The effects of high adiposity on concentric and eccentric muscle performance of upper and lower limb musculature in young and old adults

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THE EFFECTS OF HIGH ADIPOSITY ON CONCENTRIC AND ECCENTRIC MUSCLE

PERFORMANCE OF UPPER AND LOWER LIMB MUSCULATURE IN YOUNG AND OLD ADULTS

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Abstract

The present study uniquely examined the influence of old age and adiposity on maximal concentric and eccentric torque and fatigue of the elbow (EF, EE) and knee (KF, KE) flexors and extensors. 40 males were recruited and categorised into young (n=21, 23.7±3.4) and old (n=19, 68.3±6.1) and then further into normal (young = 16.9±2.5%, old = 20.6±3.1%) and high adiposity (young = 28.9±5.0%, old = 31.3±4.2%) groups. Handgrip strength, sit-to-stand performance, and isokinetic assessments of peak torque at 60°, 120° and 180° s^{-1} were measured. Older men produced significantly less concentric and eccentric peak torque (P<0.016) but this was not influenced by adiposity (P>0.055). For KE and KF, high adiposity groups demonstrated reduced peak torque normalised to body mass (P<0.021), and muscle and contractile mode specific reduction in torque normalised to segmental lean mass. Eccentric fatigue resistance was unaffected by both age and adiposity (P>0.30) and perceived muscle soreness, measured up to 72 hours post, was only enhanced in the upper body of the young group following eccentric fatigue (P=0.009). Despite the impact of adiposity on skeletal muscle function being comparable between ages, these results suggest high adiposity will have greater impact on functional performance of older adults.

Novelty:

- Irrespective of age, high adiposity may negatively impact force to body mass ratio and muscle quality in a muscle and contractile mode specific manner.

- Whilst the magnitude of adiposity effects is similar across ages, the impact for older adults will be more substantial given the age-related decline in muscle function.

Keywords: Eccentric; Muscle Quality; Muscle function; Torque

Abbreviations

ADLs Activities of daily living

ANOVA Analysis of variance

EE Elbow extensors

EF Elbow flexors

IKD Isokinetic dynamometry

KE Knee extensors

KF Knee flexors

OAs Older Adults

Introduction

Recent research indicates that obesity may be detrimental to skeletal muscle function (Maffiuletti et al. 2013; Bollinger 2017; Tallis et al. 2018). However, current work has focused on isometric (force produced whilst the muscle remains at a constant length) and concentric (force produced during shortening) muscle actions of the lower extremities (Miyatake et al. 2000; Hulens et al. 2001; Villareal et al. 2004; Maffiuletti et al. 2007; Capodaglio et al. 2009; Paolillo et al. 2012; Tomlinson et al. 2014b). Effects of obesity on eccentric (force produced during lengthening) muscle actions have not been thoroughly considered. Adequate eccentric force is important for maintaining balance, deacceleration and absorbing impact (Delbaere et al. 2003; Nishikawa et al. 2018). As such, eccentric muscle function is important for physical activity and the completion of activities of daily living (ADLs) including stair descents, descending into a seated position and dynamic balance (Choi 2016; Nishikawa et al. 2018). Obesity effects on isometric and concentric muscle function may not directly translate to eccentric performance. Potential effects of adiposity on the physiological mechanisms resulting in eccentric force production are currently unknown and given differences in mechanisms resulting in concentric and eccentric force production (Herzog et al. 2016), adiposity effects may not be uniform across contractile modalities. Given that changes in concentric and isometric muscle performance are similar in muscle ageing and adiposity it may be that eccentric function is better preserved compared to concentric and isometric contractile function in obesity as in aging (Roig et al. 2010). Furthermore, excessive adiposity is likely to increase eccentric demand (Tallis et al. 2018), particularly during stabilisation and deaccelerating phase of movements, which may result in a favourable eccentric training adaptation.

There is a growing suggestion that obesity may exacerbate the muscle ageing response (Tomlinson et al. 2014c; Hill and Tallis 2019; Eshima et al. 2020). Ageing and obesity induced declines in muscle function share similar mechanistic responses, such as, impaired excitation contraction coupling, shifts in fibre type composition and a reduction in myogenesis (Tallis et al. 2018; Larsson et al. 2019). Unlike in a young population, obesity has been shown to have little effect on the absolute force producing capacity of elderly muscle (Maffiuletti et al. 2013). However, obesity can result in a decline in force to body mass ratio (Miyatake et al. 2000; Villareal et al. 2004; Paolillo et al. 2012; Tomlinson et al. 2014b) and force normalised to muscle size (muscle quality), irrespective of age (Villareal et al. 2004; Tomlinson et al. 2014c; Valenzuela et al. 2020). Diminished muscle quality reflects reduced contractile function per unit of muscle size, and in the case of obesity, results in larger, heavier muscles and in turn an increased force requirement for movement. (Tallis et al. 2018). Despite this important insight, understanding of obesity induced changes in skeletal muscle function is limited. Previous research typically focuses on a single muscle group and a single mode of contractility (isometric or concentric), with limited assessment of muscular fatigue or direct comparisons between young and older groups (Miyatake et al. 2000; Villareal et al. 2004; Capodaglio et al. 2009; Paolillo et al. 2012; Erskine et al. 2017). Work examining the effect of obesity on eccentric function and the concomitant effects of obesity and increasing age on muscle function has been identified as an area of priority (Tallis et al. 2018)

As such, the present study used isokinetic dynamometry (IKD) to uniquely examine the effects of high adiposity and older age on concentric and eccentric maximal voluntary torque and fatigue resistance of the elbow flexors (EF) and extensors (EE) and knee flexors (KF) and extensors (KE). Torque values were also normalised for body mass and segmental muscle

mass, the latter as an indication of muscle quality. Measures of hand grip strength (HGS) and sit to stand (STS) kinetics were used to determine whether differences in concentric and eccentric function were detectable in assessments frequently used as a muscle health screening tool (Beaudart et al. 2019). STS performance also served to provide insight into the functional consequences of changes in peak torque.

Methodology

All procedures were conducted following ethics approval from Coventry University (P76153). Participants visited the human performance laboratory at Coventry University on three occasions. Participants provided written consent and upon each visit completed a departmental health screening questionnaire. Visits were separated by a minimum of seven days and assessments were performed at the same time of day on each occasion. Participants were required to be healthy, non-resistance trained, have no contraindications to exercise, nor suffer from uncontrolled hypertension. Participants were asked to abstain from vigorous physical activity 48 hours prior to testing and to empty their bladder upon arrival. Participants (*N*=40) were categorised into young (18-30) or old (60-80), then sub categorised by age specific body fat percentage (%) into young normal adiposity (YNa; 8-19.9%; N=10), young high adiposity (YHa; >20%; N=11), old normal adiposity (ONa; 13-24.9%; N=11) and old high adiposity (OHa; >25%; N=8), derived using hand to foot multi frequency bioelectrical impedance analysis (MF-BIA; following instructions from the manufacturer, which utilised boundaries from Gallagher et al. [2000]). Participant information and anthropometric data for groups are presented in Table 1.

Experimental Procedures

Familiarisation

The intention of the first visit was to familiarise participants to the experimental procedures to be used in the study.

Body Composition

Shoes, heavy clothing, and jewellery were removed prior to measures being taken. Height was measured using a stadiometer (SECA Instruments Ltd., Germany). Body composition was then determined using hand to foot MF-BIA (TANITA MC-780, TANITA, Japan; impedance frequencies 5, 50 and 250kHz). MF-BIA has previously been shown to have acceptable accuracy for overall and segmental adiposity and lean mass, when compared to dual-energy X-ray absorptiometry (DEXA) and is a reliable method of obtaining body composition measures in the populations being used (Faria et al. 2014; Yamada et al. 2017). MF-BIA devices have been developed to allow for measurements at any time of the day, without the need to impose nutritional constraints (Verney et al. 2015). From BIA assessment, body mass (kg), overall and segmental adiposity (%) and muscle mass (kg) of the limbs and trunk, and body mass index (BMI) were all recorded. All values recorded were measured to the nearest 0.1 kilogram or percentage.

Sit to Stand

Measures of lower extremity function were obtained through three consecutive STS on a force plate (AMTI, AccuGait) sampling at 100Hz (Regterschot et al. 2016). During the STS, arms were folded across the chest (Jannsen et al. 2002), and participants were instructed to stand up as quickly as possible from the chair (seat height 45cm; width 41cm; depth 38.5cm; floor to center of back support 68cm) and remain standing for a minimum of ten seconds before sitting down. Participants were given verbal queues on when to rise and sit down. Peak propulsive force normalised to body mass ($N.kg^{-1}$), rate of force development (RFD; $N.kg^{-1} s^{-1}$) and time to stabilisation (TTS; s) were recorded from each trial. RFD was calculated by dividing the peak force in the standing phase of the movement by time to peak force. Time to stabilisation (s) was calculated by subtracting the time to which the participant is within 5%

of body weight (Wikstrom et al. 2005) for the first of 50 data points by the time at which peak propulsive force occurs. The average results of the three consecutive STS were taken for each trial. All calculations for STS were completed in Microsoft Excel (Windows v. 2016).

Handgrip Strength

Handgrip strength (HGS; kg) was measured using an isometric hand dynamometer (Takei Physical Fitness Test, GRIP-D, Takei Scientific instrument Co. LTD, Japan). Participants were instructed to stand upright, with their arms by their side, whilst gripping the dynamometer maximally (Yeung et al. 2018). Assessment of handgrip was performed three times with the dominant hand for approximately 2-3 seconds, with peak HGS being recorded. Each attempt was separated by 60s rest. Participants were given verbal queues on when to grip the device. Previous literature has proposed that assessing HGS can be a cost effective and valid predictor of overall muscle strength in young and older adults (OAs) (Wind et al. 2010; Bohannon et al. 2012)

Isokinetic Dynamometry

Skeletal muscle contractile performance was further assessed using IKD, in accordance to previously published protocols (Impellizzeri et al. 2008; Tallis et al. 2016). Initially, participants completed a standardised upper body warm-up, consisting of five minutes of arm crank ergometry (Monark 857E Ergomedic, Monark, Varberg, Sweden) using an unloaded cradle and a fixed cadence of 70 revs min^{-1}. This was immediately followed by 5 minutes of dynamic stretches, focusing on the elbow flexors and extensors. Maximal voluntary isokinetic concentric and eccentric torque (N.m) of the elbow flexors and extensors for the dominant

side were measured using IKD (Cybex NORM, Humac2009, v10.000.0082, CA, USA) set up in accordance with the manufacturer's instructions. Participants were strapped to the dynamometer chair in a supine position. The rotational axis of the dynamometer head was aligned with the lateral epicondyle of the humerus. A hand grip bar at the opposing end of the lever arm was adjusted to the length of the hand and forearm to allow the participant a comfortable grip. Participant settings were retained and used for subsequent visits. During concentric measures, participants were instructed to pull upwards towards their shoulder (flexion) and extend their arm outward (extension) as hard a possible through a fixed range of 40° - 120° (relative to anatomical zero for the elbow). This range of motion falls within ranges used during ADLs (Morrey et al. 1981; Malagelada et al. 2014). During eccentric measures, participants were asked to resist the movement of the lever arm moving from 120° - 40°. Maximal concentric and eccentric force were measured at angular velocities of 60°, 120° and 180° s^{-1}. Participants performed several submaximal attempts at each angular velocity to become familiarised with the movements and test speeds (Feiring et al. 1990). During the assessment of maximal voluntary torque, participants performed a series of tests at each angular velocity, with peak torque occurring within 3 repetitions similar to previous work (Sole et al. 2007; Impellizzeri et al. 2008; Tallis and Yavuz 2018). A two-minute rest period was implemented between each set to minimise fatigue. Participants were then familiarised to part of the fatigue protocol to be used in the experimental trials. Participants completed 10 consecutive concentric contractions at 180° s^{-1} of the elbow flexors and extensors. Following a 2-minute rest period, participants then completed 10 eccentric contractions at 180° s^{-1} of the elbow flexors and extensors. All torque values collected were corrected for gravity effects by estimation of limb weight, prior to the assessment of maximal voluntary torque.

Participants then completed a standardised warm up of the lower body, consisting of 5 minutes of cycling (Monark 824E, Ergomedic, Monark, Varberg, Sweden) using an unloaded cradle and a fixed cadence of 70 revs min⁻¹, immediately followed by 5 minutes of dynamic stretches, focusing on the knee extensors and flexors. The IKD was then set up for the assessment of maximal voluntary concentric and eccentric isokinetic torque (N.m) of knee flexors and extensors. Participants were strapped to the dynamometer chair in a seated position, and the lever arm axis of rotation was aligned with the lateral femoral epicondyle of the dominant limb. The distal end of the lever arm was fitted with a shin pad approximately 3cm above the lateral malleolus. A strap was placed across the midpoint of the upper limb of the test leg. Throughout the duration of the test, participants were instructed to hold the handles provided on the chair. The range of motion was fixed at 20°-80° (relative to anatomical zero for the knee) to ensure all participants were able to generate torque throughout the whole movement. The testing protocol was then carried out in the manner previously described.

Experimental Trial One: Concentric Muscle Function

Participants completed the STS, HGS and the concentric IKD protocols, following the procedures previously described. Immediately following both the upper body and lower body assessments of maximal voluntary force, fatigability was assessed via 5 sets of 10 concentric contractions at 180° s⁻¹, with 10 seconds separating each set. Immediately following the session and at 24-hour intervals for the following three days, perceived soreness was assessed using a visual analogue scale (VAS) (Mattacola et al. 1997). Perceived soreness was recorded individually for the upper body and lower body to establish if high adiposity or old age exacerbated the delayed onset of muscle soreness following bouts of consecutive

contractions. To assess perceived soreness of the lower body participants were instructed to assume an unweighted squat of approximately 90 degrees for 3-5 seconds before noting soreness. For the upper body, participants were required to extend their arms to near anatomical zero in front of them, whilst holding a weighted object and then marked their perceived soreness. All absolute torque values were saved and later normalised for body mass (torque/body mass; $N.m.kg^{-1}$) and segmental muscle mass of the limb used (muscle quality; torque/segmental muscle mass; $N.m.kg^{-1}$).

Experimental Trial Two: Eccentric Muscle Function

Participants were asked to complete only the eccentric IKD protocol. Immediately following both the upper body and lower body assessments of maximal voluntary torque, fatigability was assessed via 5 sets of 10 eccentric contractions at $180°$ s^{-1}, with 10 seconds of rest separating each set. Immediately following the session and at 24-hour intervals for the following three days, perceived soreness was assessed using a visual analogue scale (VAS) in the manner previously described. Trials were always performed in the order described as recovery from eccentric induced muscle damage is not well known in these populations and participants may experience a decline in concentric peak torque more than 7 days post eccentric fatigue (Paulsen et al. 2010).

Data Analysis

Statistical analysis was performed using SPSS v.25 (IBM SPSS Statistics for Windows, IBM Corp, Armonk, NY, USA). All data are presented as mean ± SD. Tests of normality (Shapiro-Wilk) and homogeneity (Levenes) were utilised to ensure appropriate analysis of data. When parametric assumptions were not met, non-parametric alternatives were used where

appropriate. As such, Mann-Whitney test was utilised to assess significant differences in age, body mass and BMI. When non-parametric equivalents were not possible, data were transformed using either log10 or SQRT transformations dependent on if the data was left or right skewed. Once transformed, data were reanalysed for normality and homogeneity. Comparisons of anthropometric data, absolute torque, torque normalised to body mass and segmental muscle mass, HGS and STS performance of experimental groups were measured using a two-way analysis of variance (ANOVA), with age and adiposity as the factors. Comparisons of percentage torque loss during fatigue protocols were measured using a three factor (age, adiposity and set) ANOVA, following arcsine transformation of fatigue data. Significant interactions were explored using Bonferroni post hoc for multiple comparisons. Partial eta squared (ηp^2) was calculated to estimate effect sizes for all significant main effects. Thresholds for Partial eta squared effect size were classified as small (<0.05), moderate (0.06-0.137) or large (>0.138) (Cohen 1988). Cohen's d was calculated to measure effect size of any interactions observed. Cohen's d was then corrected for bias using Hedge's g due to the appropriate sample size of each experimental group (Hedges 1981). Cohen's d effect size was interpreted as trivial (<0.2), small (0.2-0.6), moderate (0.6-1.2) or large (>1.2) (Hopkins et al. 2009). The truncated product method (Zaykin et al. 2002) was utilised to combine all P values obtained from statistical analysis to determine whether there was a bias from multiple hypothesis testing. The P value of < 0.001 obtained from the truncated product method suggests that our results were not biased. The level of significance was set at $P \leq 0.05$.

Results

Participant Characteristics

Table 1 displays age and anthropometric measures of participants. Individuals with high adiposity had higher body mass, BMI, body fat percentage and muscle mass ($P < 0.021$, $\eta p^2 > 0.140$) compared to normal adipose individuals. A main effect of age was observed for all characteristics ($P < 0.001$, $\eta p^2 > 0.301$), other than body mass, BMI, trunk fat (%) and left arm fat (%) ($P > 0.116$; $\eta p^2 < 0.040$ in each case, except for left arm fat (%) where $P = 0.062$, $\eta p^2 = 0.940$). There were no age*adiposity interactions ($P > 0.119$; $\eta p^2 < 0.074$).

Adiposity and Age Effects on Maximal Concentric Muscle Function

For absolute concentric peak torque of the EF, EE, KF and KE, young individuals produced greater absolute torque than OAs (Fig. 1A & D, 2A & D. $P < 0.002$, $\eta p^2 > 0.263$). There was no main effect of adiposity ($P > 0.185$, $\eta p^2 < 0.048$ in each case, except for peak torque of the EE at angular velocity of 180° s^{-1} where $P = 0.055$, $\eta p^2 = 0.099$).

Young (Fig 1B & E, 2B & E. $P < 0.009$, $\eta p^2 > 0.174$) and normal adiposity (Fig 1B & E, 2B & E. $P < 0.021$, $\eta p^2 > 0.144$) groups produced greater concentric torque relative to body mass in all muscles, when compared to their old or high adiposity counterparts, except at an angular velocity of 180° s^{-1} at the EE, where no significant effect of adiposity was observed ($P = 0.086$, $\eta p^2 = 0.080$).

The young (Fig 1F, 2C & F. $P < 0.013$, $\eta p^2 > 0.159$) and normal adiposity (Fig 1F, 2C & F. $P < 0.041$, $\eta p^2 > 0.111$) groups KE, KF and EF produced greater concentric torque normalised to

segmental muscle mass compared to that of the older and high adiposity groups respectively; with the exception of the EF at 120° s^{-1} where no effect of adiposity was observed (P = 0.086, ηp^2 = 0.080). There was no effect of age or adiposity observed on concentric muscle quality of the EE (Fig 1C. P > 0.233, ηp^2 < 0.041).

There was no age*adiposity interaction observed for absolute peak concentric torque, peak concentric torque normalised to body mass or peak concentric muscle quality in any of the muscle groups (P > 0.085, ηp^2 < 0.065).

Adiposity and Age Effects on Maximal Eccentric Muscle Function

Young individuals produced greater absolute eccentric torque when compared to OAs (Fig. 3A & D, 4A & D. P < 0.016, ηp^2 > 0.152). There was no main effect of adiposity (P > 0.209, ηp^2 < 0.043) and no age*adiposity interaction observed in any muscle group (p > 0.126, np^2 < 0.064).

The young (Fig 4B & E. P < 0.012, ηp^2 > 0.162) and normal adiposity (Fig 4B & E. P < 0.010, ηp^2 > 0.172) groups KE and KF produced greater eccentric torque normalised to body mass compared to older and high adiposity groups respectively. At the EE, younger individuals produced greater eccentric peak torque relative to body mass than OAs (Fig 3B. P < 0.015, ηp^2 > 0.155), except at an angular velocity of 120° s^{-1} (P = 0.115 ηp^2 = 0.068). At the EE, normal adipose participants produced greater eccentric peak torque normalised to body mass at an angular velocity of 120° s^{-1} (Fig 3B. P = 0.013 ηp^2 = 0.160), but not at 60° or 180° s^{-1} (P > 0.580 ηp^2 < 0.096). There was no age*adiposity interaction observed for the EE, KE and KF (P > 0.234, ηp^2 < 0.039). However, for the EF, there was an age*adiposity interaction (Fig 3E. P < 0.026,

$\eta p^2 > 0.142$) for torque normalised to body mass. Bonferroni multiple comparisons indicated that YNa produced significantly greater peak eccentric torque normalised to body mass than all other experimental groups ($P < 0.001$, Cohen's d > 1.85); the other experimental groups were not different to each other ($P > 0.999$, Cohen's d < 0.46).

For the EE and EF, there was no main effect of age (Fig 3C & F. $P > 0.071$, $\eta p^2 < 0.088$) observed for eccentric muscle quality. Similarly, for the KE and KF, there was no main effect of age on eccentric muscle quality (Fig 4C & F $P > 0.103$, $\eta p^2 < 0.072$) except at an angular velocity of $60° \, s^{-1}$, where younger individuals produced greater eccentric torque normalised to segmental muscle mass compared to OAs ($P < 0.025$, $\eta p^2 > 0.132$). For the EE and KE, there was no main effect of adiposity (Fig 3C & 4C. $P > 0.224$, $\eta p^2 < 0.040$) observed for eccentric muscle quality. However, for the EF and KF, those with normal adiposity produced greater eccentric torque normalised to segmental muscle mass when compared to those with a high adiposity (Fig 3F $P < 0.034$, $\eta p^2 > 0.120$, Fig 4F $P < 0.010$, $\eta p^2 > 0.170$).

Adiposity and Age Effects on Concentric Muscle Fatigue

There was a decline in concentric torque over time in all experimental groups and muscles assessed (Fig 5A, C, E & G. $P < 0.001$, $\eta p^2 > 0.652$). There was no main effect of adiposity observed in any muscle group (Fig 5A, C & G. $P > 0.145$, $\eta p^2 < 0.120$). For the KE, there was a main effect of age (Fig 5G $P = 0.013$, $\eta p^2 = 0.034$) on percentage torque loss during concentric muscle actions. For the EE and EF, there was an age*set interaction (Fig 5A & C. $P < 0.001$, $\eta p^2 > 0.122$). Bonferroni comparisons indicated a significant difference ($P < 0.001$, Cohen's d > 1.24) in percentage of maximum torque between young and old individuals at sets 3, 4 and 5. The main effect of age and age*set interaction indicated that the younger

groups experience a greater percentage decline in concentric torque relative to their maximum, compared to older groups. For the KF, an age*adiposity interaction (Fig 5E. $P = 0.044$, $\eta p^2 = 0.022$) was observed. However, Bonferroni comparisons indicated no difference between groups ($P > 0.459$, Cohen's d < 0.47, except for comparison of fatigue in YHa and OHa, where $P = 0.459$, Cohen's d = 0.76). There were no other interactions ($P > 0.144$, $\eta p^2 < 0.012$).

Adiposity and Age Effects on Eccentric Muscle Fatigue

There was a decline in eccentric torque over time in all experimental groups and muscles assessed (Fig 5B, D & H. $P < 0.001$, $\eta p^2 > 0.232$), except at the KE (Fig 5H. $P = 0.052$, $\eta p^2 = 0.051$). For the EF, KF, and KE, there were no main effects of age (Fig 5B, F & H. $P > 0.302$, $\eta p^2 < 0.006$) or adiposity (Fig 5B, F & H. $P > 0.695$, $\eta p^2 < 0.001$) observed for percentage eccentric torque loss. For the EE, there was an age*adiposity*set interaction (Fig 5D, $P = 0.017$, $\eta p^2 = 0.064$). Bonferroni comparisons indicated a significant difference between YNa and YHa at set 1 and 4 ($P < 0.024$, set 1 Cohen's d = 0.88, set 4 Cohen's d = 1.26) and YNa and ONa at set 4 and 5 ($P = 0.038$, Cohen's d = 1.32). The interaction indicated the YNa group started at a greater percentage of their maximum but experienced greater fatigue at set 4 when compared to the YHa group. Furthermore, the YNa group experienced greater torque loss at sets 4 and 5 compared to ONa. No other interactions were observed ($P > 0.063$, $\eta p^2 < 0.043$).

Adiposity and Age Effects on Perceived Soreness Following Fatigue

Table 2 displays perceived soreness immediately following and every 24-hours for 3 days, after the fatigue protocols. Following eccentric fatigue of the dominant arm, younger individuals experienced greater soreness compared to OAs ($P = 0.009$, $\eta p^2 = 0.047$). There were no main effects or interactions observed following concentric fatigue protocols ($P > 0.263$, $\eta p^2 < 0.009$). There was however an age*adiposity interaction ($P = 0.034$, $\eta p^2 = 0.030$) in perceived soreness of the dominant leg following the eccentric fatigue protocol. However, Bonferroni comparisons identified no significant difference in perceived soreness between groups ($P > 0.470$, Cohen's $d < 0.55$).

Adiposity and Age Effects on STS performance and HGS

Table 3 displays descriptive values of HGS and STS performance. All outcome variables for STS and HGS revealed a main effect of age ($P < 0.037$, $\eta p^2 > 0.115$), whereby young individuals outperformed OAs. A main effect of adiposity was revealed for peak force during STS ($P < 0.001$, $\eta p^2 > 0.316$), indicating those with normal adiposity produced greater force normalised to body mass when compared to those with high body adiposity. There were no age*adiposity interactions observed ($p > 0.188$, $np^2 < 0.048$).

Discussion

The present study uniquely examined the influence of both old age and high adiposity on the concentric and eccentric performance of upper and lower limb musculature. These data indicate an age-related decline in peak eccentric and concentric maximal voluntary torque but no change with adiposity. Whilst concentric muscle quality (torque normalised to segmental muscle mass) was reduced with increasing age, eccentric muscle quality was generally unaffected. In comparison to absolute function and force to body mass ratio, our findings suggest that the effects of high adiposity on muscle quality are more complex. Concentric muscle quality was reduced with high adiposity, except for the EE. Whereas eccentric muscle quality was only reduced in the KF and EF. Across the contractile modalities and muscles groups assessed, older age and adiposity typically resulted in reduced maximal voluntary torque normalised to body mass. Whilst these results suggest that the severity of high adiposity effects on muscle performance are not greater in older males, implications of adiposity induced losses in muscle quality and torque relative to body mass will have much greater consequences for OAs given pronounced age-related declines in contractile function.

Adiposity and Age Effects on Peak Torque

An age-related decline in muscular strength, including both concentric and eccentric torque production, has been well established (Proctor et al. 1998; Pousson et al. 2001; Lauretani et al. 2003; Larsson et al. 2019) and our data supports these findings, with young individuals producing significantly greater absolute peak torque across all muscle groups and modes of contractility, when compared to OAs. An age-related decline in absolute function is characterised by muscular atrophy (Newman et al. 2003), and as seen in Table 1, whole body

and segmental muscle mass was significantly lower in the OAs. Mechanistic and architectural changes to skeletal muscle such as a reduction in sarco(endo)plasmic reticulum Ca^{2+} ATPase (SERCA) (Tallis et al. 2014), impaired calcium handling (Tallis et al. 2014) reduction in fascicle pennation angle (Morse et al. 2005) and atrophy of high force producing type II fibres (Lexell and Taylor 1991), likely account for the demonstrated difference in absolute torque between young and old adults.

Irrespective of age, high adiposity had no effects on concentric or eccentric peak torque of either the upper or lower limb musculature. Previous work has indicated that maximal isometric and concentric force of anti-gravitational musculature may be increased in high adiposity groups, due to the greater mechanical loading required to support the elevated body mass (Rolland et al. 2004; Villareal et al. 2004; Maffiuletti et al. 2007; Capodaglio et al. 2009; Tomlinson et al. 2014b; Erskine et al. 2017). However, as with the present findings, an increase in absolute force production is not always shown in young (Hulens et al. 2001; Lafortuna et al. 2005; Paolillo et al. 2012; Cavuoto and Nussbaum 2013; Pajoutan et al. 2016) or old obese individuals (Miyatake et al. 2000; Erskine et al. 2017). Such findings may in part be attributed to a reduction in muscle activation capacity, which has previously been observed in both young and old obese groups (Tomlinson et al. 2014a). Furthermore, as obesity impairs myogenesis, particularly in older muscle (O'Leary et al. 2018), this may limit the ability of muscle to adapt to an elevated mass. However, variability in strength assessments, physical activity, age, contractile modality assessed, muscle or muscle groups tested and duration and magnitude of adiposity, may account for disparity between findings (Tallis et al. 2018). Data from the present study are the first to indicate a consistent trend for

changes in absolute maximal voluntary toque between concentric and eccentric modes of activity and refute the idea that elevated eccentric loading in high adiposity individuals will provoke a stimulus to improve maximal eccentric torque.

Results from HGS also identified an age-related reduction in strength, with no significant effect of adiposity. The results from HGS reflect the IKD assessment of strength and therefore may be an effective measurement of absolute strength, particularly in the upper body. However, given the ambiguity of absolute function of lower limbs and other postural muscles, HGS should be used with caution when attempting to relate results to whole body strength.

Adiposity and Age Effects on Normalised Peak Torque

Normalising absolute performance to body mass is an important indicator for how high adiposity and old age may affect an individual's ability to manoeuvre their own mass (Bollinger 2017). The decline in relative concentric torque of lower limb musculature in high adiposity and OAs are comparable to previous literature (Maffiuletti et al. 2007; Capodaglio et al. 2009; Paolillo et al. 2012). However, the present study is the first to identify that relative eccentric function of lower limb musculature is significantly impaired by adiposity. A decline in relative eccentric function is likely to have profound effects in individuals with high adiposity, as an increased eccentric demand is expected during many ADLs (Tallis et al. 2018). The declines in relative performance will in part be because of muscles having to overcome greater inertia to move, carry and stabilise the elevated mass. Whilst the magnitude of adiposity effects does not differ across the age groups assessed, OHa individuals are likely to

experience greater functional impairment given a significant age-related decline in muscle function. Furthermore, the present data generally infer that the reduction in relative concentric torque is uniform between both upper and lower body musculature. Adiposity effects on relative eccentric function of upper limb musculature appear age and muscle specific, with YNa producing significantly greater torque than all other groups in the EF and adiposity and old age generally resulting in poorer relative eccentric performance of the EE.

Normalising absolute performance for segmental muscle mass gives an indication of muscle quality i.e. intrinsic force producing capacity of muscle. Adiposity induced changes in muscle quality have been debated (Tallis et al. 2018), however results from the present study add weight to the growing pool of evidence indicating that adiposity will reduce concentric muscle quality (Villareal et al. 2004; Morse et al. 2005; Delmonico et al. 2009; Paolillo et al. 2012; Erskine et al. 2017). Larger muscles of poorer quality will contribute to an already elevated mass thus increasing bodily inertia, have a greater metabolic cost to maintain and could promote a negative obesity cycle (Tallis et al. 2018).

The present study uniquely examined eccentric muscle quality. Previous literature in humans demonstrates limited ageing effects on eccentric muscle quality (Pasco et al. 2020), which is supported by our results. However, current evidence from animal models indicates that age-induced changes in eccentric muscle quality are likely muscle/fibre type specific (Hill et al. 2018). Our data indicate eccentric muscle quality was reduced in high adipose individuals in a manner that was not concurrent with changes in concentric muscle quality. This lack of consistency supports the idea of contractile mode and muscle specific effects of high adiposity

(Ciapaite et al. 2015; Tallis et al. 2018). The present work is the first to indicate differences between concentric and eccentric muscle quality and force to body mass ratio, in high adipose individuals, which may be attributed to mechanistic differences between concentric and eccentric contractions.

Adiposity and Age Effects on Fatigue Resistance

Similar to previous findings, our data indicated improved capacity to maintain maximal voluntary concentric contractions in an ageing population (Chung et al. 2007; Russ et al. 2008), although no differences were observed for eccentric fatigue resistance between young and older individuals. The effects of ageing on fatigue remain ambiguous, as other work indicates a reduction in both concentric and eccentric fatigue resistance of the ankle dorsiflexor (Baudry et al. 2007). Disparity in findings may be due to muscle specific responses, as work utilising isolated muscle indicates an age-induced decline in concentric and eccentric fatigue resistance of extensor digitorum longus, but no change in soleus (Hill et al. 2018). Whilst fatigability was improved or unchanged in the OAs, data are plotted from 100% of an individual's MVC reflecting the rate of fatigue. Given the age-related decline in contractile function, OAs will be required to produce force at a higher percentage of MVC during ADL's, and thus, likely fatigue more quickly.

Results from the present study demonstrate that high adiposity does not significantly influence concentric or eccentric fatigue resistance. Effects of high adiposity remain unresolved, whilst there is evidence indicating time to task failure or percentage torque loss

remains unaffected irrespective of BMI (Maffiuletti et al. 2008; Minetto et al. 2012), other findings show greater percentage torque loss in obese individuals when compared to lean counterparts (Maffiuletti et al. 2007). Despite this, our data support the idea that faster fatigue seen during functional tasks is likely due to elevated body inertia (Tallis et al. 2017).

In line with previous research, our results indicate no significant differences in perceived soreness between high and low adipose groups following bouts of eccentric fatigue (Yoon and Kim 2020). Similarly, there was no difference in perceived soreness following concentric contractions between young and old groups, although soreness was significantly lower in OAs following eccentric contractions, albeit with a small effect size. Such results provide promise with respect to the ability to sustain chronic eccentric interventions to improve muscle function.

Limitations and Future Directions

The extent and magnitude of both obesity and ageing are likely to impact how mechanistic responses alter contractile performance. Therefore, future work should consider how duration of obesity, and magnitude and distribution of adiposity, impacts contractile performance and if they exacerbate an age-related decline in muscle function.

The mechanisms underpinning obesity-induced changes in eccentric function are speculative and require further investigation. A particular focus on the function of the giant protein titin in response to ageing and elevated adiposity may be an important starting point, given its important role in the development of eccentric force (Enoka and Duchateau 2019).

Furthermore, future work should focus specifically on defining the impact of intramuscular fat on contractile performance, given it is proposed to contribute to poor muscle quality (Rahemi et al. 2015). However, previous research on this topic typically considers concentric muscle quality and the impact of intramuscular fat on the mechanisms responsible for eccentric force production remain unknown.

Despite using a previously established method for determining muscle quality (Maffiuletti et al. 2007; Valenzuela et al. 2020), we recognise that our results may overestimate the age-related decline in muscle quality given that MF-BIA was developed and validated against DEXA (Yamada et al. 2017). Previous work suggests that despite having a strong and significant relationship between assessments, DEXA may overestimate muscle thigh volume of older males by ~6.1% when compared to an MRI assessment (Maden-Wilkinson et al. 2013). Although, given that differences in measurements between assessments in males is small, this is unlikely to affect the trends demonstrated in the current data.

A potential limitation of the study is that we did not objectively measure physical activity (PA). However, 80% of YNa, 64% of YHa, 100% of ONa and 50% of OHa self-reported that they met the minimum guidelines for PA of at least 150 minutes of moderate or 75 minutes of vigorous intensity activity per week. These findings would appear representative given that high adiposity is associated with lower levels of PA (Zhu et al. 2020). As such, it is possible that increased PA levels may negate some of the detrimental effects of high adiposity on contractile performance (Rolland et al. 2004)

Conclusion

The present findings demonstrate that age-related decline in maximal voluntary concentric and eccentric torque is not exacerbated by adiposity. However, torque normalised to body mass and muscle quality were reduced, albeit in a muscle and contractile mode specific manner in the case of the latter. Although the severity of these effects was uniform across both young and older age groups, the consequences for OAs with respect to the safe completion of ADLs is likely to be more substantial given that both torque relative to body mass and muscle quality are already compromised by increasing age. This data suggests a need to focus on resistance training interventions focusing on both eccentric and concentric actions to offset the detrimental effect of high adiposity on skeletal muscle quality and improve performance in functional tasks.

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Figure captions

Figure 1. The effect of age and adiposity on absolute concentric torque (A, D), torque normalised to body mass (B, E) and torque normalised to segmental muscle mass of the dominant arm (C, F) of the elbow extensors and flexors. Values are presented as means ± SD; †, ††, ††† and *, **, *** indicate a significant difference between young and old and normal and high adiposity respectively at $P < 0.05$, $P < 0.01$ and $P < 0.001$.

Figure 2. The effect of age and adiposity on absolute concentric torque (A, D), torque normalised to body mass (B, E) and torque normalised to segmental muscle mass of the dominant leg (C, F) of the knee extensors and flexors. Values are presented as means ± SD; †, ††, ††† and *, **, *** indicate a significant difference between young and old and normal and high adiposity respectively at $P < 0.05$, $P < 0.01$ and $P < 0.001$.

Figure 3. The effect of age and adiposity on absolute eccentric torque (A, D), torque normalised to body mass (B, E) and torque normalised to segmental muscle mass of the dominant arm (C, F) of the elbow extensors and flexors. Values are presented as means ± SD; †, ††, †††, *, **, *** and ‡, ‡‡, ‡‡‡ indicate a significant difference between young and old, normal and high adiposity, and YNa and all other groups respectively at $P < 0.05$, $P < 0.01$ and $P < 0.001$.

Figure 4. The effect of age and adiposity on absolute eccentric torque (A, D), torque normalised to body mass (B, E) and torque normalised to segmental muscle mass of the dominant leg (C, F) of the knee extensors and flexors. Values are presented as means ± SD; †, ††, ††† and *, **, *** indicate a significant difference between young and old and normal and high adiposity respectively at $P < 0.05$, $P < 0.01$ and $P < 0.001$.

Figure 5. The effect of age and adiposity on the fatigue resistance of the elbow flexors (A, B), elbow extensors (C, D), knee flexors (E, F) and knee extensors (G, H) following five sets of 10 concentric or eccentric isokinetic contractions. Values are presented as means ± SD; †, †† and ††† indicate a significant difference between young and old at $P < 0.05$, $P < 0.01$ and $P < 0.001$; # and $ indicate a significant difference between YNa and YHa, and YNa and ONa respectively at $P < 0.05$.