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1 Article

2 **Internal loads, but not external loads and fatigue, are** 3 **similar in young and middle-aged resistance trained** 4 **males during high volume squatting exercise** [†]

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12 **Abstract: Background:** Little is known about the internal and external loads experienced during
13 resistance exercise, or the subsequent fatigue-related response, across different age groups.
14 **Methods:** This study compared the internal (heart rate, OMNI ratings of perceived exertion (RPE),
15 session RPE) and external loads (peak velocity and power and volume load) during high volume
16 squatting exercise (10x10 at 60% one-repetition maximum (1RM)) and the fatigue-related response
17 (maximal voluntary contraction (MVC), voluntary activation (VA), resting doublet force, peak
18 power and blood lactate) in young ($n=9$; age 22.3 ± 1.7 years) and middle-aged ($n=9$; age 39.9 ± 6.2
19 years) resistance-trained males. **Results:** All internal load variables and peak velocity illustrated
20 *unclear* differences between groups during exercise. Peak power and volume load were *likely* higher
21 in the young group compared to their middle-aged counterparts. The *unclear* differences in MVC,
22 VA and blood lactate between groups after exercise were accompanied by *very likely* greater
23 decrements in resting doublet force and peak power at 20 and 80% 1RM in the middle-aged group
24 compared to the young group. **Conclusion:** These data indicate that internal load is not different
25 between young and middle-aged resistance trained males, though certain external load measures
26 and the fatigue response are.

27 **Keywords:** Resistance training; training load; ageing

28

29 1. Introduction

30 Longitudinal resistance training induces muscle hypertrophy and increases in strength and
31 power that are independent of age [1]. While such morphological adaptations have been noted in
32 younger athletes [1], they have also been observed in older populations [1, 2], for whom natural age-
33 associated losses in muscle mass (sarcopenia) [3] and strength and power (dynapenia) [4] are
34 expected. For the growing number of ‘middle-aged’ athletes (i.e. those 35 to 55 years) [4], resistance
35 training can off-set or delay the effects of sarcopenia and dynapenia to maintain sporting
36 performance [5].

37 To determine the efficacy of an athlete’s resistance training a coach must quantify the stress
38 imposed on the athlete [6]. If the training load is insufficient then adaptation might not occur, whereas
39 excessive or sudden increases in stress might result in injury or poor performance [7]. As such,
40 practitioners should record markers of internal (i.e. the athlete’s individual responses, such as heart
41 rate (HR), ratings of perceived exertion (RPE)) and external (i.e. the work completed by the athlete,
42 in terms of variables such as velocity, acceleration, and power output) loads to quantify the training
43 stress. However, because of the numerous factors (e.g. movement velocity, rest times, relative

44 intensity, volume-load) that can invoke a resistance training adaptation there is no consensus
45 regarding the best method to monitor resistance training load [6].

46 There is evidence to indicate that internal load variables might differ between age groups when
47 exercising at the same relative external load. For example, higher absolute heart rates [8] and blood
48 lactate concentration [9], and lower [10], higher [11] and similar [12] RPEs have been noted in young
49 (~21 to 28 years) compared to older (~57 to 84 years) males during resistance exercise. These findings
50 are despite observations of no differences in absolute or relative heart rate [13] or blood lactate and
51 RPE [14] at the point of muscular failure between young (~21 to 28 years) and older (~48 to 67 years)
52 males. Furthermore, to the authors' knowledge, no study has yet compared the external load between
53 age groups during resistance training exercise despite external load being the primary driver of
54 resistance training adaptations [15]. A limitation of focusing on external or internal load in isolation
55 is that they might not be able to reflect the internal load for a given external load. Therefore,
56 calculating an internal to external load ratio might negate the poor sensitivity and inter-individual
57 variability of individual training load metrics [16]. The use of external load markers in isolation
58 demonstrates a limited relationship with measures of endurance capacity (velocity at lactate
59 threshold, velocity at 4 mmol·L⁻¹ and VO_{2max}), whereas the external to internal load ratios exhibit
60 moderate to large correlations ($r = .41$ to $.69$) [16, 17]. These data might suggest that the integration of
61 internal and external load is a more sensitive measure of overall training load, however the
62 application to resistance type exercise is yet to be explored.

63 The subsequent fatigue (i.e. inability to maintain the expected force or power output) [18]
64 response to resistance exercise between age groups is unclear [19, 20]. Two recent meta-analyses
65 concluded that ageing is associated with less fatigue after isometric contractions, but not dynamic
66 contractions, when assessed in terms of force production during maximal voluntary contractions [19,
67 20]. When velocity and power are used as markers of fatigue, older (~64 to 75 years) males experience
68 greater fatigue than their young (~27 years) males during knee extension [21-23], but not during sit-
69 to-stand exercise [20, 23]. It has been suggested that the age-related slowing of the muscle is
70 responsible for the greater fatigue during knee extension exercise [21, 23], whilst the group similarity
71 in fatigue during sit-to-stand exercise was attributed to task specificity; both groups would typically
72 perform sit-to-stand tasks but not knee extension movements [23]. However, the findings of these
73 studies might not be applicable to the middle-aged male who regularly resistance exercises and plays
74 sports because single-jointed knee extension and sit-to-stand movements are not applicable to the
75 multi-jointed compound movements involved in such activities. A study that quantifies the fatigue
76 response from an ecologically valid resistance training protocol would therefore be particularly
77 beneficial to the resistance trained middle-aged male.

78 Another plausible explanation for the differences in the fatigue response between age groups
79 might be sought from the internal and external loads experienced during exercise. That is, greater
80 fatigue might be an artefact of a higher internal or external load during exercise of the same relative
81 load. Resistance training protocols with a large amount of work performed are subject to greater
82 decrements in isometric force [24, 25]. However, no study has investigated the relationship between
83 internal load and post-exercise decrements in muscle function. Moreover, despite the efforts of two
84 studies [9, 13], the age-related research has focused solely on those aged over ~60 years, none of whom
85 were resistance trained. Thus, the stress imposed during resistance exercise in middle-aged males,
86 compared to younger males, is unknown. The findings from a study that quantifies the internal and
87 external load in middle-aged (35 to 55 years) males would be particularly useful for middle-age men
88 who seek to monitor their resistance training. Consequently, the primary aim of this study was to
89 quantify the internal and external loads experienced in lower-limb resistance exercise in young and
90 middle-aged males who regularly resistance train, and to determine the fatigue responses to such
91 exercise. A further aim was to determine the relationship between internal and external load with
92 post-exercise decrements in muscle function.
93

94 **2. Materials and Methods**

95 *2.1. Participants*

96 Nine young (21 to 25 years) and nine middle-aged (35 to 54 years) resistance trained males were
 97 recruited for this study from the University population, local gymnasias and sports teams using
 98 convenience sampling. Thirty-five years was selected as the lower boundary for the middle-aged
 99 group because it is the entry age for ‘Masters’ athletes (see British Masters Athletic Federation and
 100 World Masters Athletics). As age-related studies typically use older groups (60 years and over), 55
 101 was selected as the upper-limit for the middle-aged group. All participants took part in sport (i.e.
 102 team sports, racket sports and endurance type sports) for a minimum of two years (4.1 ± 1.3 and 18.0
 103 ± 5.6 years for the young and middle-aged groups, respectively), and had a minimum of two years’
 104 resistance training experience and regularly used squats as part of their resistance training
 105 programmes. Participants completed a pre-test health questionnaire and provided written consent
 106 for the study, which was approved by the Ethics Committee of the Faculty of Life Sciences at the
 107 University of Chester.

108 *2.2. Design*

109 The study used a mixed factorial design that required attendance at the strength and
 110 conditioning laboratory on two separate occasions. Participants were instructed not to consume any
 111 ergogenic supplements (for example, caffeine) on each occasion and to refrain from heavy exercise
 112 between visits. On the first occasion, they provided biometric data (stature, body mass and skinfold
 113 thicknesses for the assessment of body composition), an estimate of back squat one-repetition
 114 maximum (1RM), and were habituated with the measurements of lower limb peak power, maximal
 115 voluntary contraction (MVC) and voluntary activation (VA) during isometric knee extension.
 116 Participants were considered ‘habituated’ when they could complete three consecutive repetitions
 117 that produced peak powers or torque values each within 10% [4, 26]. On returning to the laboratory
 118 2-4 days later, they provided measurements of peak power during squats at 20 and 80% 1RM, MVC,
 119 VA and blood lactate before and after an exercise bout comprising 10 x 10 squats at 60% 1RM [27].
 120 During the exercise bout, bar peak velocity and power were recorded for each repetition, and heart
 121 rate and RPE were recorded at the end of each set. Session RPE (sRPE) was recorded 15 minutes after
 122 the squatting exercise bout. Participants were not provided with any feedback during the study that
 123 might have influenced their sRPE.

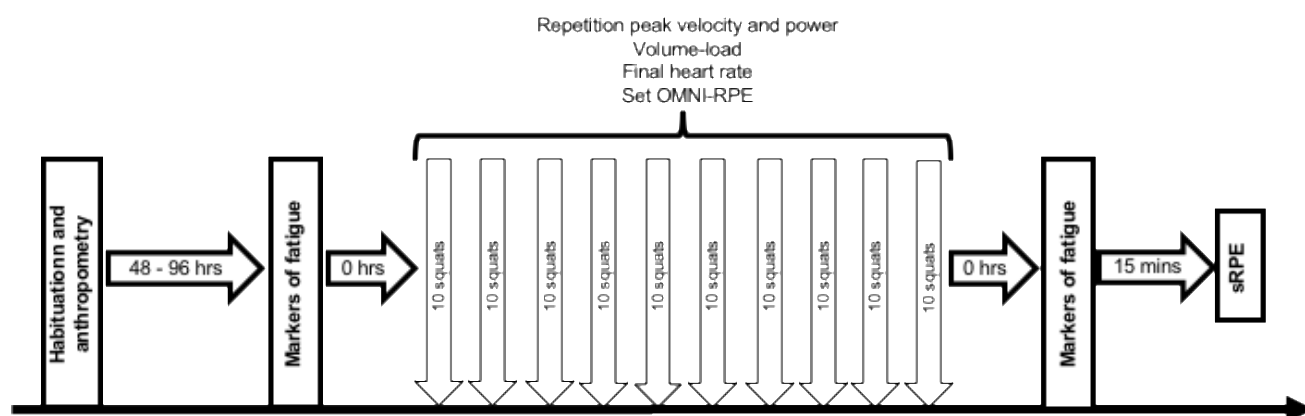


Figure 1. Schematic of study design.

127 2.3. Procedures

128 2.3.1. Biometric measures

129 Body mass and stature were determined using digital scales (Seca 813, Hamburg Germany)
130 and a wall-mounted stadiometer (Harpenden, Holtainm Crymych, Dyfed, UK). Body composition
131 was assessed via skinfold thickness measurements (Harpenden, British Indicators, Burgess Hill, UK)
132 taken at the tricep, axilla, abdominal, suprailliac, chest, subscapular, and mid-thigh incorporated into
133 the equation of Jackson and Pollock [28] for predicting body density (Db). Body fat percentage (%BF)
134 was derived from the equation [29]: %BF = $[(5.21/ Db) - 4.78] \times 100$. From this the quantities (kg) of
135 fat-mass (FM) and fat-free mass (FFM) were also derived.

136 2.3.2. Maximal strength testing

137 To avoid the risk associated with maximal strength testing, one repetition maximum (1RM) for
138 squat exercise was predicted using a three-repetition maximum (3RM) protocol. In brief, participants
139 performed 8-10 repetitions with 50% of their estimated 1RM, followed by 3-5 repetitions at 85% of
140 estimated 1RM. The load was then set at the approximate 1RM and the participants performed one
141 repetition. The load was progressively increased until the participant could no longer perform a
142 complete repetition. The final load lifted was used with the following equation [30] to estimate 1RM
143 squat load:

$$1RM = (100 \times \text{load lifted}) / (48.8 + (53.8 \times 2.71828^{-0.075 \times \text{repetitions}})) \quad (1)$$

144 The above equation has been reported to yield accurate 1RM predictions ($r = 0.969$, 0.02% different
145 from direct 1RM) [31].

146 2.3.3. Assessment of peak power during back squat

147 Peak power was assessed at loads corresponding to 20 and 80% 1RM during back squat exercise
148 using a rotary encoder (FitroDyne, Fitronic, Bratislava, Slovakia) attached via a nylon cord directly
149 under a Smith machine bar (Perform Better, Leicester, UK). As the FitroDyne measures rate of
150 displacement and assumes that the nylon cord is moving in a vertical plane, a Smith machine was
151 used to prevent deviation from this plane and decrease measurement error. The FitroDyne has been
152 shown to produce reliable intra-day measures of peak power (coefficient of variation = 3.9-4.9%) at
153 the selected loads [26].

154 With the bar positioned across the shoulders, participants squatted until their hips were below
155 the knee joint and then ascended as rapidly as possible until their knees were at full extension. A
156 bench was employed to ensure that they attained the same depth and range of motion on each
157 repetition. Three repetitions at each load were performed with self-selected rest intervals that ranged
158 from 30 to 90 s [26]. Rest times were self-selected, as lighter loads (20% 1RM) did not require the same
159 recovery time. Peak velocity was recorded from which peak power was calculated as (load x velocity
160 x 9.8)/100. The load order was randomised for each participant to negate possible ordering effects.

161 2.3.4. Assessment of maximal voluntary contraction and voluntary activation

162 Before undertaking the MVC and VA assessments, participants performed a warm-up
163 comprising five minutes of cycling at 100 W (Lode, Corival, Groningen, Netherlands). A
164 dynamometer (Biodex, Multi-joint system 3, Biodex Medical, New York, USA) was used to measure
165 isometric force of the participant's dominant knee extensors at 80° knee flexion. To prevent
166 extraneous body movements, Velcro straps were applied tightly across the chest and thigh.
167 Participants were provided with strong verbal encouragement and real-time feedback via the PC
168 monitor.

169 The knee extensors were electrically stimulated (5 s with two 100 Hz single square impulses
170 (doublet); Digitimer, D57, Hertfordshire, UK) using two 5 x 13 cm moistened surface electrodes
171 (Axelgaard Manufacturing Co LTD, Fallbrook, CA); one placed distally over the quadriceps and the

172 other proximally over the upper quadriceps. During optimisation the amplitude of a doublet was
173 progressively increased, starting at 50 amps, until a point where no further increases in intensity
174 resulted in an increase in resting doublet force. Initially a 230 volt electrically evoked doublet (set
175 20% above the value required to evoke a resting muscle doublet of maximum amplitude) was applied
176 to the resting muscle (resting doublet) at 1 s. The resting doublet was used to elucidate any peripheral
177 alterations that might have occurred as a result of the squatting protocol. Participants then performed
178 a 4 s MVC before a doublet which was applied at the isometric plateau (superimposed doublet). The
179 MVC was taken as the average force over 50 ms (AcqKnowledge 3 software, Biopac Systems,
180 Massachusetts) before the superimposed doublet was applied. VA was calculated according to the
181 interpolated twitch ratio using the equation;

$$\text{VA (\%)} = [1 - (\text{size of interpolated doublet} / \text{size of resting doublet})] \times 100 \quad (2)$$

182 A similar procedure has been deemed a reliable method (coefficient of variation = 3.38%) for assessing
183 VA [32].

184 2.3.5. High volume squat exercise

185 The exercise protocol consisted of 10 sets of 10 repetitions of squat exercise at a load
186 corresponding to 60% 1RM with 120 s rest between sets [27]. For each repetition participants
187 descended for 3 s until their hips were below the knee joint and then ascended as rapidly as possible
188 until their knees reached full extension. A bench was employed to standardise the depth of each
189 repetition. The FitroDyne was used to calculate power for each repetition in the manner outlined
190 above. Mean peak velocity and power over the sets was used to determine the relationship between
191 external load during the exercise and alterations in the markers of fatigue. Volume load was
192 calculated as the 60% 1RM load multiplied by 100.

193 2.3.6. Assessment of heart rate

194 Heart rate (HR) was recorded at rest and at the end of each set using a chest strap (Polar Electro,
195 Polar Beat, Oy, Finland).

196 2.3.7. Assessment of perceived exertion

197 At the end of each set participants provided a global indication of their perceived exertion using
198 the OMNI-RPE scale [34], which ranges from 0 to 10, 0 indicating 'extremely easy' and 10
199 corresponding to 'extremely hard'. Previously, participants were provided with detailed instructions
200 on how to rate their exertion. The OMNI-RPE scale is deemed a valid measure of perceived exertion
201 during resistance exercise [33]. Additionally, sRPE was recorded 15 minutes after the completion of
202 exercise. Participants were asked "How intense was your session?" and ranked their exertion on a 1
203 to 10 scale, where 1 indicates "really easy" and 10 indicates "maximal". This method has been deemed
204 a valid [34] and reliable [35] indicator of resistance exercise intensity.

205 2.3.8. Assessment of blood lactate concentration

206 Blood was obtained before and immediately after the exercise bout from a finger-tip capillary
207 sample and analysed for lactate concentration using a Lactate Pro analyser (Arkray, Kyoto, Japan).
208 The Lactate Pro has been deemed a reliable marker of blood lactate concentrations (coefficient of
209 variation: 2.8 to 5.0%) [36].

210 2.3.9. External to internal load ratios

211 External load was quantified using mean peak velocity and power over the 10 sets of exercise
212 and total volume load. Internal load was quantified using measures of mean heart rate and OMNI-
213 RPE. External load was divided by each measurement of internal load to calculate the external to
214 internal load ratio for the exercise protocol [16].

215 2.4. Statistical analysis

216 All data were analysed using the effect size (ES) with 90% confidence intervals (CI) [39].
 217 Magnitude-based inferential statistics were used to provide information on the size of the differences,
 218 allowing for a more practical and meaningful explanation of the data. Such information is more useful
 219 to the coach and athlete as it provides a better understanding of the alterations that occur during and
 220 after high-volume squatting exercise. Thresholds for the magnitude of the observed change for each
 221 variable were determined as the within-participant standard deviation in that variable \times 0.2, 0.6 and
 222 1.2 for a small, moderate and large effect, respectively [37]. Threshold probabilities for a meaningful
 223 effect based on the 90% CI were: <0.5% most unlikely, 0.5–5% very unlikely, 5–25% unlikely, 25–75%
 224 possibly, 75–95% likely, 95–99.5% very likely, >99.5% most likely. Effects with CI across a likely small
 225 positive or negative change were classified as unclear [38]. The rate of change of peak velocity and
 226 power, HR and OMNI-RPE during exercise was expressed as the slope of the regression line (beta
 227 coefficient) [40] of the dependent variables over the ten sets. A *post hoc* power calculation indicated
 228 that a sample size of 12 to 14 was needed to detect the changes in muscle function observed in the
 229 current study. All calculations were completed using predesigned spreadsheets (www.sportsci.org).
 230 Data are presented as ES, lower CI and upper CI. Pearson correlations were employed to quantify
 231 the association between the markers of internal and external load and the decrements in muscle
 232 function after squat exercise. The following scales were used to interpret the magnitude of the
 233 correlations: <0.1 trivial, 0.1-0.3 small, 0.31-0.5 moderate, 0.51-0.7 large, 0.71-0.9 very large, >0.9 nearly
 234 perfect [39]. Threshold probabilities for a meaningful effect based on the 90% CL were calculated
 235 using a predesigned spreadsheet [41].

236 3. Results

237 3.1. Biometric measures and training history

238 Age and sum of skinfolds were *most likely* and *likely* higher, respectively, in the middle-aged
 239 group compared to the young group (Table 1). Differences in fat mass and body fat percentage
 240 between the young and middle-aged groups were *very likely* between groups while mass and squat
 241 1RM were *unclear*.

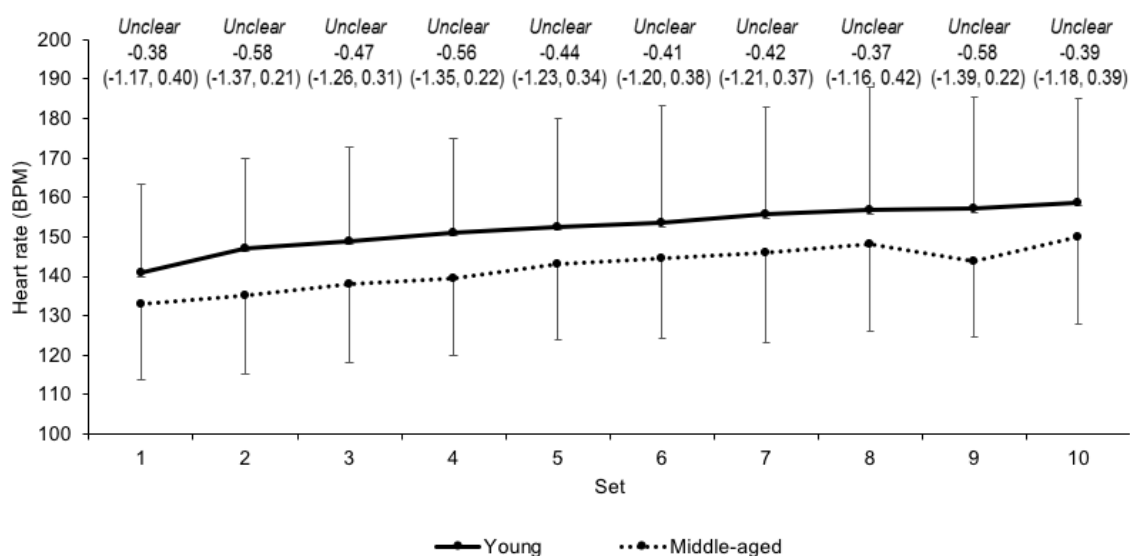
242 **Table 1.** Biometric characteristics (mean \pm SD) of the young and middle-aged groups. Qualitative
 243 descriptor, effect size and upper and lower 90% confidence intervals are noted in the effect size
 244 column.

Characteristic	Young (n = 9)	Middle-aged (n = 9)	Effect size
Age (y)	22.3 \pm 1.7	39.9 \pm 6.2	<i>Most likely</i> \uparrow 3.70 (2.87, 4.53)
Mass (kg)	82.0 \pm 9.0	79.1 \pm 10.3	<i>Unclear</i> 0.29 (-1.10, 0.52)
Fat-free mass (kg)	71.4 \pm 7.9	63.9 \pm 6.5	<i>Very likely</i> \downarrow -1.02 (-1.83, -0.22)
Fat-mass (kg)	10.5 \pm 4.5	15.2 \pm 5.7	<i>Likely</i> \uparrow 0.89 (0.09, 1.70)
Body fat (%)	12.8 \pm 4.7	18.8 \pm 5.8	<i>Very likely</i> \uparrow 1.13 (0.32, 1.94)
Sum of skinfolds (mm)	82.3 \pm 24.6	102.4 \pm 31.9	<i>Likely</i> \uparrow 0.69 (-0.12, 1.50)
Squat 1RM (kg)	130.8 \pm 26.8	109.3 \pm 22.5	<i>Unclear</i> -0.85 (-1.65, -0.04)

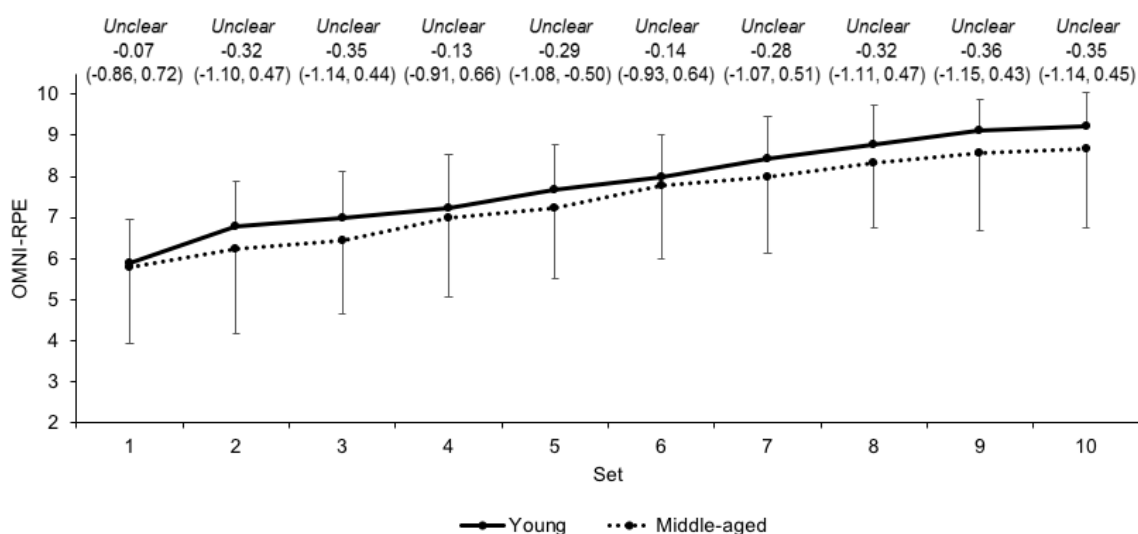
245 3.2. Internal load measures

246 Differences in heart rate (Figure 2) and OMNI-RPE (Figure 3) were *unclear* between the young
 247 and middle-aged groups over the sets. Differences in mean sRPE (7.7 \pm 1.2 and 7.8 \pm 1.3 for the young
 248 and middle-aged groups, respectively) were also *unclear* (ES 0.09, CI -0.72, 0.89). The rate of change

249 for HR over the sets was *unclear* (ES 0.17, CI -0.63, 0.98) between young ($b = 1.72 \pm 0.96$) and middle-
 250 aged ($b = 1.91 \pm 1.13$) groups, as was the beta coefficient ($b = 0.36 \pm 0.09$ and 0.34 ± 0.17 , respectively)
 251 for OMNI-RPE (ES 0.17, CI -0.98, 0.65).



252
 253 **Figure 2.** Absolute heart rate scores (mean \pm SD) across each set for young and middle-aged groups.
 254 Qualitative descriptor, effect size and upper and lower 90% confidence intervals are noted above.



255
 256 **Figure 3.** OMNI-RPE scores (mean \pm SD) across each set for young and middle-aged groups.
 257 Qualitative descriptor, effect size and upper and lower 90% confidence intervals are noted above.

258 **3.3. External load measures**

259 Differences in peak velocity over the sets between the young and middle-aged groups were
 260 *unclear* (Figure 4). Differences in peak power over the sets were *likely moderate* (Figure 5) between the
 261 groups, except for set 9 where differences were *unclear*. The *unclear* (ES -0.12, CI -0.92, 0.69) differences
 262 in mean peak velocity for the young (97.9 ± 24.9 cm/s) and middle-aged (95.2 ± 19.7 cm/s) groups over
 263 the sets was accompanied by *likely moderate* differences in mean peak power (ES -0.71, CI -1.53, 0.10;
 264 770.4 ± 278.0 and 603.2 ± 162.6 W for the young and middle-aged groups, respectively). Moreover,
 265 there was a *likely moderate* (ES -0.90, CI -1.70, -0.09) higher volume load in young (7898.2 ± 1560.0 kg)
 266 group compared to the middle-aged (6556.9 ± 1349.1 kg) group. Differences in mean beta coefficients
 267 for velocity and power across the sets were *unclear* (ES 0.31, CI -0.50, 1.11 and ES 0.31, CI -0.51, 1.10,

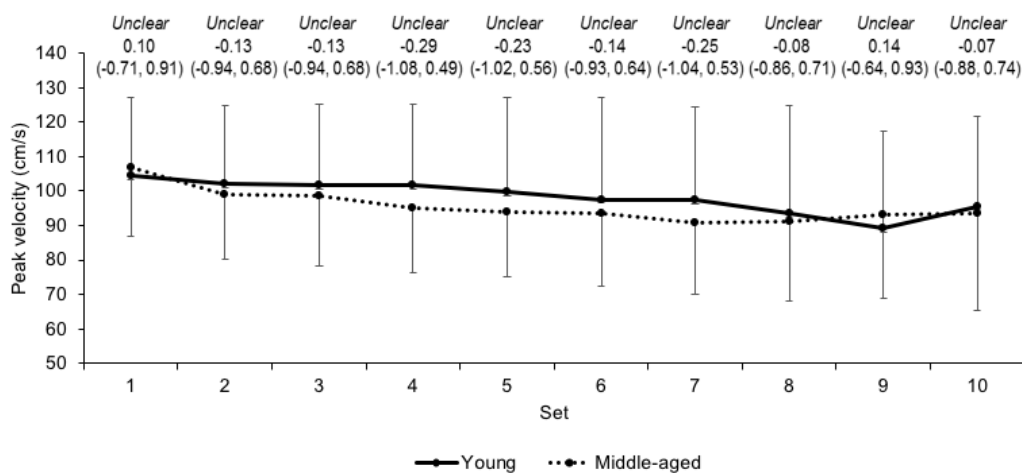
268 respectively) between young ($b = -1.7 \pm 2.8$ and -11.8 ± 20.5 , respectively) and middle-aged ($b = -0.9 \pm$
 269 2.6 and -5.9 ± 18.2 , respectively) groups.

270 3.4. External to internal load ratios

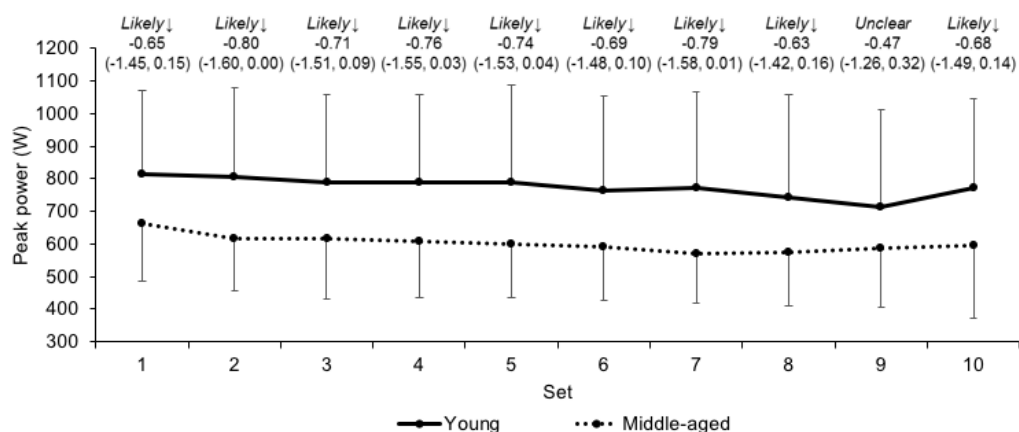
271 Differences in the external to internal load ratios between the groups were all *unclear* (Table 2).

272 **Table 2.** The external to internal load ratio during the exercise protocol in the young and middle-aged
 273 groups. Qualitative descriptor, effect size and upper and lower 90% confidence intervals are noted in
 274 the effect size column.

Load Ratio	Young	Middle-aged	Effect size
HR: peak velocity	0.7 ± 0.2	0.7 ± 0.2	<i>Unclear</i> 0.10 (-0.71, 0.90)
HR: peak power	5.2 ± 2.0	4.3 ± 1.3	<i>Unclear</i> -0.51 (-1.32, 0.30)
HR: volume load	52.2 ± 11.8	47.0 ± 13.0	<i>Unclear</i> -0.41 (-1.22, 0.39)
OMNI-RPE: peak velocity	12.6 ± 3.3	13.3 ± 2.7	<i>Unclear</i> 0.21 (-0.60, 1.01)
OMNI-RPE: peak power	99.5 ± 36.6	84.8 ± 23.1	<i>Unclear</i> -0.47 (-1.28, 0.34)
OMNI-RPE: volume load	1030.2 ± 244.6	968.5 ± 451.2	<i>Unclear</i> -0.14 (-0.95, 0.68)



275 **Figure 4.** Peak velocity (mean ± SD) across each set in young and middle-aged groups. Qualitative
 276 descriptor, effect size and upper and lower 90% confidence intervals are noted above.
 277



278
279
280

Figure 5. Peak power (mean ± SD) across each set in young and middle-aged groups. Qualitative descriptor, effect size and upper and lower 90% confidence intervals are noted above.

281 **3.5. Markers of fatigue after squatting exercise**

282 At Pre, the *likely moderate* differences in MVC (ES -0.80, CI -1.61, 0.01) and resting doublet force
 283 (ES -0.96 CI -1.77, 0.14) between the groups were accompanied by *very likely moderate* differences in
 284 20 (ES -1.03, CI -1.84, -0.22) and 80% (ES -1.03, CI -1.84, -0.21) 1RM peak power. Differences in VA (ES
 285 0.03, CI -0.77, 0.84) and blood lactate (ES -0.53, CI -1.34, 0.28) were *unclear* between the groups at Pre.
 286 The high volume squatting exercise was effective in causing decreases in markers of fatigue that were
 287 *very likely* for MVC (ES -0.96, CI -1.52, -0.39) and VA (ES -1.06, CI -1.63, -0.48), *most likely* for resting
 288 doublet force (ES -1.35, CI -1.92, -0.79) and *likely* for 80% 1RM peak power (ES -0.57, CI -1.13, 0.00).
 289 Alterations in 20% 1RM peak power were *unclear* compared to Pre (ES -0.24, CI -0.80, 0.33). Blood
 290 lactate concentration had *most likely* (ES 2.38, CI 1.82, 2.95) increases after the squatting exercise. After
 291 the squatting exercise the middle-aged group showed *very likely* greater decrements in resting doublet
 292 force and peak power at 20 and 80% 1RM than the young group (Table 3). Between-group differences
 293 after the exercise protocol were *unclear* for MVC, VA and blood lactate.

294 **Table 3.** Markers of fatigue (mean ± SD) in after squatting exercise in young and middle-aged males.
 295 Qualitative descriptor, effect size and upper and lower 90% confidence intervals are noted in the effect
 296 size column.

Fatigue Indicators	Group	Pre	Post	Comparison
MVC (N/m)	Young	265.7 ± 95.8	179.2 ± 60.7	Unclear
	Middle-aged	199.1 ± 63.3	144.9 ± 55.4	-0.56 (-1.37, 0.25)
VA (%)	Young	93.4 ± 5.8	85.3 ± 9.4	Unclear
	Middle-aged	93.6 ± 5.6	82.9 ± 12.9	-0.20 (-1.00, 0.61)
Resting doublet (N/m)	Young	85.1 ± 10.4	64.2 ± 10.4	Very likely ↓
	Middle-aged	69.2 ± 21.1	48.3 ± 9.3	-1.53 (-2.34, -0.71)
20% 1RM peak power (W)	Young	507.9 ± 134.6	486.6 ± 112.7	Very likely ↓
	Middle-aged	387.4 ± 87.9	357.6 ± 86.2	-1.21 (-2.03, -0.39)
80% 1RM peak power (W)	Young	1295.3 ± 369.1	1098.5 ± 307.1	Very likely ↓
	Middle-aged	977.1 ± 211.1	831.9 ± 215.2	-0.94 (-1.76, -0.12)
Blood lactate (mmol·L ⁻¹)	Young	1.9 ± 0.7	9.8 ± 2.9	Unclear
	Middle-aged	1.6 ± 0.4	8.1 ± 5.2	-0.39 (-1.18, 0.40)

297 3.6. Relationship between internal and external load markers with fatigue

298 Only mean HR and OMNI-RPE were related to the muscle function markers for the internal load
299 variables (Table 4). That is, mean HR was *likely* ($r = .45$, CI .06, .72) and *very likely* ($r = .50$, CI .13, .75)
300 correlated with decrements in MVC and peak power at 80% 1RM, respectively, while OMNI-RPE
301 was *likely* correlated with alterations in peak power at 20 ($r = .36$, CI -.05, .66) and 80% 1RM ($r = .32$,
302 CI -.09, .64). For external markers of load, changes in mean peak power were *likely* correlated ($r = .35$
303 to .43) with all decrements in muscle function. Similarly, a higher volume load during the protocol
304 was *very likely* related to changes in the muscle function markers ($r = .50$ to .59).
305

306
307

Table 4. Relationships (qualitative descriptor, upper and lower 90% confidence intervals) of internal and external load markers with fatigue.

Load	Load markers	Peak power		
		MVC	20% 1RM	80% 1RM
		<i>Likely</i>	<i>Unclear</i>	<i>Very likely</i>
	ΔHeart rate	.45 (.06, .72)	.28 (-.14, .61)	.50 (.13, .75)
		<i>Unclear</i>	<i>Likely</i>	<i>Likely</i>
	Mean OMNI-RPE	-.06 (-.45, .35)	.36 (-.05, .66)	.32 (-.09, .64)
		<i>Unclear</i>	<i>Unclear</i>	<i>Unclear</i>
	sRPE	.07 (-.34, .46)	.18 (-.24, .54)	.29 (-.13, .62)
		<i>Unclear</i>	<i>Unclear</i>	<i>Unclear</i>
Internal	BLA increase	.22 (-.57, 0.2)	-.20 (-.55, .22)	-.19 (-.55, .23)
		<i>Unclear</i>	<i>Unclear</i>	<i>Unclear</i>
	Mean peak velocity	-.05 (-.44, .36)	.04 (-.37, .43)	.02 (-.38, .42)
		<i>Likely</i>	<i>Likely</i>	<i>Likely</i>
	Mean peak power	.38 (-.03, .68)	.43 (.03, .71)	.35 (-.06, .66)
		<i>Very likely</i>	<i>Very likely</i>	<i>Very likely</i>
External	Volume load	.59 (.24, .80)	.55 (.19, .78)	.50 (.13, .75)

308 **4. Discussion**

309 To our knowledge this is the first study to compare internal and external load variables, and
 310 fatigue response from squatting exercise, in resistance trained young and middle-aged males. These
 311 data indicate that the internal load during squatting exercise at the same relative intensity is not
 312 different in these groups, though certain measures of external load (i.e. volume load and peak power)
 313 are. Moreover, when compared to younger males, middle-aged males can expect greater decrements
 314 in peak power after squatting exercise, which appear to be related to certain internal (HR and OMNI-
 315 RPE) and external (peak power and volume load) load measures.

316 This study recorded *unclear* differences in HR and the HR rate of change during the resistance
 317 exercise between the two age groups. These data contrast to previously observed differences in HR
 318 between young and older physically active men during isometric knee extension exercise [8], but
 319 reaffirm no difference in HR between younger and older males during leg press exercise [13].
 320 Similarly, the *unclear* differences observed in OMNI-RPE and the OMNI-RPE rate of change over the
 321 resistance exercise protocol are supported by previous data [14], but oppose previous findings in
 322 young and older males [10, 11]. The similar internal responses between groups in the current study
 323 might reflect similar alterations in vagal tone and motor command [8, 41] during resistance exercise
 324 in young and middle-aged males who regularly resistance train. sRPE demonstrated no differences
 325 between groups after the exercise, which is surprising given that sRPE is related to the volume load
 326 [42] that was moderately higher in the young group. sRPE appears to monitor the participant's
 327 perception of the exercise in the context of the physical and psychological state [43], which indicates
 328 that, holistically, the resistance trained young and middle-aged males perceived the exercise
 329 similarly. For blood lactate concentrations, *unclear* differences between groups after resistance
 330 exercise emerged. Though higher blood lactate concentrations have been observed in younger
 331 compared to older males [9], the similarities in the current study might suggest a similar reliance on
 332 glycolytic pathways during the squatting exercise in the two groups. The current study also observed
 333 no differences in any external to internal load ratios, which would indicate that the internal response
 334 for a given external load is similar between young and middle-aged males during squatting exercise.
 335 Collectively, these data suggest that internal load markers in young and middle-aged resistance
 336 trained males are similar during high volume squatting exercise at the same relative load.

337 Given that young resistance trained males can produce higher velocities than middle-aged males
 338 [4] it is perhaps surprising that differences in the peak velocity between groups during the exercise
 339 protocol were *unclear*. However, differences in velocity during exercise between age groups might
 340 only be present during less familiar movements, albeit 60% 1RM for squat demonstrated the lowest
 341 differences between groups (ES = 1.0) [4]. Also, the repeated squatting in this study, compared to
 342 single repetitions performed previous [4], might have been subject to pacing in order to prevent
 343 premature fatigue. A further explanation for the differences in velocity during exercise between age

344 groups might come from the participants' familiarity with the movement. For example, Petrella and
345 colleagues [23] noted greater fatigability and lower velocity in older adults (~64 years) compared to
346 their young (~27 years) counterparts during knee extension exercise, but no differences were present
347 during explosive sit-to-stand exercise. No difference in sit-to-stand exercise was attributed to
348 familiarity with that movement in both groups, i.e. they would perform sit-to-stand movements in
349 their daily routines whereas the older group were not familiar with knee extension exercise [23].
350 Given that all participants regularly squatted as part of their resistance programmes, this would
351 explain no difference in peak velocity between groups in the current study. Over the exercise
352 protocol, peak power was moderately higher in the young group compared to the middle-aged group
353 while the rate of change in peak power was *unclear* between groups. This supports previous
354 observations of lower power output and similar fatigability during explosive sit-to-stand exercise
355 [23]. Interestingly, Petrella and colleagues [23] noted that differences in power between ages were
356 driven by differences in velocity during exercise, yet the current study observed no differences in
357 velocity. That power is the product of the velocity and force (i.e. the load) would indicate that the
358 differences in peak power in the current study are due to the higher volume load performed by the
359 young males. That is, the differences in power between young and middle-aged resistance trained
360 males during the exercise are a consequence of differences in force (i.e. the volume load) and not
361 velocity as suggested by Petrella et al. [23] in young and old males. Accordingly, this study indicates
362 that peak power, but not peak velocity, is higher in young compared to middle-aged resistance
363 trained males during high volume squatting exercise.

364 Reductions in muscle function immediately after the squatting exercise are indicative of fatigue
365 (i.e. inability to maintain the expected force or power output) [18]. Lower VA after the squatting
366 exercise suggests that impairments in force and peak power were influenced by a reduction in drive
367 to the muscle caused by neural impairments and a reduction in excitability to the alpha motor-neuron
368 [33, 44, 45]. In addition, the lower resting doublet after exercise indicates peripheral alterations, that
369 is, a disruption of sarcomeres and impaired excitation-contraction coupling and the accumulation of
370 fatigue-related metabolites [46, 47] might have also contributed to the reductions in MVC and peak
371 power at 80% 1RM after the squatting. After exercise, resting doublet force and peak power at 20 and
372 80% 1RM had *very likely* greater decrements in the middle-aged group compared to the young group,
373 where differences in MVC and VA were *unclear*. Greater fatigue in older populations after isoinertial
374 compared to isometric actions are well supported [19, 20] and may reflect an elevated energy cost of
375 contraction [48] and impairments in cross-bridge cycling [21] with age. The greater decrements in
376 resting doublet force in the middle-aged males contrast to the similar reductions between age groups
377 after knee extension exercise reported by Dalton and colleagues [21] and are indicative of greater
378 peripheral alterations (i.e. disruption of sarcomeres and impaired excitation-contraction coupling)
379 [46, 47] after high volume exercise. The *unclear* differences between groups in VA are similar to those
380 previously reported by Dalton and colleagues [21] and suggest comparable central alterations after
381 high volume exercise. As such, middle-aged trained males can expect a similar isometric, but not
382 peak power, fatigue response after high volume squatting exercise.

383 Mean HR during exercise was moderately correlated with decrements in MVC and 80% 1RM
384 peak power ($r = .45$ and $.50$, respectively). It is unknown why a greater cardiovascular load during
385 squatting exercise might result in larger impairments in MVC and peak power at high external loads.
386 Previous work by Rezk and colleagues [49] noted that elevated HR, albeit after resistance exercise,
387 was associated with a cardiac sympathetic activation and parasympathetic deactivation. Like Rezk et
388 al. [49], the higher HR in the current study are likely to driven by alterations in cardiac sympathetic
389 and parasympathetic activity, which aim to increase oxygen delivery to the working musculature.
390 OMNI-RPE was moderately associated with decrements in peak power at both 20 and 80% 1RM ($r =$
391 $.36$ and $.32$, respectively). It is suggested that perception of effort reflects central motor command to
392 the muscles [41]. Moreover, an increase in central motor command might seek to augment muscle
393 activation in order to lift the load when the muscle is fatiguing [41]. Thus, it is understandable that
394 an elevated OMNI-RPE would be associated with reductions in post-exercise fatigue markers. These
395 data indicate a dose-response relationship between HR and OMNI-RPE during high volume

396 resistance exercise and post-exercise decrements in muscle functional markers. Practitioners should
397 be cognisant of the relationship between higher HRs and OMNI-RPEs with post-exercise decrements
398 in muscle function. This study also reported those with a higher volume load were subject to greater
399 impairments in MVC and peak power at 20 and 80% 1RM ($r = .59, .55$ and $.50$, respectively). These
400 data are similar to previous observations of greater reductions in MVC after lower-limb resistance
401 protocols with a higher amount of work performed [24, 25]. The moderate correlations with average
402 peak power during exercise and post-exercise reductions in MVC and peak power at 20 and 80%
403 1RM are the first of their kind. Like the suggestions of Brandon et al. [24] and Howatson et al. [25],
404 these reductions in MVC might be owing to metabolic (i.e. increased use of the glycolytic pathway,
405 which is indirectly supported by the higher post-exercise blood lactate) and peripheral alterations
406 (i.e. impaired excitation-contraction coupling, demonstrated by the reduction in resting doublet
407 scores after exercise). The relationships between external load (volume load and mean peak power)
408 with post-exercise decrements in peak power during back squat are novel and indicate that a dose-
409 response relationship exists between these variables. Importantly, these data suggest that the applied
410 practitioner can monitor volume-load and mean peak power during resistance exercise should they
411 need to be cognisant of the post-exercise impairments in muscle function after lower-limb exercise.

412 5. Conclusion

413 This study examined the load (internal and external) and fatigue response in young and middle-
414 aged males after high volume squatting exercise. These data indicate that internal load is not different
415 between young and middle-aged resistance trained males during squatting exercise, though certain
416 external load measures (peak power and volume-load) are. Practically, these findings suggest that
417 internal, but not external, load can be used to monitor high volume resistance training in a like
418 manner between these age groups. Moreover, high volume squatting exercise impairs peak power at
419 low and high external loads to a greater extent than isometric force in middle-aged males compared
420 to their young counterparts. The applied practitioner should be mindful of these reductions in peak
421 power in middle-aged males and programme lower-body resistance training accordingly. The
422 correlations observed in this study indicate that certain internal (HR and OMNI-RPE) and external
423 (mean peak power and volume-load) load are positively related to the post-exercise decrements in
424 muscle function. As such, it is suggested that applied practitioners monitor these variables when
425 post-exercise decrements in muscle-function are undesirable.

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