Recovery from power and heavy strength training sessions: Does mode matter when work is equal?

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The present cross-over-controlled study aimed to compare the rate of recovery from heavy strength vs. moderate load power training of equal work/volume. Sixteen strength trained individuals conducted one heavy strength training session (5 repetitions maximum (RM)) and one power session (50% of 5RM) in randomized order. Squat jump (SJ), countermovement jump (CMJ), 20-m sprint, and squat and bench press peak power and estimated 1RMs were combined with measures of perceived rate of exertion (RPE) and perceived recovery status (PRS), before, immediately after and 24 and 48 hours after exercise. Both sessions induced typically small and not more than moderate performance decrements. CMJ height was reduced by 7±6% (likely small) and 5±5% (possibly small) immediately after the heavy strength and power sessions, respectively. Twenty-four hours after both sessions CMJ and SJ heights and 20 m sprint were back to baseline. However, at 48 hours recovery was not complete after the heavy strength session compared to the power session – indicated by more impairments in CMJ eccentric force and CMJ rate of force development (RFD). In accordance with the performance measurements, session RPE and PRS demonstrated that the heavy strength session was experienced more strenuous than the power session. However, the subjective measurements agreed poorly with the objective measurements at the individual level. In conclusion, we observed larger degree of neuromuscular impairment and longer recovery times after a heavy strength session than a power session with equal total work, measured by both objective and subjective assessments. On the other hand, most differences were typically small or trivial after either session. Hence, it appears necessary to combine several tests and within test analyses (e.g., CMJ height, power and force) to reveal such differences. Objective and subjective assessments of fatigue and recovery cannot be used interchangeably; rather they should be combined to give a meaningful status of an individual in the days after a

resistance training session.

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Abstract

The present cross-over-controlled study aimed to compare the rate of recovery from heavy strength vs. moderate load power training of equal work/volume. Sixteen strength trained individuals conducted one heavy strength training session (5 repetitions maximum (RM)) and one power session (50% of 5RM) in randomized order. Squat jump (SJ), countermovement jump (CMJ), 20-m sprint, and squat and bench press peak power and estimated 1RMs were combined with measures of perceived rate of exertion (RPE) and perceived recovery status (PRS), before, immediately after and 24 and 48 hours after exercise. Both sessions induced typically small and not more than moderate performance decrements. CMJ height was reduced by 7±6% (likely small) and 5±5% (possibly small) immediately after the heavy strength and power sessions, respectively. Twenty-four hours after both sessions CMJ and SJ heights and 20 m sprint were back to baseline. However, at 48 hours recovery was not complete after the heavy strength session compared to the power session – indicated by more impairments in CMJ eccentric force and CMJ rate of force development (RFD). In accordance with the performance measurements, session RPE and PRS demonstrated that the heavy strength session was experienced more strenuous than the power session. However, the subjective measurements agreed poorly with the objective measurements at the individual level. In conclusion, we observed larger degree of neuromuscular impairment and longer recovery times after a heavy strength session than a power session with equal total work, measured by both objective and subjective assessments. On the other hand, most differences were typically small or trivial after either session. Hence, it appears necessary to combine several tests and within test analyses (e.g., CMJ height, power and force) to reveal such differences. Objective and subjective assessments of fatigue and recovery cannot be used interchangeably; rather they should be combined to give a meaningful status of an individual in the days after a resistance training session.

Introduction

Resistance training may be performed in various ways, but neuromuscular fatigue is inevitably, and typically one to three days of recovery is needed (Vincent and Vincent, 1997;Ahtiainen et al., 2003;Paulsen et al., 2012). The recovery process is obviously necessary for regaining full performance capacity, but it is also intertwined with adaptation processes (Bishop et al., 2008;Paulsen et al., 2012). Recovery is therefore vital for all who perform resistance exercise, whether recreationally trained individuals or elite athletes. However, our knowledge about recovery processes are hitherto inadequate (Bishop et al., 2008;Paulsen et al., 2012;Kellmann et al., 2018). Based on the existing literature we can hardly predict recovery times from a given training session. The difficulty to foresee recovery rates lies in the range of factors at play, including – but not restricted to – type of muscle contractions, relative load (% of maximal strength) and volume or work done (e.g., load x distance x repetitions). The recovery time increases with higher exercise volumes, but not linearly (Brown et al., 1997;Hiscock et al., 2018). In other words, recovery time levels off at a certain volume. Muscle contraction type has substantial impact on restitution as eccentric contractions cause markedly longer recovery times than isometric and concentric contractions (Jones et al., 1989;Carson et al., 2002). Moreover, when lifting weights ("isotonic" muscle work) we can expect longer recovery times with increasing relative loads; possibly as a consequence of the correspondingly higher eccentric force-generation (Faulkner et al., 1993;Black et al., 2007;Raeder et al., 2016;Hiscock et al., 2018). Long-lasting recovery (days) of the neuromuscular functions can largely be explained by damage and disturbances in the excitation-contraction-coupling and the myofibrillar machinery (Paulsen et al., 2012), although central (neural) fatigue may persist for some time (Nicol et al., 2006;Enoka et al., 2011;Carroll et al., 2017).

Other characteristics of muscle work relate to contractions velocity and the transition from eccentric to concentric phase. Indeed, classical power training utilizes low to moderate loads (e.g., 30-60% of 1 repetition maximum (RM)) and the lifts are often executed in a plyometric fashion, i.e., a fast transition from eccentric to concentric phase. Plyometric contractions allow for higher concentric power due to pre-activation and in some cases taking advantage of elastic properties in the muscle-tendon unit (Bobbert et al., 1996;Wade et al., 2018). However, surprisingly few studies have investigated the potential differences in recovery times between various modes of resistance training, such as heavy strength training (>80% of 1RM) with slow velocities (mean velocity <0.6 m/s) and power training with low/moderate loads (<50% of 1RM) lifted with moderate to high velocities (mean velocity >1 m/s; (Banyard et al., 2018;Garcia-Ramos et al., 2018)).

Linnamo et al. (1998) compared 40% of 10RM to 100% of 10RM (5 sets, 2 minutes rest periods) in the knee-extension exercise with a crossover design in non-resistance trained individuals. Utilizing an isometric strength test, the authors demonstrated less acute fatigue and faster recovery from the low-load power exercise compared to the heavy-load exercise over 48 hours, although the "power" contractions were conducted with maximal effort (and probably full muscle recruitment). Similarly, but with elite track and field athletes, Howatson et al. (2016) found a reduction in isometric strength 24 hours after heavy strength training (4 x 5 repetitions; squat, split squat and push press), but not after power training (30% of the heavy loads; 4 x 5

86   repetitions; speed squat, split squat jump and power press). However, with different exercise
87   volume (same total number of repetitions, but different loads), it is not possible to tease out the
88   true impact of load. McCaulley et al. (2009) controlled for exercise volume and reported a larger
89   acute neuromuscular fatigue after heavy loads squats than maximal power jump squats.
90   Nevertheless, McCaulley et al. (2009) could not statistically distinguish the recovery from heavy
91   strength exercise and power exercise after 24 and 48 hours. In a similar study, Hiscock et al.
92   (2018) compared heavy loads (90% of 1RM; 3x3 reps) against "power loads" (45% of 1RM; 3x6
93   reps) in the deadlift and squats. No differences were found between experimental loads;
94   however, recovery was seemingly complete within 12 hours after the power session, while 24
95   hours was required after the heavy load session. In short, our knowledge of the impact of loads
96   on recovery after different modes of resistance exercise is limited and necessitates more studies.

97   Recovery can be defined as normalisation of the neuromuscular function (Bishop et al., 2008).
98   However, it is not given which functions that should be measured. In McCaulley et al. (2009) the
99   participants conducted dynamic squat exercise, but an isometric squat was used to assess
100   neuromuscular function. Hence, it seems reasonable to ask whether a dynamic test, such as squat
101   jump (SJ) or countermovement jump (CMJ), would have yielded similar recovery rates. Indeed,
102   when a range of different recovery tests have been applied, such as CMJ, sprinting and single
103   joint isokinetic torque, the tests do not demonstrate interchangeable recovery courses (Andersson
104   et al., 2008;Chatzinikolaou et al., 2010). It can also be different recovery rates of properties
105   extracted from the same test. To exemplify, mean power have been shown to recover faster than
106   contraction time during CMJs (Gathercole et al., 2015a). In addition, the error of measurements
107   is a challenge; muscle strength and power typically nadirs in the range of ~5-20% immediately
108   after resistance exercise in trained individuals, but may be less than 5% below baseline after only
109   24 hours (Raastad and Hallen, 2000;Howatson et al., 2016;Hiscock et al., 2018). Knowing that
110   the typical error (coefficient of variation; CV) of day-to-day measurements of CMJ height and
111   power at best are ~3-5% (Raastad and Hallen, 2000;Hopkins et al., 2001;Gathercole et al.,
112   2015a), it is evident that the sensitivity of the CMJ test is limited during the final part of the
113   recovery process. In the present study we address the typical error of all tests applied.

114   Exercise load and work, neuromuscular fatigue and recovery can be tracked with objective
115   performance measures (strength and power tests), but also subjectively as rate of perceived
116   exertion (RPE) and recovery status (PRS). Session RPE has been used for years, also for
117   resistance training (Foster et al., 2017), while the PRS scale has a shorter history (Laurent et al.,
118   2011). Interestingly, few investigations have compared subjective and objective recovery
119   assessments after different modes of resistance exercise. Korak et al. (2015) observed that
120   recreationally strength trained males experienced faster recovery from single-joint than multi-
121   joint exercises, which appeared to correspond to objective measures (10RM-test). However, in a
122   case study of weightlifters/powerlifters, Zourdos et al. (2016) found that daily 1RM lifts
123   improved performance, while RPE increased, implying a divergent trend between the objective
124   and subjective measures. Clearly, more research is needed to elucidate the relation between
125   objective and subjective measures of recovery after resistance exercise.

126 The aim of the present study was to compare the recovery rates from a power session against a
127 heavy strength session of similar work/volume. A range of objective tests of strength and power
128 were combined with subjective testes to get a broad picture of the recovery processes of both
129 upper and lower body muscles. We hypothesized that the power session would require less
130 recovery time than the heavy strength session. Secondly, compared to the heavy strength session
131 the power session was hypothesized to be perceived as less strenuous and to have a faster
132 recovery by the participants.

133

Materials & Methods

135 **Study design**
136 The present study was a randomized cross-over study: Each participant completed two training
137 sessions, a heavy strength session and a power session, in randomized order. One to four weeks
138 of rest was allowed between sessions. A test battery of physical performance and perceived
139 effort and recovery was applied before, immediately after, and 24 and 48 hours after the training
140 sessions (Figure 1). The concentric work (J) done in the first session was recorded and replicated
141 in the second session, ensuring equal volume for both sessions (see details below). The exercises
142 were the same for both sessions, but somewhat adapted to serve the purpose of the sessions, i.e.,
143 heavy strength vs. power training (Table 1). The primary aim of the study was to compare the
144 recovery rates between sessions when all factors were equal except the load.

145 *** Figure 1 and Table 1***

146 Three to seven days before the first exercise session, a familiarization session was conducted.
147 The participants were familiarized to all tests and exercises (see details below) and instructed not
148 to conduct any strenuous exercise 48 hours prior to the test days. The participants were also
149 instructed to standardize breakfast, energy intake during and immediately after the training
150 sessions. Furthermore, the participants were asked to standardize their meals during the 48 hours
151 recovery phases, but this was not recorded by the investigators. Any kind of supplements or
152 medications were prohibited during the study period.

153 During the training sessions participants were given a protein bar and a protein drink (both
154 supplements containing approximately 20 g protein, 30 g carbohydrates, and a total of ~1000 KJ,
155 Yt, Tine, Oslo, Norway), and an energy drink (30 g carbohydrates; 510 KJ; Yt, Tine, Oslo,
156 Norway) to ensure sufficient protein and energy intake (in total: 40 g protein and 90 g
157 carbohydrates; ~1500 KJ). Water was allowed ad libitum.

158 **Participants**
159 Nineteen young, resistance trained individuals were recruited to this study. Sixteen participants,
160 eight males and eight females, completed all tests and both training sessions (21±4 years, 74±12
161 kg, 1.75±11 m; Table 2). Two participants dropped out due to muscle pains (hamstrings and
162 groin) during testing or training; and one was excluded after technical problems with the test
163 equipment.

164 The participants were familiar with heavy strength training and had been training upper and
165 lower body strength exercises on a weekly basis during the last year (≥2 session/weeks). Of the
166 16 participants, three were competing on a national elite level (two volleyball- and one beach
167 volleyball player), one was professional international level bike trial athlete, while the 12
168 remaining participants were physical active on a recreational level recruited from the Norwegian
169 School of Sport Sciences (Oslo, Norway).

170 The study was reviewed by the Norwegian Regional Ethical Committee of Medical and Health
171 Research (2016/1120). The participants gave written informed consent to participate, in
172 accordance with the Declaration of Helsinki (World Medical Association).

173

174 **Testing and exercises**
175 The familiarization session consisted of all the tests (see below) and 2-3 sets of five repetitions of
176 all the exercises: Squat, front squat, trap bar squat, bench press, narrow bench press and push-ups
177 (Figure 1). The loads were adjusted to get close to a 5-repetition maximum (RM) during the last
178 set. For the power exercises the loads were 50% of the estimated 5RM loads. In both sessions,
179 the exercises were executed with maximal effort in the concentric phase in all repetitions. In the
180 heavy strength training session, the eccentric phase was conducted with a controlled, slow
181 movement (>1 second). In contrast, in the power session the eccentric phase was faster (<1
182 second) in order to maximize the power output in the concentric phase, i.e., perform a plyometric
183 movement (Davies et al., 2015).

184 At the days of the training sessions, the participants rated their perceived recovery status (PRS
185 scale; 0-10; (Laurent et al., 2011)) prior to a warm-up. The warm-up consisted of a 10 minutes
186 easy run with increasing velocity, before two minutes of dynamic stretching of both upper and
187 lower body muscles. The tests were then conducted in the following order: CMJ, SJ, 10
188 consecutive multiple jumps (MJ), 20-meter sprint running, maximal push-up force, and power
189 profiles and estimated 1RMs in bench press and squat. Tests were performed before and
190 immediately after the sessions, and again after 24 and 48 hours. The power profile tests and 1RM
191 estimation in the bench press and squat were, however, not conducted immediately after the
192 sessions in order to prevent additional fatigue. Finally, about thirty minutes after the sessions the
193 participants rated the perceived exertion (sRPE; 0-10; (Foster et al., 2001)). Note that the
194 participants were introduced to the ratings and descriptors of both the RPE and the PRS scales at
195 the familiarization session.

196 *Tests*
197 The CMJ, SJ, and MJ were conducted on an AMTI force platform (sampling rate, 2000 Hz;
198 OR6-5-1; AMTI, Watertown, MA, USA). All tests were performed with hands fixed on the hips
199 (akimbo). CMJ and SJ are previously described in detail (Helland et al., 2017). In the MJ test, the
200 participants were instructed to jump 10 consecutive jumps as high as possible. The jump tests
201 analyses were conducted in a custom-made software (Biomekanikk AS, Oslo, Norway), and the
202 average of each individual's two best attempts of 3-6 jumps were used for subsequent statistical
203 analyses. We divided the CMJ into the eccentric phase and the concentric phase (Figure 2); i.e.,

204   the phase where the centre of mass was descending and ascending, respectively (calculations
205   based on the impulse–momentum method (Linthorne, 2001)). Eccentric time was defined as the
206   time from when the force equalled body weight to the start of the concentric phase, and the
207   maximal rate of force development (RFD) was calculated as the largest increase in force over a 5
208   ms time window (Figure 2). The variation of coefficient (CV) for these and all applied tests are
209   given in Table 2.

210   Two to three maximal 20-meter sprint runs were performed on a rubberized indoor track
211   (Mondo, Conshohocken, PA, USA) with 3-4 minutes rest between trials. The sprints were
212   measured with an electric timing system (Biomekanikk AS, Oslo, Norway) with a timing trigger
213   (single-beamed timing gate 0.6 m after the start line and 0.4 m above ground level) and duel-
214   beamed timing gates placed every 5 m along the sprint track. Participants were instructed to
215   accelerate as fast as possible from a stand-still start with one foot in front of another.

216   After a specific warm-up consisting of ten push-ups with increasing effort and three maximal
217   singles, three single maximal push-ups were assessed on a force platform (sampling rate: 2000
218   Hz; OR6-5-1; AMTI, Watertown, MA). One minute of rest was given between the single push-
219   up efforts. The participants were instructed to keep their body straight and to do a controlled
220   slow eccentric phase to a position where the chest was 2-3 cm above to floor, and then do a fast
221   as possible push.

222   Bench press and squat performance were assessed using a linear encoder (Musclelab Linear
223   Encoder; Ergotest Innovation, Langesund, Norway). The string of the encoder was attached to
224   the bar, with the device measuring vertical velocity (v) and the displacement (d) during the
225   concentric press phase (200 Hz sampling rate; 0.019 mm resolution). The participants completed
226   sets of three maximal repetitions at four different loads, with about ~5 seconds between each lift
227   and 2-4 minutes between sets. All repetitions were conducted with maximal effort in the
228   concentric phase. The external loads were 25, 50, 75 and 90% of estimated 1RM (estimated
229   during the familiarization session). The attempts with the highest power from each load were
230   selected for further analysis. A concentric force-velocity relationship was established and peak
231   power and 1RM were estimated (software from Ergotest Innovation, Langesund, Norway). For
232   the squat, the participants were instructed to squat down to a position where the femur was
233   approximately parallel with the floor in a slowly controlled manner, and then extend as fast and
234   powerful as possible. For squat we estimated P on the system mass (90% of body weight) and the
235   external mass ($v = d/t$; acceleration $[a] = v/t$, force $[F] = mg + ma$; $P= Fv$), and for the bench
236   press external mass only was used.

237   *Training sessions*
238   The heavy strength session consisted of three exercises for the lower body, in the following
239   order: squat, front squat, trap bar squat; and three exercises for the upper body, performed in the
240   following order: bench press smith, narrow bench press smith and weighted push-ups (Table 1).
241   A warm-up set of 8 repetitions at 60-80% of 5RM before each exercise preceded 5 sets of 5RM.
242   The 5RM loads were estimated from the familiarization session for each exercise. The inter-sets
243   rest period was 3-4 minutes. The loads were adjusted between sets, if necessary. All exercises
244   were conducted with the same tempo with a controlled slow eccentric phase and a fast as

245 possible concentric phase. The leg exercises were performed with free weights (Eleiko,
246 Halmstad, Sweden), while both narrow- and bench press were performed in a smith rack
247 (Multipower, Technogym, Cesena FC, Italy). Weighted push-ups were performed on three 30 cm
248 custom made boxes, and loads were applied by a weight-vest (1-9 kg; Reebok, Boston, Ma, US)
249 and (if needed) weight discs (5-20 kg) placed on the participants back – positioned over their
250 scapulae.

251 The power training session was conducted with loads corresponding to 50% of the external load
252 used in the heavy strength training session. Loaded CMJ, front squat with overhead push, trap
253 bar CMJ, bench press smith throw, narrow bench press smith throw, and explosive push-ups
254 were performed with a continues high velocity tempo in the concentric phase (Table 1).

255 We measured the concentric displacement and velocity for all the exercises in both sessions with
256 a linear encoder. The encoders string was attached to the bar in all cases except both push-ups
257 variations were the string was attached to a light chest belt at the distal part of the sternum bone.

258 The total work was calculated by summarizing the products of repetitions, load and displacement
259 for each set of each exercise: Only the displacement of the concentric phase was used; i.e., the
260 distance from the vertically lowest to the vertically highest position of the bar in the squat
261 exercise. For the lower body exercises we assumed the load to be the sum of 90% of the body
262 mass and the external load. This was based on the encoder manufacture's advice (Ergotest
263 Innovation, Langesund, Norway) and very close to what has been used by others (Cormie et al.,
264 2007). For the front squat push, the squat part was calculated as described, but for the final
265 overhead push only the external load was used; thus, the squat work and push work were
266 calculated separately and then added together. For the bench press exercises, only the external
267 load was used, while for the push-ups the weight of the upper body (measured with the force
268 plate during testing) was added to the external load.

269 The first session (randomly heavy strength or power) was used as a template for the second
270 session for each participant. Hence, we adjusted the number of sets per exercise, so that the
271 concentric work done in each exercise was similar between sessions. The amount of work per
272 exercise was fine-tuned by adjusting the number of repetitions in the final set (e.g., performing
273 only two repetitions in order to reach the required amount of work).

274 **Statistics**
275 The data were analysed in spreadsheets that allow for adjustment of one or two predictor
276 variables in the changes within or difference between sessions (Hopkins, 2007). The spreadsheet
277 is basically a t-test that gives the opportunity to adjust for baseline to control for the regression to
278 the mean effect. All data were log-transformed, and changes are reported as percent with its
279 associated 90% Confidence Interval.

280 Effects were evaluated using clinical magnitude-based inferences (MBI; (Hopkins et al., 2009)),
281 a method appropriate for small samples. The magnitude of changes within and difference in
282 mean between sessions was assessed by standardization (mean change/difference divided by
283 baseline SD of all subjects), and the resulting standardized effect evaluated with a modification
284 of Cohen's (1992) scale: <0.2, trivial; 0.2-0.6, small; 0.6-1.2, moderate; >1.2, large (Hopkins et

285 al., 2009). The subjective variables (RPE and PRS) were evaluated with the following scale:
286 <10% trivial, 10-30% small, 30-50% moderate, 50-70% large, 70-90% very large, and 90-100%
287 extremely large (Hopkins, 2010).The initial RPE and PRS values therefore factored by 10 (0-
288 100).

289 To make clinical inferences about true values of effects in the population studied, the effects
290 were expressed as probabilities of harm or benefit in relation to the smallest worthwhile change
291 (0.2 of SD; (Hopkins et al., 2009)). The ratio of wanting to use the experimental training
292 corresponds to the case of an effect that is almost certainly not harmful (<0.5% risk of harm) and
293 possibly beneficial (>25% chance of benefit). The effect is shown as the difference or change
294 with the greatest probability, and the probability is shown qualitatively using the following scale:
295 25-75%, possibly; 75-95%, likely; 95-99.5%, very likely; > 99.5%, most likely (Hopkins et al.,
296 2009).

Results

298 Baseline values for the 16 participants before each training modality are presented in Table 2.
299 One participant was removed for the push-up force data in the power modality due to outlier
300 values. The removal did not benefit the recovery from the power session. The differences
301 between the two modalities at baseline were trivial, nevertheless baseline values were included
302 as a covariate in all analyses of within-session changes and between session differences, and
303 thereby controlled for.

304 ***Table 2***

305 The smallest worthwhile change (SWC) and the coefficient of variation (CV) for each variable
306 are presented as relative values (Table 2). Note that the CV was larger than the SWC for most
307 variables (e.g., CMJ and SJ RFDmax), but equal or lower for some such as eccentric peak force.

308 Within-session changes immediately after (0 hours), and 24 and 48 hours after the training
309 sessions are shown in Figure 3 and Table 3. We analysed the effect of session sequence (order),
310 but it was trivial for all variables and not included in further analyses. The changes immediately
311 after the training sessions were generally negative, both sessions showed small clear negative
312 changes for most CMJ variables (height, mean power, concentric peak force, eccentric peak
313 force; Figure 3) and SJ mean power (Table 3). The CMJ RFDmax and the subjective variables
314 (RPE and PRS) had a clear moderate negative change after both sessions. In addition, the heavy
315 strength session gave clear small negative changes in CMJ depth, SJ height, SJ RFDmax, SJ
316 duration and MJ RSI, while these were trivial after the power session (Table 3 and Figure 3).

317 ***Table 3 & Figure 3***

318 At 24 hours similar trends emerged, with the heavy strength session showing clear small
319 negative effects on SJ RFDmax, SJ duration and squat peak power; while the changes in these
320 variables were trivial after the power session. In addition, the heavy strength session showed a
321 clear moderate negative effect on CMJ break time and PRS lower body, compared to a small
322 negative effect after the power session. On the contrary, the power session gave some small
323 possibly beneficial effects on MJ RSI and height.

324 At 48 hours, most clear negative changes were small and merely evident after the heavy strength
325 session (Table 3). Further, CMJ RFDmax and CMJ eccentric time displayed clear moderate
326 negative changes after the heavy strength session (Figure 3); this was also reflected in a small
327 possibly increase of total duration of the CMJ (5.3 ± 6.4%) 48 hours after the heavy strength
328 session. In contrast to heavy strength, the power session gave a small possibly beneficial change
329 in squat peak power and push-up peak force at 48 hours (Table 3).

330 A few clear differences were observed between sessions (Table 4). Compared to the power
331 session, the heavy strength had a small negative effect on CMJ depth, SJ duration and MJ height
332 immediately after the session. At 24 hours, the heavy strength session showed clear small
333 negative effects on CMJ eccentric time and eccentric peak force, SJ height, SJ RFDmax, squat
334 peak power, and upper and lower body PRS compared to the power session. However, there was
335 a small clear likely beneficial effect of the strength session on MJ vertical stiffness.

336   ***Table 4***

337   At 48 hours, the heavy strength session still demonstrated small and possibly to likely negative
338   effects compared to the power session on CMJ concentric peak force, CMJ RFDmax, CMJ
339   eccentric time, CMJ eccentric peak force, CMJ depth, SJ RFDmax, squat peak power, push-up
340   peak force, and upper body PRS.

341   To investigate the relationship between subjective and objective tests, we selected the apparently
342   most sensitive objective tests for monitoring recovery for the lower and upper body. Hence, we
343   correlated the CMJ eccentric peak force against PRS at 24 and 48 hours after exercise; and, for
344   the upper body, push-up peak force against PRS at 24 and 48 hours after exercise (Figure 4).
345   There were no clear positive or systematic correlations between these variables. There was a
346   clear negative correlation between push-up peak force and PRS at 24 hours after the power
347   session (but not after 48 hours), indicating an (counterintuitive) relationship between high force
348   and low degree of perceived recovery.

349   ***Figure 4***

350

Discussion

352   Herein, we aimed to compare the recovery rates after a heavy load strength session and a
353   moderate load power session of similar concentric work. Our main findings were: 1) The heavy
354   strength session had overall the largest detrimental effects on the neuromuscular system,
355   reducing both the eccentric and concentric phases of jumping. However, the differences in
356   performance assessments between the sessions were generally of small or trivial magnitudes. 2)
357   The apparently most specific recovery markers for demonstrating a difference between the heavy
358   strength session and the power session were CMJ eccentric peak force, CMJ eccentric time and
359   squat peak power, showing likely small differences between sessions after 48 hours of recovery.
360   3) In contrast to the heavy strength session, the power session seemed to potentiate performance,
361   as we observed small increases in MJ height and MJ RSI after 24 hours and squat peak power
362   and push-up peak force after 48 hours. 4) The heavy load strength session was perceived as more
363   strenuous and rate of recovery slower compared to the power session; however, subjective and
364   objective correlated poorly.

365   **Previous studies**
366   Small to trivial impairments of neuromuscular performance were seen after both training
367   sessions. To exemplify, measures of CMJ and SJ heights and sprint times were maximally
368   reduced ~8%, which are in the low end compared to previous studies (Raastad and Hallen,
369   2000;Howatson et al., 2016;Raeder et al., 2016;Davies et al., 2018;Hiscock et al., 2018). We
370   believe that this is because our participants were well trained, and more importantly, familiarized
371   with the exercises and tests.

372   In line with the existing literature (Linnamo et al., 1998;Brandon et al., 2015;Howatson et al.,
373   2016), a heavy strength session attenuated the neuromuscular system more than a low or
374   moderate load power session. However, in previous studies where the exercise work was

375 controlled for, the differences between heavy strength and power sessions are close to abolished
376 (McCaulley et al., 2009;Hiscock et al., 2018). Our observations confirm these findings, but add
377 some nuances to this picture, as we did report some differences between the heavy strength
378 session and power session. We believe that differences in recovery rates between resistance
379 exercise sessions of different modes but of similar exercise volume must be expected to be rather
380 subtle, although yet important; we must therefore consider both methodological issues and the
381 biological mechanisms behind the exercise-induced impairments of the neuromuscular system.

382 Methodological issues: Reliability and fatigue sensitivity
383 To discriminate the recovery rates of closely related exercise modalities as heavy strength and
384 power sessions, highly reliable (day-to-day) tests must be applied. Indeed, the sprint test
385 demonstrated very high reliability (CV: ~1%). CMJ and SJ height and estimation of 1RMs had
386 good reliability (CV: 3-5%), while peak power in the squat and bench press and MJ height had
387 acceptable reliability (CV: ~9-10%). Push-up peak force reached near acceptable reliability (CV:
388 ~11). Overall, the reliability of tests applied herein is well in line with those of others (Raastad
389 and Hallen, 2000;Hopkins et al., 2001;Byrne and Eston, 2002;Cronin et al., 2004;Cormack et al.,
390 2008;Taylor et al., 2010;Gathercole et al., 2015a;Gathercole et al., 2015b). An exception among
391 our tests were RFDmax gleaned from CMJ and SJ, which demonstrated poor reliability (CV
392 >20%). Previous studies confirm a moderate to poor reliability for RFD measurements in single
393 joint knee-extension (CV = 7-17%) (Buckthorpe et al., 2012), and for CMJ and SJ (CV = 16-
394 18%) (McLellan et al., 2011;Gathercole et al., 2015a).

395 Functional and performance tests may also be judged by comparing the "smallest worthwhile
396 change" (SWC) with the typical error (Cormack et al., 2008): If the SWC is larger than the
397 typical error, the test should allegedly be able to (confidently) detect relevant and meaningful
398 changes. Among our tests, jump height and measures of force (concentric and eccentric peak
399 force) demonstrated CVs equal or lower than the SWC (see Table 2). Nevertheless, an evaluation
400 of tests must be applied in practice. Gathercole et al. (2015a) used the term "fatigue sensitivity"
401 that refer to a tests ability to detect impairments in the neuromuscular function after exercise. As
402 the conditions of the neuromuscular system changes – due to different forms of central and
403 peripheral fatigue (Enoka et al., 2011), high reliability measured in the rested state is not
404 necessarily valid for the fatigued state. In fact, tests of isolated joints, e.g. isokinetic knee-
405 extension assessments, appear to demonstrate larger changes than multi-joint tests, such as sprint
406 and jump tests after different multi-joint activities (Byrne and Eston, 2002;Andersson et al.,
407 2008;Howatson et al., 2016). To this end, we suggest that tests allowing for subtle changes in the
408 movement pattern, such as sprint and CMJ, may be highly reliable, but can lack fatigue
409 sensitivity. Subtle movement/technique compensations that optimize the conditions for the
410 current state of neuromuscular system may indeed "mask" fatigue (Van Ingen Schenau et al.,
411 1995;Gathercole et al., 2015b).

412 Interestingly, we observed only trivial changes in CMJ height and peak power from before to
413 after both sessions, but clear changes in CMJ eccentric time and CMJ eccentric peak force.
414 Similar findings have recently been reported by others (Gathercole et al., 2015a). These
415 observations indicate that the participants ability to utilize the eccentric phase was impaired in

416   the recovery phase, but some movement or coordination compensations apparently minimized
417   the reductions in jump height and power production. The reduction in eccentric peak force
418   seemed primarily related to a slower eccentric phase during the CMJ, i.e., increased eccentric
419   time, since the lowering the centre of mass was not changed after the heavy strength session.
420   Still, there were differences between sessions, because the participants appeared to lower centre
421   of mass more after the power session than at pre-test, especially at 48 hours. Further studies
422   should investigate changes in the kinetics and kinematics (movement strategies) of a CMJ in the
423   phase of recovery compared to the rested state. Nevertheless, we suggest the eccentric peak force
424   is a more sensitive marker of fatigue and neuromuscular impairments than jump height and
425   maximal power.

426   We found no clear meaningful differences between sessions or in the recovery rates between
427   sessions for CMJ and SJ height. This contrasts observations by Byrne and Eston (2002) who
428   reported that SJ was reduced more and recovered slower than CMJ (and drop jump) after a squat
429   exercise session (10 x 10 repetitions at 70% of body weight). The discrepancy of findings may
430   be related to more muscle damage in the study by Byrne and Eston (2002) than the present study
431   – as indicated by a larger drop in performance (Paulsen et al., 2012). Moreover, studies have
432   investigated various measures of RFD and observed that the impairment and recovery of this
433   quality differ from maximal force (Penailillo et al., 2015;Farup et al., 2016). In our study we
434   extracted RFDmax from CMJ and SJ, and despite low reliability we report small possible
435   differences between sessions at 24 and 48 hours – in accordance with previous observations
436   (Gathercole et al., 2015a). Thus, we recognize RFDmax-values from jump tests as possible
437   fatigue sensitive, but we warn about high day-to-day test variability. A practical consequence
438   could be that RFDmax measures are more relevant for group data than individual monitoring of
439   athletes.

440   From the force-velocity tests in bench press and squat we calculated peak power and estimated
441   1RM. The 1RM values had allegedly good reliability (CV<5% and CV<SWC), but contrary to
442   the peak power the 1RM values showed trivial changes after both training sessions. Although it
443   has been suggested to be worth using (Jovanovic and Flanagan, 2014;Scott et al., 2016), force-
444   velocity estimated 1RMs appears to have limited value for monitoring small changes in recovery
445   status; i.e., estimated (or predicted) 1RM test appear to have low fatigue sensitivity. We applied
446   ~90% of 1RM as the heaviest load which may have been too low to get an accurate estimation of
447   1RM, as observed by some (Banyard et al., 2017), but not others (Jidovtseff et al., 2011).

448   **Mechanisms for neuromuscular recovery**
449   Exercise-induced impairment of neuromuscular function and the following recovery phase are
450   multifaceted (Lieber and Friden, 2002;Enoka et al., 2011;Paulsen et al., 2012). But, if we
451   consider a particular exercise, i.e. the squat, and assume a constant range of motion (muscle
452   lengthening/strain) and a given total exercise volume (sets x repetitions; as herein), the
453   determining factors would be narrowed down to contraction/lengthening velocity and force. With
454   the criterion of maximal effort (intention to move) in the concentric phase, velocity will be high
455   and force low during light or moderate load power exercises, and visa-versa for heavy load
456   strength exercises (cf. the force-velocity relationship). Higher concentric forces during the heavy

457 load strength exercises will logically put more mechanical stress on the muscle tissue. However,
458 even high-force concentric contractions cause minimal muscle damage and a swift recovery of
459 muscle function (~24 hours; (Jones et al., 1989;Lee et al., 1999;Carson et al., 2002)). Thus,
460 concentric work can probably only explain perturbations in the neuromuscular function shortly
461 after exercise (i.e., minutes to few hours; (Allen et al., 2008)). This led us to suggest that the
462 eccentric phase was probably of greater importance for the differences in neuromuscular
463 impairment and recovery rate between sessions. In other words, the higher eccentric forces –
464 simply due to higher loads – during the heavy strength session likely explains the slower
465 recovery compared to the power session (Faulkner et al., 1992;Black et al., 2007).

466 Even though the loads were largely different (50%), the differences between the power and
467 heavy strength sessions were overall small. One reason for the small differences between
468 sessions could lay in the fact that – contrary to concentric contractions – eccentric force
469 generation is (apparently) independent of lengthening velocity (Edman, 1988;Westing et al.,
470 1988;Westing et al., 1990). This implicates that high forces can be combined with high velocities
471 during eccentric work. Eccentric velocity *per se* appears to play a minor role in muscle damage
472 and recovery (McCully and Faulkner, 1986;Warren et al., 1993;Willems and Stauber, 2002), but
473 during power training the transition from eccentric to concentric phase is intentionally short and
474 creates a large end-range eccentric force-generation – necessary in order to utilize the stretch-
475 shortening cycle (Bosco et al., 1981). Indeed, the peak eccentric force seems rather independent
476 of load when the intention to move is maximal (own unpublished observations). We suggest that
477 the moderate loads applied in the power sessions did induce a rather high mechanical stress on
478 the muscle tissue. Consequently, the difference in functional impairments and recovery times
479 between the power session and the heavy strength session became less in our study than what
480 could be expected if the loads had been lifted with the same eccentric velocity. Strenuous stretch-
481 shortening cycle exercises have in fact been shown to require days of recovery (Nicol et al.,
482 2006).

483 Herein, both upper body and lower body exercises were applied. Studies exploring muscle
484 damage and recovery after eccentric exercise have reported that upper body muscles sustain
485 more damage and longer recovery times than lower body muscles (Jamurtas et al., 2005;Chen et
486 al., 2011;Chen et al., 2019). On the contrary, recovery rates after traditional strength training do
487 not appear to be different between upper and lower body exercises, such as the bench press and
488 squat (McLester et al., 2003;Korak et al., 2015;Moran-Navarro et al., 2017). In line with these
489 studies, our data demonstrate a similar recovery course in upper and lower body exercises.
490 Moreover, as for the lower body, the heavy strength seemed to induce somewhat more fatigue
491 and longer recovery times than the power session for the upper body. In contrast to most studies
492 that have investigated recovery after eccentric exercise (as cited above), we recruited well-
493 trained individuals, which points to training status as an important parameter for recovery times
494 – rather than an inherent difference between upper or lower body muscles. Nevertheless, great
495 care should be taken to compare recovery from different exercises/sessions because variables
496 such as muscle strain, force and work are very difficult to control for.

Fatigue vs. potentiation and supercompensation

497
498 The neuromuscular function can be altered through adaptation to training over weeks and months
499 (Goldspink, 1985), but the neuromuscular system is also history dependent for shorter time
500 periods. In fact, both fatigue and potentiation are possible outcomes of muscle contractions (Sale,
501 2002). While heavy loads and large exercise volumes may induce long-lasting neuromuscular
502 fatigue (hours and days), exercises conducted with low volume and high/maximal effort can
503 result in potentiation and enhanced neuromuscular function that lasts for minutes to several hours
504 (Cook et al., 2014;Russell et al., 2016). Interestingly, in the present study the power session
505 appeared to enhance MJ height and RSI at 24 hours and squat peak power and push-ups peak
506 force 48 hours after exercise. This is in line with Tsoukos et al. (2018) who observed increased
507 CMJ height and RFDmax 24 and 48 hours after loaded jump squats (40% of 1RM; 5 x 4
508 repetitions). In contrast to squat peak power, we observed no such "supercompensation" in CMJ,
509 SJ or 20 m sprint (which were all back to baseline at 48 hours). Noteworthy, our participants
510 executed a large exercise volume, about three times that of Tsoukos et al. (2018), and fatigue
511 mechanisms may have overshadowed most of the supercompensation effects of power exercises.
512 Moreover, we only followed the participants for 48 hours, which means that we do not know if
513 the supercompensation occurred later after the heavy strength session (e.g. after 72 hours). As
514 finale note, potentiation/supercompensation is indeed relevant for athletes, as it is common
515 practice for "power athletes", e.g., rugby players, track and field throwers and sprinters, to
516 perform a power session close to competitions (~4-48 hours; (Russell et al., 2016); and own
517 observations from the Norwegian Olympic Center, Oslo, Norway).

Objective vs subjective measures of recovery

518
519 Session RPE (sRPE) for resistance exercise was reviewed by McGuigan (2004) and validated for
520 "intensity", i.e. load in % of 1RM, by Sweet et al. (2004). Later studies have found the session
521 RPE to be related to both volume and work rate during strength training (Scott et al.,
522 2016;Hiscock et al., 2018). The present study ensured equal concentric work, but different loads
523 – i.e., the power session was performed with 50% of the heavy strength loads. Nevertheless,
524 because the power session lasted ~12% (~13 minutes) longer than the heavy strength session, the
525 work rate was highest during the heavy strength session. As the difference in loads (% of 1RM)
526 between sessions was much larger than the difference in work rate, we suggest that the higher
527 loads (% of 1RM) were the dominant factor influencing the RPE scores (although we
528 acknowledge that this cannot be ascertained with the present study design). Notably, it has been
529 purposed that exercise intensity/load (% of 1RM) influence RPE scores via a positive
530 relationship with the central motor control discharge (Gearhart et al., 2002); cf. the "corollary
531 discharge model" (Pageaux, 2016). However, our participants were in both sessions strongly
532 impelled to execute every repetition with the intention to move as fast as possible in the
533 concentric phase. Indeed, both the motor-related cortical potentials (MRCP; (Slobounov et al.,
534 2004)) and the electromyographic (EMG) amplitude seem independent of load (% of 1RM) if the
535 intention to move is maximal – at least for lower body exercises (Bosco et al., 1982;Hakkinen et
536 al., 1986;Kawamori and Haff, 2004;McBride et al., 2010). If we assume that our participants
537 mobilized maximally in all repetitions, the corollary discharge model seems unable to explain a
538 higher session RPE after the heavy strength session than the power session. Consequently, we

539   suggest that the sRPE scores in the present study were influenced by afferent feedback from the
540   muscles; supporting a "combined model" (Pageaux, 2016). The afferent feedback may be a
541   combination of different sensors including tendon organs ("force sensors") and nociceptor
542   receptors responding to metabolic perturbations. Metabolic perturbations, such as elevated
543   extracellular levels of adenosine, lactate and protons (Allen et al., 2008), stimulate capsaicin
544   fibres (Aδ and C-nerves; (Pollak et al., 2014)); and accordingly, muscular fatigue may be an
545   important underlaying mechanism behind the sRPE scores (Hardee et al., 2012;Vasquez et al.,
546   2013). Indeed, when working at maximal intensity fatigue will starts develop within seconds
547   (Allen et al., 2008), and probably to larger degree during the heavy strength session than the
548   power session due to more time under tension (i.e., longer acceleration phase during the lifts
549   and/or less deacceleration). We cannot exclude the possibility the participants utilized elastic
550   energy storage and release (the stretch shortening cycle) during the power session, and thereby
551   were more energy economic during the power sessions than the heavy strength session (Bosco et
552   al., 1982). Higher energy expenditure and more fatigue in combination with the heavier loads
553   could explain the higher RPE after the heavy strength session than the power session. Finally, it
554   is noteworthy that the "contents"/definition of the RPE concept, i.e., effort vs. force, pain and
555   discomfort, and the mechanisms behind RPE are debatable (Pageaux, 2016); thus, more
556   scientific work are needed to entangle this, particularly in relation to different modes of
557   resistance exercise.

558   While sRPE scores are collected after a session, PRS is obtained before a training session. PRS
559   are supposed to give an evaluation of the athletes' readiness and performance status in the
560   upcoming session (Laurent et al., 2011). In the present study, recovery status 24 and 48 hours
561   after the heavy strength session were reported lower compared to the power session. Indeed, as
562   for sRPE, PRS pointed in the same direction as the objective tests. However, no consistent
563   correlations were found between the PRS and objective variables, such as CMJ eccentric peak
564   force and push-ups peak force. Interestingly, the state of recovery was perceived incomplete both
565   24 and 48 hours after the power session although performance was back to baseline, or even
566   above (squat peak power and MJ). In line with our findings, Zourdos et al. (2016) observed
567   improved strength performance (1RM) concomitantly with either worsened, improved or
568   unchanged PRS in three competitive powerlifting/weightlifting athletes over 37 consecutive
569   training days. Recent studies support a dissociated time course between objective and subjective
570   recovery status – for both upper and lower body muscles – indicating a slower recovery when
571   assessed subjectively (Ferreira et al., 2017a;Ferreira et al., 2017b;Marshall et al., 2018). In sum,
572   this advocates caution about how to interpret subjective and objective measures of recovery. In
573   our case (and perhaps most cases), it is conceivable that neither the subjective nor the objective
574   measures reveal the true recovery status. On the objective side we merely measure some
575   properties of the neuromuscular system, leaving the possibility that unassessed properties are not
576   recovered. Interstingly, Zourdos et al. (2016) observed a difference in the PRS when assessed
577   before and after warm-up (higher PRS after warm-up). We assessed PRS only before warm-up,
578   leaving the possibility for higher coherence between objective measurments and PRS if
579   evaluated after warm-up. Certainly, we know that a warm-up transietly reduces muscle soreness
580   (DOMS; (Paulsen and Benestad, 2019)). As reported by others, the perceived recovery after
581   heavy strength session than the power session might be related to DOMS (Sikorski et al., 2013).

582 Intuitively it appears unlikely that athletes will feel recovered while experiencing DOMS.
583 Intriguingly, DOMS may be present without measurable strength impairments and muscle
584 damage (Vincent and Vincent, 1997;Mizumura and Taguchi, 2016;Paulsen and Benestad, 2019),
585 which could explain some of the inconsistency between objective measures and PRS.
586 Unfortunately, we did not assess DOMS, but we know that all participants experienced some
587 degree of DOMS. Future studies should investigate the possible interaction between PRS and
588 DOMS.

589 **Limitations**
590 The present study has several limitations. First, we applied a series of tests and we cannot
591 exclude that the tests themselves induced fatigue that affected the results; e.g., reduced the test
592 reliability. Moreover, we had no control-trial where the participants simply conducted all tests
593 but no training session; consequently, we must be careful interpreting the changes in relations to
594 time after each training session (within-session changes).

595 Second, we calculated the work done based on concentric work; thus, we excluded eccentric
596 work, and we cannot rule out that some differences between session could have been explained
597 by this information.

598 Third, each participant conducted two sessions. Due to the repeated bout effect, a faster recovery
599 must be expected after the second session (McHugh, 2003). Moreover, since the loads (in % of
600 1RM) were higher in the heavy strength session, the adaptative processes may have been better
601 stimulated after the heavy strength than the power session (i.e., strengthening of myofibers'
602 cytoskeleton (Paulsen et al., 2009)). If true, this may have created a bias to a faster recovery after
603 the power session. However, the order of sessions was randomized, and we tested the impact of
604 session-order statistically but found no clear effect of it.

605 Fourth, we did not include tests that allowed us to distinguish between central and peripheral
606 fatigue, nor did we measure systemic markers of recovery (such as creatine kinase, and
607 testosterone and cortisol; (Buckthorpe et al., 2014;Hiscock et al., 2018;Tsoukos et al., 2018)).
608 This could have given us valuable information about the subtle impairments of neuromuscular
609 performance and recovery between sessions.

610 Finally, we did not fully control the diets of the participants. We can therefore not exclude that
611 certain differences in the energy intake or the macronutrient intake in the recovery phases might
612 have affected the results.

613 **Practical applications**
614 Recovery from training sessions is intertwined with adaptation to training. Knowledge of
615 recovery from training sessions is therefore needed to make qualified assumptions when
616 designing training programs, in particularly for elite athletes that must handle large training
617 volumes and avoid overtraining. Present and previous studies have shown that to monitor
618 recovery one must consider a combination of tests and be aware of the error of measurements. In
619 our study the eccentric peak force and eccentric time during a CMJ, as well as peak power
620 calculated from a squat force-velocity test, were the tests that seemingly best differentiated
621 between a heavy strength session and a power session. Further research is warranted to see if

622 these tests are valid for other modes of resistance exercise. Assessing RFD from CMJ and SJ
623 seems worthwhile, although the day-to-day variability was high in the present study. Moreover,
624 for the upper body our applied tests were not fully satisfactory in terms of reliability and fatigue
625 sensitivity, demonstrating that more work is needed.

626 The power training tended to improve performance in certain tests at 24 and/or 48 hours after
627 exercise. Potentiation or a fast supercompensation from power sessions is highly relevant for
628 athletes preparing for competitions.

629 Objective and subjective tests of recovery may not correlate. Consequently, both test modalities
630 should be used and interpret together to ensure a holistic approach (Kiely, 2012). Because the
631 recovery process is so complex, it is important to acknowledge that there is much we do not
632 know and understand; thus, relying on only objective or only subjective measurers could prove
633 inadequate for most athletes.

634 It appears that the best test(s) for assessing recovery will significantly differ according to the
635 exercise(s) that has been conducted. Consequently, we cannot expect a "gold standard" test
636 battery. Rather, we need to use a selected number of tests to each specific athlete or group of
637 athletes, and a combination of subjective and objective tests appear advisable.

638

Conclusion
640 We hypothesized that heavy strength training session would require longer recovery than a
641 power training session of equal concentric work. Our main findings were: 1) Heavy strength
642 training has an overall larger detrimental effect on the neuromuscular system, reducing both
643 sprint and jumping properties acutely. However, differences in the performance assessments
644 between the training sessions were generally small or trivial. 2) The apparently best markers for
645 detecting differences between heavy strength and power were CMJ derivates: eccentric peak
646 force, eccentric time and RFDmax, as well as squat peak power. Considering the reliability and
647 SWC, the CMJ eccentric peak force seemed to be the most valuable parameter. For the upper
648 body, the push-ups peak force seemed more sensitive as a recovery marker than bench press peak
649 power and 1RM. 3) In contrast to the heavy strength session, the power session seemed to
650 potentiate multi-jump performance and squat peak power in the lower body, and push-ups peak
651 force in the upper body. 4) Finally, the heavy strength session was experienced more strenuous
652 (higher sRPE) and more recovery was perceived required (lower PRS) compared to the power
653 session. Furthermore, these subjective measurements correlated poorly with the objective
654 measurements indicating the need for both in practice.

655

Data availability statement
657 Raw data will be made available by the authors upon reasonable request.

658

659 **Author contributions statement**

660 CH, DSO, LH and GP conceived and designed the study. CH, MM, FS, LH, DSO, and GP
661 carried out the study and collected the data. CH, DSO, PS, and GP performed statistical analyses
662 and interpreted the data. CH, PS and GP wrote the manuscript. All authors read and approved the
663 final manuscript.

664

665 **Conflicts of interest**

666 Author Daniela Schäfer Olstad was employed by the company Polar®. Of note, the present study
667 does not contain any data collected by Polar® equipment/devices. The remaining authors declare
668 that the research was conducted in the absence of any commercial or financial relationships that
669 could be construed as a potential conflict of interest.

670

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Study design

Overview of the study design. The session (power or heavy strength) that was performed first, was randomized.

Figure 1

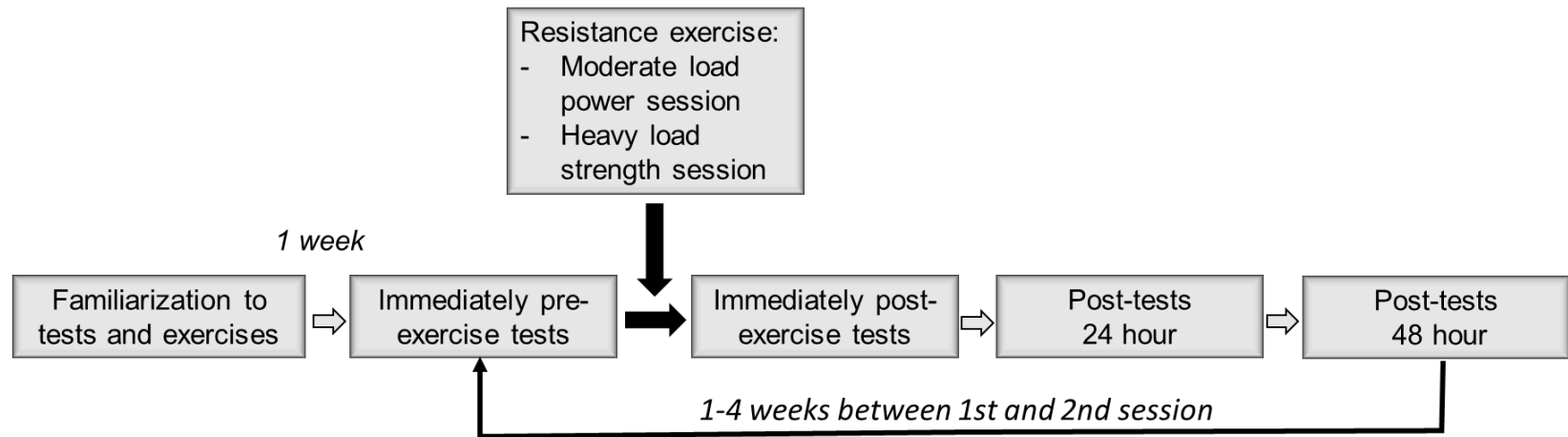



Figure 2

Force-time curve of a countermovement jump

An example of a force-time curve of a countermovement jump (CMJ). The eccentric and concentric phase are displayed.

RFD: Rate of Force Development

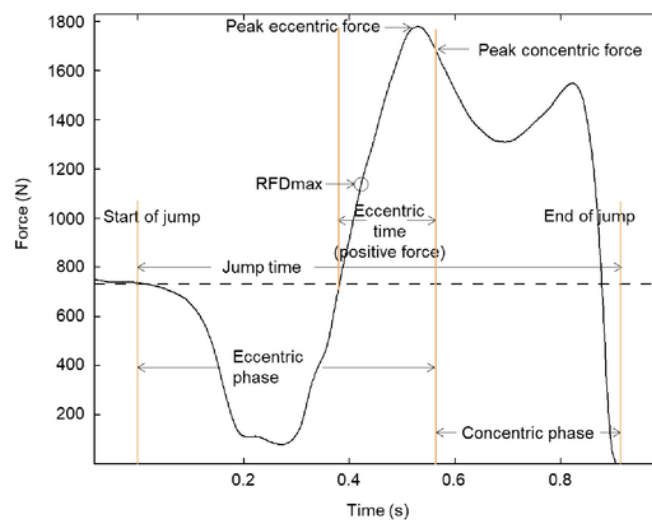



Figure 3

Variables derived from the countermovement jump (CMJ) before and after exercise

Variables derived from the countermovement jump (CMJ) test obtained before, immediately after (0 hours) and 24 and 48 hours after the power and heavy strength sessions. Values mean percentage changes from pre-values. Grey areas represent the smallest worthwhile change. A: Jump height, B: Peak power, C: Mean power, D: Peak concentric force, E: RFDmax, F: Eccentric time, G: Eccentric peak force, H: Depth (lowering of centre of mass).

RFDmax: Maximal Rate of Force Development. Trivial (Triv): <0.2, Small: 0.2-0.6; Moderate (Mod): 0.6-1.2; Large: 1.2-2.0; Very large: 2.0-4.0; Extremely large: <4.0 *: Possibly beneficial, **: Likely beneficial, ***: Very likely beneficial +: Possibly harmful, ++: Likely harmful, +++: Very likely harmful, ++++: most likely harmful 0: Possibly trivial, 00: Likely trivial, 000: Very likely trivial, 0000: Most likely trivial

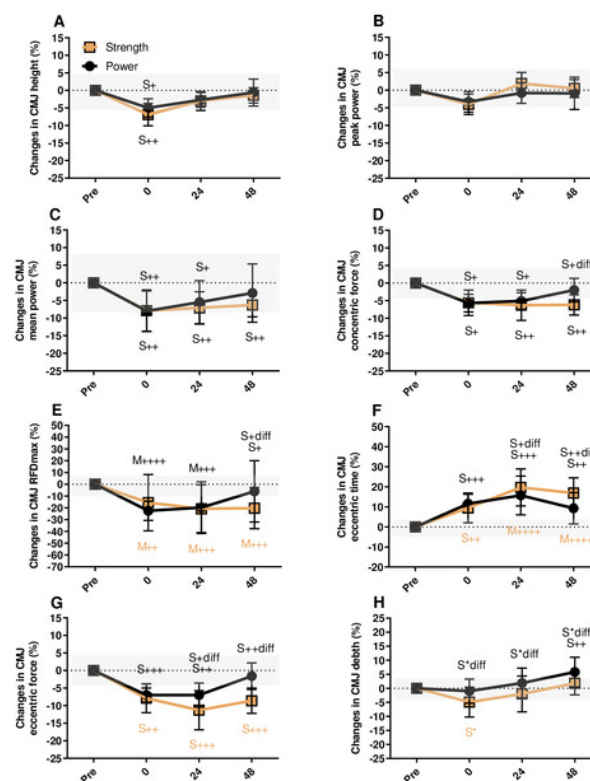
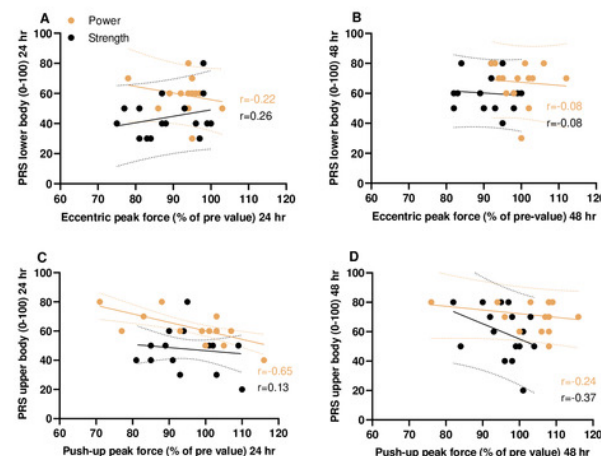



Figure 4

Objective vs. subjective measures

X-y-plots of individual values, and regression line with 90% confidence bands. A and B display the relationship between eccentric peak force and perceived recovery status (PRS; lower body) 24 and 48 hours after the power and heavy strength sessions. C and D display the relationship between peak push-up force and PRS (upper body) 24 and 48 hours after the power and heavy strength sessions. PRS values are given in the range 0-100, where 100 is fully recovered.

The exercises applied

Exercises for each of the two training sessions

1   Table 1. Exercises for each of the two training sessions

Power session	Heavy strength session	Comment
Loaded CMJ	Squat	Same depth in the eccentric phase.
Front squat with overhead push	Front squat	Same depth in the eccentric phase.
Trap bar CMJ	Trap bar squat	Same depth in the eccentric phase.
Bench press throw	Bench press	Conducted in a smith machine.
Narrow bench press throw	Narrow bench press	Conducted in a smith machine.
Explosive push-ups	Weighted push-ups	Load by weight-vest (1-9 kg) and discs (5-20 kg). Boxes (25 cm) were placed under feet and hands.

3

Baseline values

Baseline values before the training sessions.

1   Table 2: Baseline values in the two training modalities.

Variable	Power Mean ± SD	Strength Mean ± SD	SD used for standardizing (adjusted)	Smallest worthwhile change % (0.2SD)	Coefficient of Variation % (CV)
CMJ (cm)	34.8 ± 8.7	34.7 ± 9.0	8.9	5.0	5.1
CMJ peak power (W)	1905 ± 670	1869 ± 722	703	7.5	6.5
CMJ mean power (W)	316 ± 116	317 ± 128	123	8.0	8.7
CMJ concentric peak force (N)	1788 ± 406	1774 ± 348	381	4.3	4.0
CMJ RFDmax (N/s)	13169 ± 5317	12843 ± 589	5663	8.8	21.2
CMJ duration (s)	0.84 ± 0.08	0.84 ± 0.09	0.09	2.1	7.4
CMJ eccentric peak force (N)	1793 ± 410	1787 ± 357	378	4.4	4.2
CMJ eccentric time (s)	0.18 ± 0.04	0.19 ± 0.03	0.04	3.8	9.9
CMJ depth (cm)	-39.2 ± 6.0	40.1 ± 6.4	6.3	3.2	8.3
SJ (cm)	32.0 ± 8.0	32.3 ± 8.2	8.2	5.0	5.7
SJ peak power (W)	1980 ± 672	2003 ± 748	717	7.3	6.3
SJ mean power (W)	586 ± 220	606 ± 254	240	8.2	9.8
SJ peak force (N)	1630 ± 326	1637 ± 361	347	4.3	4.3
SJ RFDmax (N/s)	7155 ± 2090	7675 ± 3210	2744	6.9	21.0
SJ duration (s)	0.40 ± 0.03	0.40 ± 0.05	0.04	2.1	8.6
MJ (cm)	27.6 ± 6.8	29.6 ± 8.2	7.7	5.2	9.1
MJ RSI	45.2 ± 12.0	47.4 ± 15.6	14.1	6.0	14.9
MJ vertical stiffness (N/m)	6.0 ± 1.9	5.9 ± 1.7	1.8	6.0	19.9
20 m (s)	3.08 ± 0.22	3.08 ± 0.23	0.23	1.5	1.3
Push-up peak force (N)	986 ± 254	1105 ± 422	359	6.4	11.2

2	Squat peak power (W)	1380 ± 332	1438 ± 314	319	4.8	7.2
	Bench press peak power (W)	433 ± 180	450 ± 184	194	9.4	9.3
	Squat estimated 1RM (kg)	121 ± 39	120 ± 41	39.9	6.6	4.6
	Bench press estimated 1RM (kg)	80 ± 29	81 ± 30	30.0	7.5	3.3
	PRS (%)	83.1 ± 9.5	76.9 ± 10.1	10.4	10	14.5
	sRPE upper body (0-10)	5.1 ± 1.5	6.8 ± 1.5	--	10	--
	sRPE lower body (0-10)	5.3 ± 1.1	7.4 ± 1.3	--	10	--
	Total work upper body (kJ)	12 ± 7	11 ± 7	--	--	--
	Total work lower body (kJ)	57 ± 14	57 ± 14	--	--	--

1RM = 1 Repetition Maximum, CMJ = Countermovement Jump, MJ = Multi Jump, PRS = Perceived Recovery Status, RSI = Reactive Strength Index, RFDmax = Maximal Rate of Force Development, SJ = Squat Jump, sRPE = session Rate of Perceived Exertion.

Changes and recovery over time

Percent changes after each session with their associated effect size and inference.

1 Table 3: Percent changes within groups with their associated effect size and inference.

Variable		Post 0 0 hours Mean ± SD; 90%CI	Inference	Post 1 24 hours Mean ± SD; 90%CI	Inference	Post 2 48 hours Mean ± SD; 90%CI	Inference
SJ (cm)	Power	-4.2 ± 3.8; 1.6	Triv^{00}	-1.2 ± 3.9; 1.7	Triv^{0000}	0.7 ± 4.4; 2.0	Triv^{0000}
	Strength	-8.2 ± 5.8; 2.3	Small+++	-3.7 ± 6.5; 2.7	Triv^{00}	-2.1 ± 6.7; 2.8	Triv^{000}
SJ peak power (W)	Power	-2.9 ± 4.3; 1.8	Triv^{000}	-1.5 ± 5.6; 2.4	Triv^{000}	-1.1 ± 7.0; 3.1	Triv^{000}
	Strength	-4.3 ± 4.8; 2.0	Triv+	-2.6 ±9.4; 3.9	Triv^{00}	-3.8 ± 8.6; 3.5	Triv+
SJ mean power (W)	Power	-5.9 ± 7.9; 3.1	Small+	-5.4 ± 11.8; 4.6	Small+	-1.5 ± 12.9; 5.5	Triv^{00}
	Strength	-11.5 ± 12.9; 4.7	Small+++	-7.8 ± 14.1; 5.4	Small++	-6.3 ± 15.1; 5.8	Small+
SJ peak force (N)	Power	-0.7 ± 3.2; 1.4	Triv^{0000}	-0.9 ± 3.7; 1.6	Triv^{0000}	-1.4 ± 4.3; 1.9	Triv^{0000}
	Strength	-0.6 ± 3.0; 1.3	Triv^{0000}	-1.2 ± 5.8; 2.5	Triv^{000}	-2.7 ± 4.6; 1.9	Triv^{000}
SJ RFDmax (N/s)	Power	-4.4 ± 15.3; 6.0	Triv+	0.0 ± 16.0; 6.5	Triv^{00}	4.2 ± 17.5; 7.7	Triv^{uncl}
	Strength	-7.0 ± 17.3; 6.5	Small+	-11.5 ± 28.1; 9.7	Small++	-7.3 ± 32.9; 11.6	Small+
SJ duration (s)	Power	1.9 ± 6.8; 3.0	Triv^{000}	4.1 ± 9.8; 4.3	Triv+	1.7 ± 9.5; 4.2	Triv^{00}
	Strength	5.3 ± 8.8; 3.9	Small+	5.5 ± 9.8; 4.3	Small+	4.4 ± 9.8; 4.3	Triv+
MJ (cm)	Power	2.4 ± 12.4; 5.3	Triv^{00}	6.4 ± 9.3; 4.3	Small*	4.4 ± 10.7; 4.7	Triv*
	Strength	-3.2 ± 10.0; 4.1	Triv^{00}	-0.5 ± 8.4; 3.5	Triv^{000}	1.4 ± 4.8; 2.1	Triv^{0000}
MJ RSI	Power	-3.1 ± 15.0; 6.2	Triv+	4.1 ± 11.3; 5.1	Small*	1.1 ± 11.3; 4.8	Triv^{00}
	Strength	-6.3 ± 11.4; 4.4	Small+	-0.7 ± 7.3; 3.1	Triv^{000}	1.6 ± 8.3; 3.6	Triv^{000}
MJ vertical stiffness (N/m)	Power	2.8 ± 19.9; 8.6	Triv^{uncl}	-5.3 ± 18.0; 7.5	Small+	-5.2 ± 24.4; 9.5	Small+
	Strength	0.4 ± 11.6; 5.0	Triv^{00}	5.3 ± 10.5; 4.8	Small*	-1.1 ± 15.2; 6.4	Triv^{00}
20 m (s)	Power	-0.0 ± 1.8; 0.8	Triv^{0000}	0.7 ± 1.6; 0.7	Triv^{000}	0.6 ± 1.7; 0.8	Triv^{000}
	Strength	1.5 ± 1.8; 0.8	Triv*	1.4 ±1.8; 0.8	Triv*	0.5 ± 1.7; 0.8	Triv^{000}
Push-up peak force (N)	Power	1.0 ± 10.9; 4.8	Triv^{000}	-2.2 ± 12.2; 5.6	Triv^{00}	8.2 ± 10.6 ;5.7	Small*
	Strength	-1.0 ± 7.3; 3.1	Triv^{0000}	-4.7 ± 9.6; 3.9	Triv^{00}	-4.3 ± 7.1; 2.9	Triv^{00}
Squat peak power (W)	Power	--	--	2.9 ± 9.0; 3.9	Triv^{00}	5.8 ± 6.7; 3.1	Small*
	Strength	--	--	-6.4 ± 7.6; 3.0	Small++	-3.7 ± 8.3; 3.8	Triv+
Bench press peak power (W)	Power	--	--	-0.1 ± 5.3; 2.5	Triv^{0000}	3.5 ± 8.9; 4.2	Triv^{000}
	Strength	--	--	-5.3 ± 6.6; 2.9	Triv^{000}	-2.6 ± 10.7; 5.2	Triv^{000}
Squat estimated 1RM (kg)	Power	--	--	-1.6 ± 6.2; 2.6	Triv^{0000}	-1.3 ± 5.5; 2.4	Triv^{0000}
	Strength	--	--	-0.5 ± 5.7; 2.4	Triv^{0000}	-2.5 ± 4.8; 2.3	Triv^{0000}

Bench press estimated 1RM (kg)	Power Strength	-- --	-- --	-1.6 ± 4.8; 2.2 -3.2 ± 5.4; 2.4	Triv[0000] Triv[000]	-1.1 ± 3.9; 1.8 -2.8 ± 5.0; 2.5	Triv[0000] Triv[0000]
PRS total (%)	Power Strength	-36.9 ±16.5; 7.3 -41.9 ± 15.7; 7.5	Mod++++ Mod++++	-23.8 ± 8.7; 3.8 -30.0 ± 11.9; 5.2	Small+++ + Mod++++	-13.6 ± 9.1; 4.2 -16.3 ± 14.7; 6.5	Small++ Small+++
PRS upper body (%)	Power Strength	-38.1 ± 17.5; 7.7 -43.8 ± 11.7; 5.1	Mod++++ Mod++++	-21.3 ± 10.4; 4.6 -29.4 ± 10.3; 4.5	Small+++ + Small+++ +	-11.3 ± 8.8; 3.9 -17.5 ± 18.1; 8.0	Small+ Small++
PRS lower body (%)	Power Strength	-40.6 ± 14.5; 6.4 -45.0 ± 13.6; 6.0	Mod++++ Mod++++	-24.4 ± 11.3; 5.0 -32.5 ± 13.3; 5.8	Small+++ + Mod++++	-15.6 ± 13.0; 5.7 -16.9 ± 12.5; 5.5	Small++ Small+++

1RM = 1 Repetition Maximum, CI: Confidence Interval, MJ = Multi Jump, PRS = Perceived Recovery Status, RSI = Reactive Strength Index, RFDmax = Maximal Rate of Force Development, SD: Standard Deviation, SJ = Squat Jump.
Trivial (Triv): <0.2, Small: 0.2-0.6; Moderate (Mod): 0.6-1.2; Large: 1.2-2.0; Very large: 2.0-4.0; Extremely large: <4.0
*: Possibly beneficial, **: Likely beneficial, ***: Very likely beneficial
+: Possibly harmful, ++: Likely harmful, +++: Very likely harmful, ++++: most likely harmful
[0]: Possibly trivial, [00]: Likely trivial, [000]: Very likely trivial, [0000]: Most likely trivial

Differences between the training sessions

Percent differences between the power and the heavy strength session.

1   Table 4. Percent differences between the power and the heavy strength session.

Variable	Post 0 0 hours Mean ± 90%CI	Inference	Post 1 24 hours Mean ± 90%CI	Inference	Post 2 48 hours Mean ± 90%CI	Inference
CMJ (cm)	-2.0 ± 3.5	Triv[00]	-0.3 ± 3.0	Triv[000]	-0.7 ± 4.1	Triv[00]
CMJ peak power (W)	-0.7 ± 3.5	Triv[0000]	2.6 ± 3.4	Triv[000]	1.4 ± 5.0	Triv[000]
CMJ mean power(W)	0.1 ± 4.6	Triv[000]	-1.7 ± 5.3	Triv[000]	-3.5 ± 7.4	Triv[00]
CMJ peak concentric force (N)	0.2 ± 2.7	Triv[000]	-1.5 ± 2.8	Triv[00]	-4.2 ± 3.1	Small+
CMJ RFD max (N/s)	8.0 ± 16.7	Triv[uncl]	-1.6 ± 17.2	Triv[0]	-15.3 ± 18.9	Small+
CMJ duration (s)	-1.7 ± 3.3	Triv[uncl]	1.3 ± 3.6	Triv+	2.3 ± 5.4	Small+
CMJ eccentric peak force (N)	-1.0 ± 3.0	Triv[000]	-4.6 ± 4.8	Small+	-7.1 ± 3.7	Small++
CMJ eccentric time (s)	-1.5 ± 5.3	Triv[0]	4.1 ± 8.6	Small+	7.6 ± 7.0	Small++
CMJ depth (cm)	-3.7 ± 4.1	Small+	-3.4 ± 3.9	Small+	-3.1 ± 4.8	Small+
SJ height (cm)	-4.1 ± 2.8	Triv[+]	-2.5 ± 3.1	Triv[00]	-2.8 ± 3.0	Triv[00]
SJ peak power (W)	-1.4 ± 2.9	Triv[0000]	-1.1 ± 4.3	Triv[000]	-2.7 ± 4.3	Triv[000]
SJ mean power (W)	-6.0 ± 4.7	Triv[00]	-2.5 ± 6.9	Triv[00]	-4.8 ± 8.1	Triv+
SJ peak force (N)	0.1 ± 2.0	Triv[0000]	-0.3 ± 2.7	Triv[000]	-1.3 ± 2.5	Triv[000]
SJ RFD max (N/s)	-1.8 ± 9.3	Triv[0]	-11.3 ± 11.3	Small++	-10.5 ± 12.3	Small+
SJ time (s)	2.9 ± 4.3	Small+	0.4 ± 5.6	Triv+	1.7 ± 6.1	Triv+
MJ height (cm)	-5.1 ± 7.0	Small+	-6.0 ± 5.2	Small+	-1.7 ± 4.3	Triv[00]
MJ RSI	-3.5 ± 7.4	Triv+	-4.2 ± 5.3	Triv+	1.2 ± 4.6	Triv[000]
MJ vertical stiffness (N/m)	-2.7 ± 7.1	Triv[0]	10.8 ± 9.6	Small**	4.0 ± 10.6	Triv[uncl]
20 m (s)	1.4 ± 1.0	Triv+	0.5 ± 1.2	Triv[00]	-0.1 ± 1.1	Triv[000]
Push-up peak force (N)	-2.3 ± 6.1	Triv[00]	0.0 ± 7.7	Triv[00]	-7.7 ± 6.8	Small+
Squat peak power (W)	--	--	-9.1 ± 4.6	Small++	-8.8 ± 4.5	Small++
Bench press peak power (W)	--	--	-5.3 ± 3.8	Triv[00]	-5.7 ± 7.7	Triv+
Squat estimated 1RM (kg)	--	--	-1.6 ± 2.8	Triv[0000]	-1.2 ± 3.5	Triv[000]
Bench press estimated 1RM (kg)	--	--	-1.6 ± 2.8	Triv[0000]	-1.7 ± 3.6	Triv[000]
sRPE total (%)	-20.6 ± 8.4	Small+++	--	--	--	--
sRPE upper body (%)	-16.9 ± 8.9	Small++	--	--	--	--
sRPE lower body (%)	-21.9 ± 7.4	Small+++	--	--	--	--
PRS total (%)	-11.1 ± 5.7	Small+	-10.1 ± 7.5	Small+	-6.8 ± 8.6	Triv+
PRS upper body (%)	-9.4 ± 3.9	Triv+	-10.2 ± 6.6	Small+	-10.1 ± 9.0	Small+
PRS lower body	-8.5 ± 5.4	Triv+	-12.8 ± 9.2	Small+	-6.1 ± 8.9	Triv[00]

(%)							

1RM = 1 Repetition Maximum, CI: Confidence Interval, CMJ: Countermovement Jump; MJ = Multi Jump,
PRS = Perceived Recovery Status, RSI = Reactive Strength Index, RFDmax = Maximal Rate of Force
Development, SD: Standard Deviation, SJ = Squat Jump, sRPE = session Rate of Perceived Exertion.
Trivial (Triv): <0.2, Small: 0.2-0.6; Moderate (Mod): 0.6-1.2; Large: 1.2-2.0; Very large: 2.0-4.0; Extremely
large: <4.0
*: Possibly beneficial, **: Likely beneficial, ***: Very likely beneficial
+: Possibly harmful, ++: Likely harmful, +++: Very likely harmful, ++++: most likely harmful
[0]: Possibly trivial, [00]: Likely trivial, [000]: Very likely trivial, [0000]: Most likely trivial