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Title: REPRODUCIBILITY AND CHANGES IN TWITCH PROPERTIES ASSOCIATED WITH AGE AND RESISTANCE TRAINING IN YOUNG AND ELDERLY WOMEN

Running Head: Evoked twitch contractile properties

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Abstract

We compared knee extensor twitch contractile properties (TP) between nine young women (20-30 years) and 10 elderly women (63-78 years) and examined changes associated with resistance training in addition to measurement reproducibility. Data were obtained on two occasions three weeks apart after which subjects performed bilateral leg extension and bilateral leg curl exercises three days per week for 10 weeks. TP demonstrated moderate to good reproducibility in both age groups with Pearson’s r and the Intra-class Correlation Coefficient ranging from 0.67-0.85 (p< 0.05) and the technical error of the measurement ranging from 4.2-7.8%. Pre-training, peak twitch torque, rate of torque development, and the rate of relaxation were 24-32% greater for the young women (p< 0.05). Time to peak torque, half-relaxation time, and contraction duration were not significantly different between groups. Post-training, changes of 2.6-6.1% were observed in TP; however these changes were not significant in either group. These data suggest the presence of an age-associated slowing in the rate of muscle contraction. Furthermore, the lack of change in TP in both groups suggests resistance training failed to alter contractile function. However, these findings are discussed in relation to measurement reproducibility and the meaningfulness of the data obtained.

Key Words: Evoked twitch properties, Knee extensors, Ageing, Women, Reliability, Strength training
INTRODUCTION

Undoubtedly, the most notable decline in physical performance associated with ageing is the reduction in maximal voluntary isometric joint torque (MVC), which generally becomes significant after the sixth decade of life (Akima et al. 2001; Bemben et al. 1991). In addition to the reduction in MVC, ageing is also accompanied by changes in evoked twitch contractile properties, in which stimulated forces are often lower and the rate of contraction is slowed compared with young individuals (Roos et al. 1999). Such age changes in evoked twitch properties have been reported in a variety of muscle groups, including the ankle dorsiflexors (Vandervoort and McComas 1986) and plantar flexors (Pääsuke et al. 2000), triceps surae (Klein et al. 1988), elbow flexors (Doherty et al. 1993b), and gastrocnemius (Petrella et al. 1989). However, studies specifically examining age-associated changes in evoked twitch properties of the knee extensors are limited and have not been adequately examined (Cannon et al. 2006; Roos et al. 1999). This is surprising as knee extensor strength has a strong correlation with functional status and a variety of performance measures in older adults, including walking speed, chair rise time, and the risk of falls (Hyatt et al. 1990; Kwon et al. 2001). As such, examining age-associated changes in knee extensor evoked twitch properties may provide additional insight into the etiology of the age-associated impairment of knee extensor muscle performance.

Although ageing is associated with a significant reduction in MVC, elderly individuals can achieve considerable strength gains through resistance training (cf Macaluso et al. 2004). Although neural mechanisms contribute to strength development associated with resistance training in the elderly (Häkkinen et al. 1998a; Häkkinen et al. 1998b; Cannon et al. 2007), older individuals also experience muscle hypertrophy (Charette, et al. 1991; Häkkinen et al. 1998a; Häkkinen et al. 1998b; Häkkinen et al. 2001; Cannon et al. 2007) and alterations in fiber-type proportions (Häkkinen et al. 2001; Häkkinen et al. 1998a). Furthermore, resistance training in the young and elderly have been demonstrated to improve single fiber function, including peak tension, increased maximal rate of sarcoplasmic
reticulum Ca^{2+} uptake, and various force-velocity parameters (Hunter et al. 1999; Trappe et al. 2001; Trappe et al. 2000). However, few available studies has examined the effect of resistance training on evoked twitch properties in the elderly (Brown et al. 1990; Rice et al. 1993) and age comparisons are lacking (Hunter et al. 1999). Since the evoked twitch represents the basic functional component from which motor output is comprised, investigating the effects of resistance training on evoked twitch properties in the elderly is important as such changes may influence the expression of MVC independent of increased muscle recruitment or muscle hypertrophy (Rice et al. 1993).

While there is much value in comparing evoked twitch properties between the young and elderly, and examining changes associated with resistance training, the usefulness of such studies are dependent on data demonstrating acceptable reproducibility. Reproducibility refers to measurement stability when a testing protocol is executed repeatedly (Hopkins et al. 2001). Knowledge of measurement reproducibility is important as using a testing protocol with inadequate reproducibility may lead to erroneous results regarding differences between subjects and/or changes within subjects due to high levels of measurement error. However, studies examining the reproducibility of evoked twitch properties are limited (Winegard et al. 1998).

The purpose of the present study was to compare knee extensor evoked twitch properties between young and elderly women; and examine the effect of resistance training on evoked twitch properties in both age groups. A further aim of the present study was to evaluate the reproducibility of evoked twitch measurements and discuss the presence of between subject differences associated with ageing and/or within subject changes associated with resistance training against the magnitude of variation within measurements.
MATERIALS AND METHODS

Subject Sample

Nine young women (YW; 25.0 ± 4.0 years, height 167.7cm ± 7.6cm, mass 71.4 ± 10.1kg and BMI 25.9 ± 4.5 kg/m²) and 10 elderly women (EW; 67.1 ± 6.6 years, height 166.0 ± 6.0cm, mass 69.5 ± 12.7kg, and BMI 27.1 ± 4.2 kg/m²) volunteered to participate in the present study. Subjects were recruited from within the University and the local community and were considered asymptomatic subsequent to completing a pre-activity health questionnaire. None of the subjects had ever been diagnosed with any medical condition thought likely to affect performance, including hypertension, diabetes, or any respiratory, vascular or neuromuscular disease. All subjects were non-smokers and moderately active, regularly participating in various low to moderate intensity recreational activities, such as walking and swimming, 2-3 days per week. None of the participants had any background in regular resistance or endurance training, or competitive sport prior to the study. No subjects had ever taken any medications thought likely to influence the results of the study, including hormone replacement therapy or Angiotension Converting Enzyme (ACE) inhibitors. Written consent was obtained from all participants prior to the commencement of the investigation. The study was conducted with the approval of the Ethics in Human Research Committee of Charles Sturt University. There was no conflict of interest with respect to the present study.

Research Design

The data reported in the present study were obtained over a 13 week period (Figure 1). Subjects were assessed for knee extensor maximal voluntary isometric joint torque (MVC) and evoked twitch properties at the completion of weeks –3, 0, 3, 6, and 10 at the same time of day by the same investigator using identical testing procedures. The first 3 weeks of the study served as a control period where no resistance training was performed with the data obtained at weeks -3 and 0 used to evaluate measurement reproducibility. Data obtained at week 0 was used to examine age-associated differences. A fully supervised resistance training program was performed between weeks 0 and 10. For the entire 13-week period, subjects were instructed to continue participating in normal activities of daily living and
recreational activities that they were usually accustomed, such as walking and swimming, and to avoid any unaccustomed strenuous physical activity. In addition, subjects were instructed not to undergo any changes in diet or consume any nutritional supplements. All data reported were obtained following a thorough familiarisation session conducted approximately 1 week prior to the first test session, which involved subjects performing the evoked twitch assessment and MVC protocols used during testing. The sample size employed in this study is sufficient for assessing measurement reproducibility as the number of subjects involved is highly comparable to previous studies examining evoked twitch properties and neuromuscular adaptations to resistance training (Alway et al. 1989; Rice et al. 1993; Roos et al. 1999; Pääsuke et al. 2000).

Insert Figure 1 about here

**Evoked Twitch and Maximal Voluntary Isometric Joint Torque Testing**

Evoked twitch properties and MVC and of the right knee extensors were assessed using an isokinetic dynamometer (Kin-Com model 125, Chattanooga Group Inc, Hixon, TN) linked to an AMLab system (AMLab Technologies, Lewisham, Australia). Analogue force signals were tapped from an internal circuit board in the dynamometer processor, which was identified from schematics provided by the manufacturer. The force signal was fed to an AMLab system (AMLab Technologies, Lewisham, Australia) where the signal was low-pass filtered and 12-bit A/D converted. A mathematical equation was then developed that converted the electrical signal in volts into units of measurement (ie newtons). This was achieved by linearly loading the force transducer with a series of known forces from 0-1000N with 25N increments. These procedures were performed using a custom designed instrument in AMLab software (AMLab Technologies, Lewisham, Australia). The force values recorded using the AMLab system between 0-1000N had a measurement error <1.2% compared with the actual load applied and the systematic test-retest error was <0.31%. Data sampled at a rate of 2500Hz. For all tests, subjects were seated upright with the hip flexed at 75° (0° being full extension) and the knee flexed at 65° (0° being full extension), which were determined using a goniometer. Furthermore, a 20mm thick plywood board (600mm x
700mm) was placed on the seat under all subjects, which increased chair stiffness. Once the subject was fully positioned they were secured to the Kin-Com via waist and shoulder straps. During all tests subjects crossed their arms against their chest to ensure that additional forces did not contribute to performance. The axis of rotation of the dynamometer was aligned with the lateral epicondyle of the femur with the lower leg attached to the lever arm 1cm above the lateral malleolus of the ankle. At no time prior to or during the assessment of evoked twitch properties or MVC testing did participants engage in any stretching activities.

To limit the influence of post-tetanic potentiation, evoked twitch testing was performed at rest prior to MVC testing where six pulses, each separated by 4 seconds, were delivered to the nerve with the subject at complete rest. This was determined based on the absence of electromyogram signals from the vastus lateralis or vastus medialis and the absence of any load placed on the force transducer other than that due to the effect of gravity on the lower leg. Muscle activation was achieved by percutaneous stimulation of the femoral nerve using a felt pad bipolar electrode with a tip spacing of 30mm (Nicolet Biomedical, Madison, WI) positioned about the medio-anterior aspect of the upper thigh directly below the inguinal fold, which was secured using a velcro strap. The current applied to the nerve was delivered by a Digitimer DS7 stimulator (Digitimer Ltd, Welwyn Garden City, Hertfordshire, England) using a single square-wave pulse with a width of 200μsec (400V with a current of 15-80mA), which was driven by a custom designed instrument using AMLab software (AMLab Technologies, Lewisham, Australia). Initially, the current was manually applied in incremental steps until a muscle twitch of moderate amplitude was observed on the computer monitor. The position of the stimulating electrode was then adjusted medially and/or laterally until the site most responsive to stimulation was located. The electrode was then secured in position and the stimulus intensity was gradually increased until a plateau in twitch amplitude was achieved. Following this, stimulus intensity was increased by a further 25% to ensure that supramaximal stimulation was delivered to the nerve.

Prior to MVC testing, subjects performed a standardised warm-up involving six 5 second submaximal isometric knee extension actions at an angle of 65° knee flexion (0° being full extension); two at ~50% of maximal voluntary effort, two at ~70% maximal
voluntary effort, and two at ~90% maximal voluntary effort. A rest period of 30 seconds separated each of the six submaximal exercises. MVC testing consisted of a minimum of six trials where subjects were instructed to attain peak torque within 2 seconds and continue exerting maximal effort for a period of 5 seconds. A minimum rest period of 1 minute separated each trial and testing continued until the final 3 trials had values within approximately ±5% of each other, which typically required 6-8 trials for each subject. Strong verbal encouragement was provided during all voluntary efforts and subjects received continuous visual feedback of performance from a graphic display on a computer monitor.

For analysis, force data were exported into spreadsheet software and corrected for the effect of gravity on the lower leg offline. Gravity correction was achieved by determining the average force applied to the transducer during the 1 second period immediately prior to the delivery of the stimulus (for evoked testing) and during the 1 second period immediately prior to voluntary muscle contraction (for MVC testing) while the subject was at complete rest. The average force applied to the transducer during these 1 second periods was then used to offset the performance data obtained during testing. This is an appropriate procedure to use for gravity correction in the present study as all contractions were isometric, thus the contribution of non-linear viscoelastic forces are minimal. Following this, performance data were multiplied by lever arm length to express data in units of torque (Nm). MVC was determined from the trial that attained the highest peak torque value and was recorded as the single highest value produced. Twitch torque-time curves were averaged over all evoked contractions with the mean used to determine the following characteristics; 1) peak twitch torque (PT; defined as the highest isometric torque value achieved during the evoked contraction), 2) time to peak torque (TPT; defined as the time from torque onset to PT), 3) half-relaxation time (1/2RT; defined as the time required for PT to decline by half), 4) contraction duration (CD; TPT plus 1/2RT), 5) the rate of torque development (RTD; defined as the mean tangential slope of the twitch torque-time curve between the onset of torque development and PT), and 6) the rate of relaxation (RR; defined as the mean tangential slope of the twitch torque-time curve between PT and 1/2RT). For all evoked twitch contractions, torque onset was defined as the point at which torque data following stimulation
increased beyond 2 standard deviations of the mean torque value calculated over a 1 second period immediately prior to stimulation. A twitch torque-time curve produced by a representative young woman during evoked testing labelled with the time periods used to determine evoked twitch properties is provided in Figure 2.

Insert Figure 2 about here

**Resistance Training Protocol**

Subjects participated in a fully supervised resistance training program for the knee extensors and knee flexors 3 days per week (Monday, Wednesday, and Friday) for a period of 10 weeks. Training involved three sets of 10 repetitions for a bilateral leg extension and the bilateral knee flexion exercises, which were performed using a plate-loaded leg extension and leg curl bench (York Barbell Co., Toronto, ON, Canada). Training intensity was 50% of one repetition maximum (1 RM) during week 1 and 75% 1 RM for weeks 2-10. The lower training intensity during week 1 was used to familiarise the subjects and enhance motor learning of the task prior to exposing them to the higher training intensity. Both exercises were performed throughout the full range of motion with subjects instructed to perform the movements in a smooth, continuous motion without pausing. Each repetition was approximately 5 seconds in duration. The shortening phase of the movement was approximately 2 seconds in duration. A 1 second pause occurred when the load reached the end of range of motion. This was followed by the lengthening phase of the movement, which was also approximately 2 seconds in duration. A rest period of 90-120 seconds separated each of the 3 sets for each exercise and a 3-minute rest period elapsed between exercises. Each training session commenced with a warm-up, which consisted of 1 set of 10 repetitions for each exercise at an intensity of 40% 1 RM. Although data collection was only performed on the knee extensors, the knee flexors were also trained in an attempt to minimise the likelihood of developing any muscular imbalance about the knee joint. 1 RM testing for the bilateral knee extension and bilateral knee flexion exercises were performed prior to training and at 2-week intervals throughout the training period using the method described by Charette et al. (1991). These data were used to adjust training loads as necessary to ensure
that all subjects continued to training at the required intensity. All 1 RM assessments were performed during the Monday training session following the warm-up. After 1 RM testing, subjects were given a 10-minute rest and then performed the required training session as usual. Exercise adherence rates over the training period were 89 ± 3% for the young women and 92 ± 5% for the older women, which were not significantly different based on the results of an unpaired t-test (p= 0.12).

**Statistics**

Measurement reproducibility was analysed using a paired t-test, Pearson’s r, the Intra-Class correlation coefficient (ICC), and the technical error of the measurement (TEM). These procedures were performed using the data obtained at week –3 (test 1) and week 0 (test 2). An alpha model was used for the calculation of the ICC. TEM was calculated as; the square root of the sum of the squared differences between corresponding test scores divided by twice the sample size (Dahlberg 1940) and expressed as a percentage of half the sum of the mean scores for test 1 and test 2 (Duffield et al. 2004). The magnitude of change in each subject across all performance variables associated with resistance training were determined as; Delta (%)= (Week 10 – Week 0) / Week 0. Between group differences and within subject changes associated with training were determined using a two-way ANOVA (group x time). The critical level for significance was set at p< 0.05. These procedures were performed using SPSS (Statistical Package for the Social Sciences version 14.0) software. To determine the clinical (practical) significance of the performance changes observed associated with resistance training measures of effect size (ES) were also calculated. Effect size is expressed in absolute arbitrary units and examines the magnitude of change associated with the intervention relative to the pooled standard deviation and was calculated as; ES= [(Week 10 Group Mean – Week 0 Group Mean) / Pooled Standard Deviation]. Descriptive statistics are presented as the mean ± SD, which were calculated using standard methods.
RESULTS

MVC and evoked twitch properties for YW and EW for weeks −3 and 0 are presented in Table I. No significant difference was observed in MVC between weeks −3 and 0 in either group (p> 0.05). Pearson’s r and the ICC between weeks −3 and 0 for MVC ranged between 0.87-0.94 in both groups (p< 0.05). TEM between weeks −3 and 0 for MVC was 4.3% for YW and 5.9% for EW. No significant difference was observed between weeks −3 and 0 for any of the evoked twitch properties assessed in either age group (p> 0.05). Pearson’s r and the ICC between weeks −3 and 0 for all evoked twitch properties ranged from 0.67-0.85 in both groups (p< 0.05). TEM between weeks −3 and 0 for all evoked twitch properties ranged from 4.2-7.8% in YW and 5.4-8.2% in EW.

MVC, PT, RTD, and RR were significantly higher for YW compared with EW at week 0 (Table I) (p< 0.05). No significant difference between groups was observed at week 0 with respect to PT/MVC ratio, TPT, 1/2RT, or CD (p> 0.05).

<<Insert Table I about here>>

MVC and evoked twitch properties over the course of the 10-week resistance training period for YW and EW are presented in Table II. At the completion of the resistance training period, MVC increased by 16.0 ± 2.9% and 18.0 ± 2.7% in YW and EW, respectively (p< 0.05). The magnitude of the increase in MVC associated with resistance training was not significantly different between groups (p> 0.05). PT/MVC ratio was significantly reduced after resistance training by 10.5 ± 2.5% and 12.2 ± 1.2% in YW and EW, respectively (p< 0.05), and the magnitude of the decreases observed were not significantly different between age groups (p> 0.05). Although changes in all other evoked twitch properties ranging from 1.2-6.4% were observed in YW and EW, these changes did not reach statistical significance in either group (p> 0.05).

<<Insert Table II about here>>
DISCUSSION

We compared knee extensor evoked twitch properties between young and elderly women and examined the effect of resistance training on evoked twitch properties in both age groups. We observed that PT, RTD, and RR were significantly higher for the young women compared with the elderly, however the PT/MVC ratio, TPT, 1/2RT, and CD were comparable between groups. These data suggest that ageing in women is associated with a significant change in evoked twitch performance of the knee extensors, specifically a reduction in twitch torque and a decline in the rate of contraction and relaxation.

Furthermore, at the completion of the resistance training period all evoked twitch properties, other than the PT/MVC ratio, remained unchanged in both groups. These data suggest that the evoked twitch properties of the knee extensors in young and elderly women may not be responsive to a resistance training intervention. However, before any conclusions regarding the present results can be made, it is necessary to evaluate the magnitude of the between subject differences associated with age and the within subject changes associated with resistance training against the reproducibility of the measurements.

Because there is no preferred method to evaluate measurement reliability and no single statistical approach is universally recommended (Hopkins et al. 2001), assessing measurement reproducibility is somewhat problematic. Furthermore, as only one available study has examined the reproducibility of evoked twitch properties (Winegard et al. 1998) an established approach and the criteria for determining sufficient measurement stability for these data are not currently available. In this regard, we used three approaches to evaluate measurement reproducibility; a paired t-test, the ICC, and the TEM. These approaches were selected as they have been used in combination consistently in the literature for assessing the reproducibility of a variety of voluntary neuromuscular parameters (Rainoldi et al. 2001; Todd et al. 2004).

It has been suggested that Pearson’s $r \geq 0.80$ (Baumgartner and Jackson, 1998), an ICC $>0.75$ (Fleiss, 1986), and a TEM $\leq 5\%$ (Duffield et al. 2004) represent excellent measurement
stability, while Pearson’s r of 0.65-80 (Baumgartner and Jackson, 1998), ICC 0.60-0.70 (Fleiss, 1986), and TEM of 5-10% (Duffield et al. 2004) represents good reproducibility. We observed that Pearson’s r and the ICC, and the TEM to range from 0.67-0.85 and 4.2-7.8% between tests, respectively, for all evoked twitch properties in both groups. Winegard et al. (1998) examining the reliability of PT, TPT and 1/2RT in the plantar flexors and dorsiflexors of elderly men and women reported comparable results the present study. Pearson’s r, the ICC, and the TEM between tests ranging from 0.86-0.94 and ~5-12%, respectively, for both muscle groups. Furthermore, the reproducibility of our evoked twitch data appears highly comparable to reliability data previously reported for MVC, voluntary activation, and surface electromyography amplitude parameters (Rainoldi et al. 2001; Todd et al. 2004). As such, these results clearly demonstrate the reliability of the data obtained using the present testing procedures. This information may be beneficial for future researchers likely to perform similar assessments.

Although our evoked twitch data appears sufficiently reproducible, the usefulness of the measurements must be determined based on the magnitude of expected differences between groups or changes within subjects over time. As such, only a significant difference between groups or change within subjects that is greater than the error within the measurement can considered meaningful. To this end, the smallest worthwhile difference in knee extensor MVC and evoked twitch properties between groups, or change within subjects associated with resistance training able to be detected using the present measurements is between ~4-8%.

We observed that the maximal force generating capacity of the knee extensors assessed as either MVC or PT was significantly reduced with age, which is in agreement with previous studies examining other muscle groups (Doherty et al. 1993; Pääsuke et al. 2000; Vandervoort and McComas, 1986). In our study, the reductions in MVC and PT were 29% and 26%, respectively. These values are substantially higher than the measurement error observed (<5.8%), which suggest these between group differences represent
meaningful age-associated changes. Much of the age-associated reduction in maximal force
capacity may be explained by a decline in muscle fiber numbers and the atrophy of those
fibers remaining (Lexell et al. 1988). The selective loss of Type II muscle fibers with age has
also been demonstrated (Lexell and Downham 1992), which may serve to accentuate
muscle force losses. We also found that the PT/MVC ratio was highly comparable between
groups, which indicates that the relative reduction in MVC and PT with age were highly
comparable. Pääsuke et al. (2000) reported a significant increase in the PT/MVC ratio of the
plantar flexors in women age 71 years compared with women aged 20 years. These authors
suggested the age-associated increase in the PT/MVC ratio may be related to incomplete
neural activation during the MVC. However, we are of the option that an age-associated
increase in antagonist coactivation during MVC testing may also contribute to an age-
associated increase in the PT/MVC ratio despite complete voluntary activation of the agonist
muscle groups during MVC testing (Häkkinen et al. 1998b). As we failed to observe an age-
associated change in the PT/MVC ratio it is probable the age changes described above were
not apparent in the elderly women involved in our study.

Significant age-associated declines of 32% and 28% were observed in RTD and RR,
respectively. As the RTD and RR measurements demonstrated an error of ~7-8%, the
observed difference between groups most likely represents a meaningful age-associated
change within these properties. The age-associated decline in RTD observed in the present
investigation is in agreement with previous studies examining the dorsiflexors in men
(Connelly et al. 1999) and the plantar flexors in women (Pääsuke et al. 2000). Because RTD
is thought to be largely dependent on the speed of cross-bridge formation (Lewis et al. 1986),
the decline in RTD associated with age may reflect a depression in muscle Ca²⁺ kinetics
(Delbono et al. 1997;Hunter et al. 1999;Hunter et al. 1999). A previous study has also
reported an age-associated decline in RR in women (Pääsuke et al. 2000). As RR is
primarily affected by sarcoplasmic reticulum Ca²⁺ re-uptake and the rate of cross-bridge
detachment (Westerblad et al. 1997), the age-associated decline RR probably indicates a
reduction in the efficiency of sarcoplasmic reticulum to reabsorb Ca²⁺ (Klitgaard et al. 1989;
Petrella et al. 1989). Although direct evidence is lacking, it has been suggested the age-associated reduction in the rate of muscle contraction and relaxation is related to the remodelling of motor unit pools and the selective denervation of Type II muscle fibers (Larsson et al. 1979).

Despite declines in RTD and RR with age, TPT, 1/2RT, and CD were not significantly different between groups. The comparable TPT, 1/2RT, and CD measurement between age groups despite the decreases in RTD and RR observed in EW most probably reflects the fact that TPT, 1/2RT, and CD are quantified solely on the time course of the twitch contraction/relaxation cycle. In contrast, RTD and RR are quantified based on the velocity at which PT is attained or declines. As such, peak twitch amplitude and the time course of twitch contraction and relaxation are both considered within the calculation of RTD and RR. However, it should be noted that as the measurement error between tests for TPT, 1/2RT, and CD ranged from 4.9-7.3%, a meaningful difference between age groups of up to ~8% may have been present but was unable to be detected using the present testing protocol.

A significant decrease in the PT/MVC ratio following resistance training is yet to be reported in the literature. This observation appears to be a meaningful outcome associated with the resistance training in both YW and EW as the ~10-12% decreased observed is substantially greater than the ~4-6% error of the method. We suspect this finding would be related to the greater contribution from neural mechanisms to MVC associated with resistance training (Häkkinen et al. 1998a; Häkkinen et al. 1998b; Cannon et al. 2007). In contrast, all other evoked twitch properties remained statistically unchanged at the completion of the resistance training period in both groups. Previous studies examining changes in evoked twitch properties associated with resistance training in the young and/or elderly provide equivocal results. For instance, Always et al (1989) reported that resistance training of the plantar flexors in young men resulted in a significant increase in RTD and a significant decrease in CD, while PT and RR were unchanged. Brown et al. (1990) examining elderly men observed that at the completion of the resistance training period the trained elbow flexors exhibited a
significant increase in 1/2RT compared with the untrained limb, while PT and TPT remained comparable between the trained and untrained limb. Hunter et al. (1999) reported that 1/2 RT and RR remained unchanged following a period of resistance training of the knee extensors in both young and elderly women. Furthermore, Rice et al. (1993) examining elderly men reported that resistance training of the elbow flexors significantly increased TPT, however PT, 1/2RT, RTD and RR remained unchanged. A possible reason for the contrasting reports between studies may be related to the inability to consistently detect within group differences in evoked twitch properties over time due to insufficient measurement reproducibility. In our study, a change within subjects over time of up to ~8% may have been present but was unable to be detected due to the error of the measurement. As such, it appears that MVC may be a more sensitive in detecting changes in muscle performance with resistance training, and therefore may be a more useful measure when assessing resistance training-induced adaptations in muscle properties.

Although measurement error may have limited the ability to identify a change in the evoked twitch properties following resistance training in the young and elderly women, it is possible that the altered expression of the evoked twitch response following training may have been masked due to musculotendinous compliance. Although it has been reported that resistance training in the young (Kubo et al. 2002) and elderly (Reeves et al. 2003a; Reeves et al. 2003b) is associated with a significant increase in patellar tendon stiffness, the stress-strain relationship exhibited by patellar tendon remains curvilinear (Reeves et al. 2003a). As such, it is possible that the stress applied to the tendon during evoked testing may not have been sufficient to strain the tendon to the point as which maximal stiffness was achieved. In this way, it is plausible that the musculotendinous unit may have partially dampened the application of PT to the lower limb during assessment. Support for this comes from studies demonstrating that resistance training is associated with a reduction in the twitch force/tetanus force ratio (Hill 1951; Sale et al. 1982). Due to the extreme discomfort associated with tetanic stimulation of the knee extensors, we did not assess the PT/tetanus torque ratio in the present study. As such, the extent to which young and elderly women
exhibit adaptations in evoked twitch properties associated with resistance training is yet to be fully determined. To clarify these issues we recommend that the effects of resistance training on contractile apparatus function, evoked twitch properties, and tendon compliance be examined in a single study.

Although measurement error and musculotendinous compliance may have limited our ability to detect age-related changes and resistance training-induced changes in some of the evoked twitch contractile properties, the influence of knee joint angle and the duration of the training period should also be considered. As evoked testing was performed at a knee angle of 65º flexion (0º being full extension) it is possible that the contractile apparatus may have been in a sub-optimal position for evoked twitch testing as a low level of resting tension would have been applied to the musculotendinous unit. As a result, the early phase of the evoked contraction may have used to absorb the slack within the contractile system. However, as no available studies have compared the evoked twitch response across different joint angles we can only speculate regarding the effect that the present knee angle may have on the data obtained. Additionally, we also suggest that future investigations in this area that are likely to employ the same method we have described to assess evoked twitch contractile properties perform their study over a longer training duration (eg 16-24 weeks). Longer duration resistance training may result in greater contractile adaptation. This could increase the signal to noise ratio, thereby enhancing the likelihood that meaningful training-induced changes in contractile function may be detected.

**PERSPECTIVES**

We observed a significant age-associated reduction in PT, RTD and RR. These age-associated changes appear to be highly meaningful as the magnitude of the differences observed between age groups were substantially greater than measurement variability. As such, these data demonstrate an age-associated decline in knee extensor contractile function in women. In contrast, PT/MVC, TPT, 1/2RT and CD were not significantly different between age groups, which suggests these parameters may not be as suitable in identifying
age-associated changes in evoked contractile function as PT, RTD, or RR. Furthermore, we
failed to observe a change in evoked twitch properties in either the young or elderly women
following the 10-week resistance training intervention. The lack of change in these properties
after the training period may be related to inadequate measurement sensitivity and/or the
musculotendinous adaptations that potentially masked the altered expression of the evoked
twitch response. However, it is possible that our ability to observe age-related and training-
induced changes in some of the evoked twitch properties assessed may have been impaired
due to the knee joint angle used for testing and the relatively short duration of the resistance
training period.
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Table I

*Knee extensor MVC and evoked twitch properties for the young women and elderly women at week –3 (test 1) and week 0 (test 2) with Pearson’s r, the Intra-Class correlation, and the mean coefficient of variation between tests.*

<table>
<thead>
<tr>
<th></th>
<th>MVC (Nm)</th>
<th>PT (Nm)</th>
<th>PT/MVC (%)</th>
<th>TPT (ms)</th>
<th>RTD (Nm·s⁻¹)</th>
<th>1/2RT (ms)</th>
<th>RR (Nm·s⁻¹)</th>
<th>CD (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>YW</strong> (n= 9)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test 1</td>
<td>172 ± 25</td>
<td>26.5 ± 3.2</td>
<td>15.4 ± 1.4</td>
<td>69.4 ± 7.5</td>
<td>380 ± 43</td>
<td>66.9 ± 8.8</td>
<td>204 ± 28</td>
<td>136.3 ± 16.0</td>
</tr>
<tr>
<td>Test 2</td>
<td>169 ± 19#</td>
<td>26.4 ± 2.5#</td>
<td>15.6 ± 1.2</td>
<td>68.4 ± 6.3</td>
<td>395 ± 56#</td>
<td>65.3 ± 6.0</td>
<td>215 ± 24#</td>
<td>133.6 ± 11.8</td>
</tr>
<tr>
<td>r</td>
<td>0.91*</td>
<td>0.70*</td>
<td>0.73*</td>
<td>0.74*</td>
<td>0.70*</td>
<td>0.73*</td>
<td>0.71*</td>
<td>0.77*</td>
</tr>
<tr>
<td>ICC</td>
<td>0.94*</td>
<td>0.81*</td>
<td>0.85*</td>
<td>0.84*</td>
<td>0.81*</td>
<td>0.81*</td>
<td>0.82*</td>
<td>0.85*</td>
</tr>
<tr>
<td>TEM (%)</td>
<td>4.3</td>
<td>5.8</td>
<td>4.2</td>
<td>5.1</td>
<td>7.8</td>
<td>6.3</td>
<td>7.4</td>
<td>7.3</td>
</tr>
<tr>
<td><strong>EW</strong> (n= 10)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test 1</td>
<td>127 ± 19</td>
<td>20.1 ± 2.5</td>
<td>16.1 ± 1.6</td>
<td>73.4 ± 7.1</td>
<td>281 ± 34</td>
<td>71.5 ± 7.3</td>
<td>161 ± 24</td>
<td>144.9 ± 14.3</td>
</tr>
<tr>
<td>Test 2</td>
<td>131 ± 21</td>
<td>21.1 ± 2.0</td>
<td>16.4 ± 1.9</td>
<td>71.1 ± 6.0</td>
<td>300 ± 37</td>
<td>70.2 ± 5.5</td>
<td>168 ± 23</td>
<td>141.3 ± 11.2</td>
</tr>
<tr>
<td>r</td>
<td>0.87*</td>
<td>0.83*</td>
<td>0.67*</td>
<td>0.76*</td>
<td>0.70*</td>
<td>0.68*</td>
<td>0.72*</td>
<td>0.72*</td>
</tr>
<tr>
<td>ICC</td>
<td>0.92*</td>
<td>0.84*</td>
<td>0.78*</td>
<td>0.84*</td>
<td>0.80*</td>
<td>0.77*</td>
<td>0.84*</td>
<td>0.81*</td>
</tr>
<tr>
<td>TEM (%)</td>
<td>5.9</td>
<td>5.4</td>
<td>5.8</td>
<td>4.9</td>
<td>7.8</td>
<td>5.5</td>
<td>8.2</td>
<td>5.4</td>
</tr>
</tbody>
</table>

YW= young women; EW= elderly women; MVC= voluntary isometric peak force; PT= peak twitch force; TPT= time to PT; RTD= rate of torque development; 1/2RT= half-relaxation time; RR= rate of relaxation; CD= contraction duration; TEM= technical error of the measurement; r= Pearson’s correlation coefficient between sessions; and ICC= Intra-class Correlation between session. *Indicates significant correlation (p< 0.05). #Indicates significant difference between age groups (p< 0.05). Values presented as mean ± SD.
Table II

Changes in knee extensor MVC and evoked twitch properties in the young women and elderly women associated with 10 weeks of resistance training.

<table>
<thead>
<tr>
<th></th>
<th>MVC (Nm)</th>
<th>PT (Nm)</th>
<th>PT/MVC (%)</th>
<th>TPT (ms)</th>
<th>RTD (Nm·s⁻¹)</th>
<th>1/2RT (ms)</th>
<th>RR (Nm·s⁻¹)</th>
<th>CD (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>YW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Week 0</td>
<td>169 ± 19</td>
<td>26.4 ± 2.5</td>
<td>15.6 ± 1.2</td>
<td>68.4 ± 6.3</td>
<td>395 ± 56</td>
<td>65.3 ± 6.0</td>
<td>215 ± 24</td>
<td>133.6 ± 11.8</td>
</tr>
<tr>
<td>Week 3</td>
<td>174 ± 19</td>
<td>26.1 ± 2.5</td>
<td>15.0 ± 0.8</td>
<td>68.7 ± 7.4</td>
<td>389 ± 43</td>
<td>66.4 ± 5.5</td>
<td>197 ± 17</td>
<td>135.1 ± 12.3</td>
</tr>
<tr>
<td>Week 6</td>
<td>186 ± 17*</td>
<td>25.3 ± 2.5</td>
<td>13.6 ± 1.4*</td>
<td>66.7 ± 6.5</td>
<td>405 ± 45</td>
<td>63.4 ± 5.7</td>
<td>201 ± 18</td>
<td>130.1 ± 11.8</td>
</tr>
<tr>
<td>Week 10</td>
<td>197 ± 22*#</td>
<td>27.6 ± 2.2</td>
<td>13.9 ± 1.0*#</td>
<td>66.0 ± 6.2</td>
<td>414 ± 49</td>
<td>62.0 ± 6.1</td>
<td>227 ± 23</td>
<td>128.0 ± 11.5</td>
</tr>
<tr>
<td>Delta (%)</td>
<td>+16.0 ± 2.9</td>
<td>+3.8 ± 2.0</td>
<td>−10.5 ± 2.5</td>
<td>−3.5 ± 1.1</td>
<td>+5.1 ± 3.1</td>
<td>−5.0 ± 1.9</td>
<td>+5.6 ± 4.0</td>
<td>−4.2 ± 1.2</td>
</tr>
<tr>
<td>ES</td>
<td>1.1</td>
<td>0.4</td>
<td>1.2</td>
<td>0.4</td>
<td>0.4</td>
<td>0.5</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td>EW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Week 0</td>
<td>131 ± 21</td>
<td>21.1 ± 2.1</td>
<td>16.4 ± 1.9</td>
<td>71.1 ± 6.0</td>
<td>300 ± 37</td>
<td>70.2 ± 5.5</td>
<td>168 ± 23</td>
<td>141.3 ± 11.2</td>
</tr>
<tr>
<td>Week 3</td>
<td>136 ± 23</td>
<td>21.1 ± 2.3</td>
<td>15.8 ± 1.5</td>
<td>72.2 ± 5.6</td>
<td>302 ± 34</td>
<td>71.0 ± 5.3</td>
<td>170 ± 19</td>
<td>142.4 ± 10.6</td>
</tr>
<tr>
<td>Week 6</td>
<td>143 ± 22*</td>
<td>21.4 ± 2.4</td>
<td>15.2 ± 1.7*</td>
<td>69.9 ± 5.2</td>
<td>311 ± 43</td>
<td>68.7 ± 4.3</td>
<td>173 ± 17</td>
<td>138.6 ± 9.2</td>
</tr>
<tr>
<td>Week 10</td>
<td>153 ± 24*#</td>
<td>21.7 ± 2.4</td>
<td>14.4 ± 1.6*#</td>
<td>70.3.1 ± 7.2</td>
<td>317 ± 54</td>
<td>68.0 ± 6.6</td>
<td>179 ± 23</td>
<td>132.2 ± 12.5</td>
</tr>
<tr>
<td>Delta (%)</td>
<td>+18.0 ± 2.7</td>
<td>+2.6 ± 1.9</td>
<td>−12.2 ± 1.2</td>
<td>−1.2 ± 2.3</td>
<td>+5.3 ± 6.3</td>
<td>−3.2 ± 4.9</td>
<td>+6.1 ± 3.0</td>
<td>−2.2 ± 2.6</td>
</tr>
<tr>
<td>ES</td>
<td>1.0</td>
<td>0.2</td>
<td>1.0</td>
<td>0.1</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.3</td>
</tr>
</tbody>
</table>

YW= young women; EW= elderly women; MVC= voluntary isometric peak force; PT= peak twitch force; TPT= time to PT; RTD= rate of torque development; 1/2RT= half-relaxation time; RR= rate of relaxation; CD= contraction duration; and ES= effect size. Delta represents the percentage
change from week 1 to week 10. *Indicates significant difference from week 0 (p< 0.05). #Indicates significant difference from week 3 (p< 0.05). Values presented as mean ± SD.
Figure 1- The research design employed in the present study. The first 3 weeks of the study served as a control period where no resistance training was performed where the data obtained between weeks –3 and 0 was used to evaluate measurement reproducibility. Age-associated differences in voluntary peak isometric torque (MVC) and evoked twitch properties of the knee extensors were assessed using the data obtained at week 0. Between weeks 0-10 subjects performed a fully supervised resistance training program where MVC and evoked twitch properties were assessed periodically at weeks 3, 6, and 10, with the data used to assess within subject changes associated with the training intervention.
**Figure 2** - A twitch torque-time curve produced by a representative young woman during evoked testing labelled with the time periods used to determine twitch contractile properties; a) Peak twitch torque (PT); defined as the highest isometric torque value achieved during the evoked contraction. b) Time to PT (TPT); defined as the time from torque onset to PT. c) Rate of torque development (RTD); defined as the mean tangential slope of the twitch torque-time curve between the onset of torque development and PT. d) Half-relaxation time (1/2RT); defined as the time required for PT to decline by half. e) Rate of relaxation (RR); defined as the mean tangential slope of the twitch torque-time curve between PT and 1/2RT. f) Contraction duration (CD); defined as TPT plus 1/2RT. For all evoked twitch contractions, torque onset was defined as the point at which torque data following stimulation increased beyond 2 standard deviations of the mean torque value calculated over the 1 second period immediately prior to stimulation.