significantly differ in regard to selected measures of muscle function and soreness following high-intensity eccentric exercise.

### Exercise and Measurements

If you agree to participate in the study, you will be asked to report to the laboratory on nineteen separate occasions. The first and second occasions will be five and three days prior to the first exercise session. These initial laboratory visits will be used to familiarise you with 1) the testing and exercise apparatus, and 2) the testing and exercise procedures that will be employed in the study. The actual exercise and testing will be conducted over two eight-day blocks, with a six-week non-exercise rest period between the blocks. On the first day of each block, you will be asked to perform exercise with one arm. Several measurements will be taken immediately before and after, 30 minutes after, and 1, 2, 3, 4, 5, 6 and 7 days following exercise. We will also require your approval to take a small sample of blood from your finger on eight separate occasions (before, and 1, 2, 3, 4, 5, 6 and 7 days after exercise) for analysis of an enzyme called creatine kinase. During the second block of eight days the other arm, referred to as the contralateral arm, will be exercised and tested. The session will take approximately two and a half hours for the first day, and a maximum of 30 minutes for each of the remaining days of each block. The exercise and measurements will take place at a sports science research laboratory located at Joondalup campus.

*Exercise:* You will be asked to perform your exercise task on a machine known as a Cybex 6000 isokinetic dynamometer. Your upper arm will be resting on the arm support of a preacher curl bench forming a 45-degree angle with the trunk of the body. Your wrist will be secured to the pad of a lever arm, which will cause the forearm to form a 90-degree angle with the upper arm at the starting position. During exercise the lever arm will be driven in a downward motion at $90^o$/ sec by the motor of the Cybex forcing the arm angle to extend to a finish position of 180 degrees in one second. You will be verbally encouraged to maximally resist the motion of the lever arm and thereby produce what we call a “maximal voluntary eccentric contraction” of the elbow flexor muscles. The lever arm, and therefore your arm, will be returned to the starting position at $9^o$/ sec by the Cybex during which time you will be requested to “relax and let the machine move your arm back to the starting position”. Exercise will consist of 10 sets of 6 maximal eccentric repetitions with a 10-second rest between repetitions and a 3-minute recovery between sets.

*Measurements*: The following measurements will be taken from the exercised arm.

Range of motion: Your elbow joint angles will be measured by an investigator using a plastic goniometer when you, in a standing position, try to fully flex the elbow joint to touch your shoulder with the palm, try to straighten the elbow joint, and relax your arm at your side. Range of motion of the elbow joint will be assessed by the difference between the flexed and stretched elbow joint angle. To obtain consistent measurements, four marks will be placed on the skin by a semi-permanent ink marker pen.

Upper arm circumference: Circumference will be assessed by a constant tension tape measure at five sites on your upper arm (3, 5, 7, 9, 11 cm from the elbow crease) when you relax and let the arm hang down by your side. To obtain the measurements at consistent sites, the five sites will be marked on the skin over the elbow flexors by semi-permanent ink.

Muscle soreness: Following novel eccentric exercise muscle soreness and tenderness may be experienced by subjects. In this study muscle soreness will be assessed by palpating the selected elbow flexor muscles (primarily the biceps brachii) at a number of sites, and extending and flexing the elbow joint forcibly, during which time the subjects will be asked to report their level of discomfort using a visual analog scale (VAS) with 100 mm line (0: no pain, 100: very painful).

Plasma creatine kinase activity: Creatine kinase is an intramuscular enzyme that may be detected in the blood following novel or unaccustomed exercise. Approximately 50 μl of blood will be collected in a heparinised capillary tube following the piercing of a selected finger with a spring loaded lancet. Blood collection will occur immediately prior to the eccentric exercise task and at 1, 2, 3, 4, and 7 days post exercise. The blood will be immediately assessed by a spectrophotometer for plasma creatine kinase concentration.

Maximal isometric torque: Maximal voluntary isometric torque of the elbow flexors at elbow joint angles of 90 and 150 degrees will be measured twice, for 3-seconds each, using an isokinetic dynamometer and a preacher curl bench.

Force-velocity relationship: Maximal voluntary torque of the elbow flexor muscles will be measured through a set range of motion ($90^o$) for five specific velocities (30, 90, 150, 210, and $300^o$/ sec). Two attempts will be allowed at each velocity and exercise will be performed on an isokinetic dynamometer and a preacher curl bench.

## Risk and Ethical Considerations

You may experience some degree of muscle soreness and decreases in muscle function, such as muscle strength and range of motion, in the days following exercises. You may also experience swelling of the upper arm and forearm. These symptoms are often seen after unaccustomed exercise containing eccentric muscle actions, and will disappear in a week or so.

You will experience transient discomfort when a lancet pierces your finger during the process of blood sampling for creatine kinase analysis. Since blood is withdrawn by an experienced researcher in accordance with a safety manual of blood sampling, risk for infections or injury are negligible. Other measurements employed in the study are risk free.

No direct comparisons between different individuals participating in the study will be made at any stage of the testing. Analysis of data will be made on a group basis with means and variance between selected groups being compared. You are therefore not in competition with any other individuals in the study and will in no way be made to feel that your results are inadequate or incorrect.

All personal information and test results recorded will remain confidential and will not be used for any purpose other than the current study. Moreover, no data analysis will include your name or information that may identify you specifically as a subject.

You will be free to withdraw from this study at any stage and for any reason without prejudice.

## Requirements

As the study is aimed at assessing any changes that may occur across a period of time, you will be requested not to perform unaccustomed exercises or sports activities, not to take any anabolic steroids, anti-inflammatory drugs or nutritional supplements, and not to alter your diet and life style (sleeping time etc) that may influence your results during the experimental periods.
Additionally, as the study involves an exercise protocol, it is required that you be healthy at the time of testing. For this reason, you will be asked to complete a medical questionnaire prior to the commencement of testing.

Should you have any questions relating to any of the information provided above, please feel free to contact me for a further explanation. If you have any concerns about this research, or would just like to speak to an independent person, you may contact the Head of our School, Assoc Prof. Barry Gibson on telephone (6304 5037).

Thank you very much for your cooperation and contribution to the study.

Yours Sincerely,

Mike Newton B.App.Sci (Hons) MSc. (PhD candidate)
School of Biomedical and Sports Science, Edith Cowan University
100 Joondalup Drive, Joondalup WA 6027
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## Declaration

I ______________________________________________ have read all of the information contained on this sheet, have completed a medical questionnaire, and have had all questions relating to the study answered to my satisfaction.

I agree to participate in this study realising that I am free to withdraw at any time, for any reason without prejudice.

I agree that the research data obtained from this study may be published, provided I am not identifiable in any way.

Participant _______________________________ Date _________________________

Investigator ______________________________ Date _________________________

# APPENDIX C

# INFORMED CONSENT FOR STUDY TWO

# Informed Consent Form

For the study

## *Comparison of selected measures of muscle function and soreness between elbow flexor muscles of trained and untrained subjects following high-intensity eccentric exercise*

Thank you for expressing interest in my research. The reason for providing you with the following information is to fully inform you of the purpose and the nature of the study.

### Purpose of the study

The objective of this study is to investigate whether the elbow flexor muscles of trained and untrained subjects significantly differ in regard to selected measures of muscle function and soreness following high-intensity eccentric exercise.

### Exercise and Measurements

If you agree to participate in the study, you will be asked to report to the laboratory on eight separate occasions. The first and second occasions will be approximately five and three days prior to the first exercise session. These initial laboratory visits will be used to familiarise you with 1) the testing and exercise apparatus, and 2) the testing and exercise procedures that will be employed in the study. The actual exercise and testing for the main component of the study will be conducted over a six day block. Several measurements will be taken immediately before and after, 30 minutes after, and 1, 2, 3, 4, and 5 days following exercise. We will also require your approval to take a small sample of blood from your finger on seven separate occasions (during familiarisation session 1, immediately before, and 1, 2, 3, 4, and 5 days after exercise) for analysis of an enzyme called creatine kinase. The session will take approximately two and a half hours for the eccentric exercise day, and a maximum of 30 minutes for each of the remaining days of each block. The exercise and measurements will take place at a sports science research laboratory located at Joondalup campus.

*Exercise:* You will be asked to perform your exercise task on a machine known as a Cybex 6000 isokinetic dynamometer. Your upper arm will be resting on the arm support of a preacher curl bench forming a 45-degree angle with the trunk of the body. Your wrist will be secured to the pad of a lever arm, which will cause the forearm to form a 60-degree angle with the upper arm at the starting position. During exercise the lever arm will be driven in a downward motion at $90^o$/ sec by the motor of the Cybex forcing the arm angle to extend to a finish position of 180 degrees in just over one second. You will be verbally encouraged to maximally resist the motion of the lever arm and thereby produce what we call a “maximal voluntary eccentric contraction” of the elbow flexor muscles. The lever arm, and therefore your arm, will be returned to the starting position at $12^o$/ sec by the Cybex during which time you will be requested to “relax and let the machine move your arm back to the starting position”. Exercise will consist of 10 sets of 6 maximal eccentric repetitions with a 10-second rest between repetitions and a 3-minute recovery between sets.

*Measurements*: The following measurements will be taken from the exercised arm.

Range of motion: Your elbow joint angles will be measured by an investigator using a plastic goniometer when you, in a standing position, try to fully flex the elbow joint to touch your shoulder with the palm, try to straighten the elbow joint, and relax your arm at your side. Range of motion of the elbow joint will be assessed by the difference between the flexed and stretched elbow joint angle. To obtain consistent measurements, four marks will be placed on the skin by a semi-permanent ink marker pen.

Upper arm circumference: Circumference will be assessed by a constant tension tape measure at five sites on your upper arm (3, 5, 7, 9, 11 cm from the elbow crease) when you relax and let the arm hang down by your side. To obtain the measurements at consistent sites, the five sites will be marked on the skin over the elbow flexors by semi-permanent ink.

Muscle soreness: Following novel eccentric exercise muscle soreness and tenderness may be experienced by subjects. In this study muscle soreness will be assessed by palpating the selected elbow flexor muscles (primarily the biceps brachii) at a number of sites, and extending and flexing the elbow joint forcibly, during which time the subjects will be asked to report their level of discomfort using a visual analog scale (VAS) with 100 mm line (0: no pain, 100: very painful).

Plasma creatine kinase activity: Creatine kinase is an intramuscular enzyme that may be detected in the blood following novel or unaccustomed exercise. Approximately 30 μl of blood will be collected in a heparinised capillary tube following the piercing of a selected finger with a spring loaded lancet. Blood collection will occur during familiarisation session 1, immediately prior to the eccentric exercise task and at 1, 2, 3, 4, and 5 days post exercise. The blood will be immediately assessed by a spectrophotometer for plasma creatine kinase concentration.

Maximal isometric torque: Maximal voluntary isometric torque of the elbow flexors at elbow joint angles of 90 and 150 degrees will be measured twice, for 3-seconds each, using an isokinetic dynamometer and a preacher curl bench.

Force-velocity relationship: Maximal voluntary torque of the elbow flexor muscles will be measured through a set range of motion ($90^o$) for five specific velocities (30, 90, 150, 210, and $300^o$/ sec). Two attempts will be allowed at each velocity and exercise will be performed on an isokinetic dynamometer and a preacher curl bench.

## Risk and Ethical Considerations

You may experience some degree of muscle soreness and decreases in muscle function, such as muscle strength and range of motion, in the days following exercises. You may also experience swelling of the upper arm and forearm. These symptoms are often seen after unaccustomed exercise containing eccentric muscle actions, and will disappear in a week or so.

You will experience transient discomfort when a lancet pierces your finger during the process of blood sampling for creatine kinase analysis. Since blood is withdrawn by an experienced researcher in accordance with a safety manual of blood sampling, risk for infections or injury are negligible. Other measurements employed in the study are risk free.

No direct comparisons between different individuals participating in the study will be made at any stage of the testing. Analysis of data will be made on a group basis with means and variance between selected groups being compared. You are therefore not in competition with any other individuals in the study and will in no way be made to feel that your results are inadequate or incorrect.

All personal information and test results recorded will remain confidential and will not be used for any purpose other than the current study. Moreover, no data analysis will include your name or information that may identify you specifically as a subject.

You will be free to withdraw from this study at any stage and for any reason without prejudice.

## Requirements

As the study is aimed at assessing any changes that may occur across a period of time, you will be requested not to perform unaccustomed exercises or sports activities, not to take any anabolic steroids, anti-inflammatory drugs or nutritional supplements, and not to alter your diet and life style (sleeping time, etc) that may influence your results during the experimental periods.
Additionally, as the study involves an exercise protocol, it is required that you be healthy at the time of testing. For this reason, you will be asked to complete a medical questionnaire prior to the commencement of testing.

Should you have any questions relating to any of the information provided above, please feel free to contact me for a further explanation. If you have any concerns about this research, or would just like to speak to an independent person, you may contact the Head of our School, Assoc Prof. Barry Gibson on telephone (6304-5037).

Thank you very much for your cooperation and contribution to the study.

Yours Sincerely,

Mike Newton B.App.Sci (Hons) MSc. (PhD candidate)
School of Biomedical and Sports Science, Edith Cowan University
100 Joondalup Drive, Joondalup WA 6027
Phone: 6304-5961 E-mail: m.newton@ecu.edu.au

## Declaration

I ______________________________________________ have read all of the information contained on this sheet, have completed a medical questionnaire, and have had all questions relating to the study answered to my satisfaction.

I agree to participate in this study realising that I am free to withdraw at any time, for any reason without prejudice.

I agree that the research data obtained from this study may be published, provided I am not identifiable in any way.

Participant _______________________________ Date _________________________

Investigator ______________________________ Date _________________________

# APPENDIX D

# INFORMED CONSENT FOR STUDY THREE

# Informed Consent Form

For the study

## *Comparison of selected measures of muscle function and soreness between elbow flexor muscles of Caucasian and Japanese subjects following high-intensity eccentric exercise*

Thank you for expressing interest in my research. The reason for providing you with the following information is to fully inform you of the purpose and the nature of the study.

### Purpose of the study

The objective of this study is to investigate whether the elbow flexor muscles of Caucasian and Japanese subjects significantly differ with regard to selected measures of muscle function and soreness following high-intensity eccentric exercise.

### Exercise and Measurements

If you agree to participate in the study, you will be asked to report to the laboratory on seven separate occasions. The first and second occasions will be approximately five and three days prior to the first exercise session. These initial laboratory visits will be used to familiarise you with 1) the testing and exercise apparatus, and 2) the testing and exercise procedures that will be employed in the study. The actual exercise and testing for the main component of the study will be conducted over a five day block. Several measurements will be taken immediately before and after, and 1, 2, 3, and 4 days following exercise. We will also require your approval to take a small sample of blood from your finger on six separate occasions (during familiarisation session 1, immediately before, and 1, 2, 3, and 4 days after exercise) for analysis of an enzyme called creatine kinase. The session will take approximately two and a half hours for the eccentric exercise day, and a maximum of 30 minutes for each of the remaining days. The exercise and measurements will take place at a sports science research laboratory located at Joondalup campus.

*Exercise:* You will be asked to perform your exercise task on a machine known as a Cybex 6000 isokinetic dynamometer. Your upper arm will be resting on the arm support of a preacher curl bench forming a 45-degree angle with the trunk of the body. Your wrist will be secured to the pad of a lever arm, which will cause the forearm to form a 60-degree angle with the upper arm at the starting position. During exercise the lever arm will be driven in a downward motion at $90^{o}$/ sec by the motor of the Cybex forcing the arm angle to extend to a finish position of 180 degrees in just over one second. You will be verbally encouraged to maximally resist the motion of the lever arm and thereby produce what we call a “maximal voluntary eccentric contraction” of the elbow flexor muscles. The lever arm, and therefore your arm, will be returned to the starting position at $12^{o}$/ sec by the Cybex during which time you will be requested to “relax and let the machine move your arm back to the starting position”. Exercise will consist of 10 sets of 6 maximal eccentric repetitions with a 10-second rest between repetitions and a 3-minute recovery between sets.

*Measurements*: The following measurements will be taken from the exercised arm.

<u>Range of motion</u>: Your elbow joint angles will be measured by an investigator using a plastic goniometer when you, in a standing position, try to fully flex the elbow joint to touch your shoulder with the palm, try to straighten the elbow joint, and relax your arm at your side. Range of motion of the elbow joint will be assessed by the difference between the flexed and stretched elbow joint angle. To obtain consistent measurements, four marks will be placed on the skin by a semi-permanent ink marker pen.

<u>Upper arm circumference</u>: Circumference will be assessed by a constant tension tape measure at five sites on your upper arm (3, 5, 7, 9, 11 cm from the elbow crease) when you relax and let the arm hang down by your side. To obtain the measurements at consistent sites, the five sites will be marked on the skin over the elbow flexors by semi-permanent ink.

<u>Muscle soreness</u>: Following novel eccentric exercise muscle soreness and tenderness may be experienced by subjects. In this study muscle soreness will be assessed by palpating the selected elbow flexor muscles (primarily the biceps brachii) at a number of sites, and extending and flexing the elbow joint forcibly, during which time the subjects will be asked to report their level of discomfort using a visual analog scale (VAS) with 100 mm line (0: no pain, 100: very painful).

<u>Plasma creatine kinase activity</u>: Creatine kinase is an intramuscular enzyme that may be detected in the blood following novel or unaccustomed exercise. Approximately 30 μl of blood will be collected in a heparinised capillary tube following the piercing of a selected finger with a spring loaded lancet. Blood collection will occur during familiarisation session 1, immediately prior to the eccentric exercise task and at 1, 2, 3, and 4 days post exercise. The blood will be immediately assessed by a spectrophotometer for plasma creatine kinase concentration.

<u>Maximal isometric torque</u>: Maximal voluntary isometric torque of the elbow flexors at elbow joint angles of 90 and 150 degrees will be measured twice, for 3-seconds each, using an isokinetic dynamometer and a preacher curl bench.

## Risk and Ethical Considerations

You may experience some degree of muscle soreness and decreases in muscle function, such as muscle strength and range of motion, in the days following exercises. You may also experience swelling of the upper arm and forearm. These symptoms are often seen after unaccustomed exercise containing eccentric muscle actions, and will disappear in a week or so.

You will experience transient discomfort when a lancet pierces your finger during the process of blood sampling for creatine kinase analysis. Since blood is withdrawn by an experienced researcher in accordance with a safety manual of blood sampling, risk for infections or injury are negligible. Other measurements employed in the study are risk free.

No direct comparisons between different individuals participating in the study will be made at any stage of the testing. Analysis of data will be made on a group basis with means and variance between selected groups being compared. You are therefore not in competition with any other individuals in the study and will in no way be made to feel that your results are inadequate or incorrect.

All personal information and test results recorded will remain confidential and will not be used for any purpose other than the current study. Moreover, no data analysis will include your name or information that may identify you specifically as a subject.

You will be free to withdraw from this study at any stage and for any reason without prejudice.

**Requirements**

As the study is aimed at assessing any changes that may occur across a period of time, you will be requested not to perform unaccustomed exercises or sports activities, not to take any anabolic steroids, anti-inflammatory drugs or nutritional supplements, and not to alter your diet and life style (sleeping time, etc) that may influence your results during the experimental periods.
Additionally, as the study involves an exercise protocol, it is required that you be healthy at the time of testing. For this reason, you will be asked to complete a medical questionnaire prior to the commencement of testing.

Should you have any questions relating to any of the information provided above, please feel free to contact me for a further explanation. If you have any concerns about this research, or would just like to speak to an independent person, you may contact the Head of our School, Assoc Prof. Barry Gibson on telephone (6304-5037).

Thank you very much for your cooperation and contribution to the study.

Yours Sincerely,

Mike Newton B.App.Sci (Hons) MSc. (PhD candidate)
School of Biomedical and Sports Science, Edith Cowan University
100 Joondalup Drive, Joondalup WA 6027
Phone: 6304-5961 E-mail: m.newton@ecu.edu.au

**Declaration**

I _______________________________________________ have read all of the information contained on this sheet, have completed a medical questionnaire, and have had all questions relating to the study answered to my satisfaction.

I agree to participate in this study realising that I am free to withdraw at any time, for any reason without prejudice.

I agree that the research data obtained from this study may be published, provided I am not identifiable in any way.

Participant ________________________________ Date _________________________

Investigator _______________________________ Date _________________________

# APPENDIX E

# VISUAL ANALOG SCALE FOR RATING OF SORENESS

Name ______________________________________ Bout

Exercised Arm: L R STUDY __________________

D1 D2 D3 D4 D5 D6 D7

Upper arm

Palpation 1 ( 3-5) 0___________________________________________________100

Palpation 2 (9-11) 0___________________________________________________100

Brachialis

Palpation 3 0___________________________________________________100

Forearm

Palpation 4 0___________________________________________________100

Extension & Flexion Soreness

Extension 0___________________________________________________100

Flexion 0___________________________________________________100