Recovery from power and heavy strength training sessions: Does mode matter when work is equal? (#46939)

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

Christian Helland [1] , **Magnus Midttun** [1] , **Fredrik Sæland** [1] , **Lars Haugvad** [1] , **Daniela Schäfer Olstad** [2] , **Paul Solberg** [1] , **Gøran Paulsen** [Corresp. 1, 3]

[1] Norwegian Olympic and Paralympic Committee and Confederation of Sports, Oslo, Norway

[2] Polar Electro Oy, Kempele, Finland

[3] Department of Physical Performance, Norwegian School of Sport Sciences, Oslo, Norway

Corresponding Author: Gøran Paulsen
Email address: goran.paulsen@nih.no

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

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[1] Norwegian Olympic and Paralympic Committee and Confederation of Sports, Oslo, Norway
[2] Polar Electro Oy, Kempele, Finland
[3] Department of Physical Performance, Norwegian School of Sport Sciences, Oslo, Norway

Corresponding Author:
Gøran Paulsen
Norwegian School of Sport Sciences, Oslo, Norway
Sognsveien 220, 0806 Oslo, Norway
goran.paulsen@nih.no

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

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

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

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

Materials & Methods

Study design

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

*** Figure 1 and Table 1***

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

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

Participants

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

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

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

Testing and exercises

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

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

Tests

The CMJ, SJ, and MJ were conducted on an AMTI force platform (sampling rate, 2000 Hz; OR6-5-1; AMTI, Watertown, MA, USA). All tests were performed with hands fixed on the hips (akimbo). CMJ and SJ are previously described in detail (Helland et al., 2017). In the MJ test, the participants were instructed to jump 10 consecutive jumps as high as possible. The jump tests analyses were conducted in a custom-made software (Biomekanikk AS, Oslo, Norway), and the average of each individual's two best attempts of 3-6 jumps were used for subsequent statistical analyses. We divided the CMJ into the eccentric phase and the concentric phase (Figure 2); i.e., the phase where the centre of mass was descending and ascending, respectively (calculations based on the impulse–momentum method (Linthorne, 2001)). Eccentric time was defined as the time from when the force equalled body weight to the start of the concentric phase, and the maximal rate of force development (RFD) was calculated as the largest increase in force over a 5 ms time window (Figure 2). The variation of coefficient (CV) for these and all applied tests are given in Table 2.

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

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

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

Training sessions

The heavy strength session consisted of three exercises for the lower body, in the following order: squat, front squat, trap bar squat; and three exercises for the upper body, performed in the following order: bench press smith, narrow bench press smith and weighted push-ups (Table 1). A warm-up set of 8 repetitions at 60-80% of 5RM before each exercise preceded 5 sets of 5RM. The 5RM loads were estimated from the familiarization session for each exercise. The inter-sets rest period was 3-4 minutes. The loads were adjusted between sets, if necessary. All exercises were conducted with the same tempo with a controlled slow eccentric phase and a fast as possible concentric phase. The leg exercises were performed with free weights (Eleiko, Halmstad, Sweden), while both narrow- and bench press were performed in a smith rack (Multipower, Technogym, Cesena FC, Italy). Weighted push-ups were performed on three 30 cm custom made boxes, and loads were applied by a weight-vest (1-9 kg; Reebok, Boston, Ma, US) and (if needed) weight discs (5-20 kg) placed on the participants back – positioned over their scapulae.

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

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

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

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

Statistics

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

Effects were evaluated using clinical magnitude-based inferences (MBI; (Hopkins et al., 2009)), a method appropriate for small samples. The magnitude of changes within and difference in mean between sessions was assessed by standardization (mean change/difference divided by baseline SD of all subjects), and the resulting standardized effect evaluated with a modification of Cohen's (1992) scale: <0.2, trivial; 0.2-0.6, small; 0.6-1.2, moderate; >1.2, large (Hopkins et al., 2009). The subjective variables (RPE and PRS) were evaluated with the following scale: <10% trivial, 10-30% small, 30-50% moderate, 50-70% large, 70-90% very large, and 90-100% extremely large (Hopkins, 2010).The initial RPE and PRS values therefore factored by 10 (0-100).

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

Results

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

Table 2

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

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

Table 3 & Figure 3

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

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

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

Table 4

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

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

Figure 4

Discussion

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

Previous studies

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

In line with the existing literature (Linnamo et al., 1998;Brandon et al., 2015;Howatson et al., 2016), a heavy strength session attenuated the neuromuscular system more than a low or moderate load power session. However, in previous studies where the exercise work was controlled for, the differences between heavy strength and power sessions are close to abolished (McCaulley et al., 2009;Hiscock et al., 2018). Our observations confirm these findings, but add some nuances to this picture, as we did report some differences between the heavy strength session and power session. We believe that differences in recovery rates between resistance exercise sessions of different modes but of similar exercise volume must be expected to be rather subtle, although yet important; we must therefore consider both methodological issues and the biological mechanisms behind the exercise-induced impairments of the neuromuscular system.

Methodological issues: Reliability and fatigue sensitivity

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

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

Interestingly, we observed only trivial changes in CMJ height and peak power from before to after both sessions, but clear changes in CMJ eccentric time and CMJ eccentric peak force. Similar findings have recently been reported by others (Gathercole et al., 2015a). These observations indicate that the participants ability to utilize the eccentric phase was impaired in the recovery phase, but some movement or coordination compensations apparently minimized the reductions in jump height and power production. The reduction in eccentric peak force seemed primarily related to a slower eccentric phase during the CMJ, i.e., increased eccentric time, since the lowering the centre of mass was not changed after the heavy strength session. Still, there were differences between sessions, because the participants appeared to lower centre of mass more after the power session than at pre-test, especially at 48 hours. Further studies should investigate changes in the kinetics and kinematics (movement strategies) of a CMJ in the phase of recovery compared to the rested state. Nevertheless, we suggest the eccentric peak force is a more sensitive marker of fatigue and neuromuscular impairments than jump height and maximal power.

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

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

Mechanisms for neuromuscular recovery

Exercise-induced impairment of neuromuscular function and the following recovery phase are multifaceted (Lieber and Friden, 2002;Enoka et al., 2011;Paulsen et al., 2012). But, if we consider a particular exercise, i.e. the squat, and assume a constant range of motion (muscle lengthening/strain) and a given total exercise volume (sets x repetitions; as herein), the determining factors would be narrowed down to contraction/lengthening velocity and force. With the criterion of maximal effort (intention to move) in the concentric phase, velocity will be high and force low during light or moderate load power exercises, and visa-versa for heavy load strength exercises (cf. the force-velocity relationship). Higher concentric forces during the heavy load strength exercises will logically put more mechanical stress on the muscle tissue. However, even high-force concentric contractions cause minimal muscle damage and a swift recovery of muscle function (~24 hours; (Jones et al., 1989;Lee et al., 1999;Carson et al., 2002)). Thus, concentric work can probably only explain perturbations in the neuromuscular function shortly after exercise (i.e., minutes to few hours; (Allen et al., 2008)). This led us to suggest that the eccentric phase was probably of greater importance for the differences in neuromuscular impairment and recovery rate between sessions. In other words, the higher eccentric forces – simply due to higher loads – during the heavy strength session likely explains the slower recovery compared to the power session (Faulkner et al., 1992;Black et al., 2007).

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

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

Fatigue vs. potentiation and supercompensation

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

Objective vs subjective measures of recovery

Session RPE (sRPE) for resistance exercise was reviewed by McGuigan (2004) and validated for "intensity", i.e. load in % of 1RM, by Sweet et al. (2004). Later studies have found the session RPE to be related to both volume and work rate during strength training (Scott et al., 2016;Hiscock et al., 2018). The present study ensured equal concentric work, but different loads – i.e., the power session was performed with 50% of the heavy strength loads. Nevertheless, because the power session lasted ~12% (~13 minutes) longer than the heavy strength session, the work rate was highest during the heavy strength session. As the difference in loads (% of 1RM) between sessions was much larger than the difference in work rate, we suggest that the higher loads (% of 1RM) were the dominant factor influencing the RPE scores (although we acknowledge that this cannot be ascertained with the present study design). Notably, it has been purposed that exercise intensity/load (% of 1RM) influence RPE scores via a positive relationship with the central motor control discharge (Gearhart et al., 2002); cf. the "corollary discharge model" (Pageaux, 2016). However, our participants were in both sessions strongly impelled to execute every repetition with the intention to move as fast as possible in the concentric phase. Indeed, both the motor-related cortical potentials (MRCP; (Slobounov et al., 2004)) and the electromyographic (EMG) amplitude seem independent of load (% of 1RM) if the intention to move is maximal – at least for lower body exercises (Bosco et al., 1982;Hakkinen et al., 1986;Kawamori and Haff, 2004;McBride et al., 2010). If we assume that our participants mobilized maximally in all repetitions, the corollary discharge model seems unable to explain a higher session RPE after the heavy strength session than the power session. Consequently, we suggest that the sRPE scores in the present study were influenced by afferent feedback from the muscles; supporting a “combined model” (Pageaux, 2016). The afferent feedback may be a combination of different sensors including tendon organs (“force sensors”) and nociceptor receptors responding to metabolic perturbations. Metabolic perturbations, such as elevated extracellular levels of adenosine, lactate and protons (Allen et al., 2008), stimulate capsaicin fibres (Aδ and C-nerves; (Pollak et al., 2014)); and accordingly, muscular fatigue may be an important underlaying mechanism behind the sRPE scores (Hardee et al., 2012;Vasquez et al., 2013). Indeed, when working at maximal intensity fatigue will starts develop within seconds (Allen et al., 2008), and probably to larger degree during the heavy strength session than the power session due to more time under tension (i.e., longer acceleration phase during the lifts and/or less deacceleration). We cannot exclude the possibility the participants utilized elastic energy storage and release (the stretch shortening cycle) during the power session, and thereby were more energy economic during the power sessions than the heavy strength session (Bosco et al., 1982). Higher energy expenditure and more fatigue in combination with the heavier loads could explain the higher RPE after the heavy strength session than the power session. Finally, it is noteworthy that the “contents”/definition of the RPE concept, i.e., effort vs. force, pain and discomfort, and the mechanisms behind RPE are debatable (Pageaux, 2016); thus, more scientific work are needed to entangle this, particularly in relation to different modes of resistance exercise.

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

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

Limitations

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

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

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

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

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

Practical applications

Recovery from training sessions is intertwined with adaptation to training. Knowledge of recovery from training sessions is therefore needed to make qualified assumptions when designing training programs, in particularly for elite athletes that must handle large training volumes and avoid overtraining. Present and previous studies have shown that to monitor recovery one must consider a combination of tests and be aware of the error of measurements. In our study the eccentric peak force and eccentric time during a CMJ, as well as peak power calculated from a squat force-velocity test, were the tests that seemingly best differentiated between a heavy strength session and a power session. Further research is warranted to see if these tests are valid for other modes of resistance exercise. Assessing RFD from CMJ and SJ seems worthwhile, although the day-to-day variability was high in the present study. Moreover, for the upper body our applied tests were not fully satisfactory in terms of reliability and fatigue sensitivity, demonstrating that more work is needed.

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

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

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

Conclusion

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

Data availability statement

Raw data will be made available by the authors upon reasonable request.

Author contributions statement

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

Conflicts of interest

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

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Figure 1(on next page)

Study design

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

Figure 1

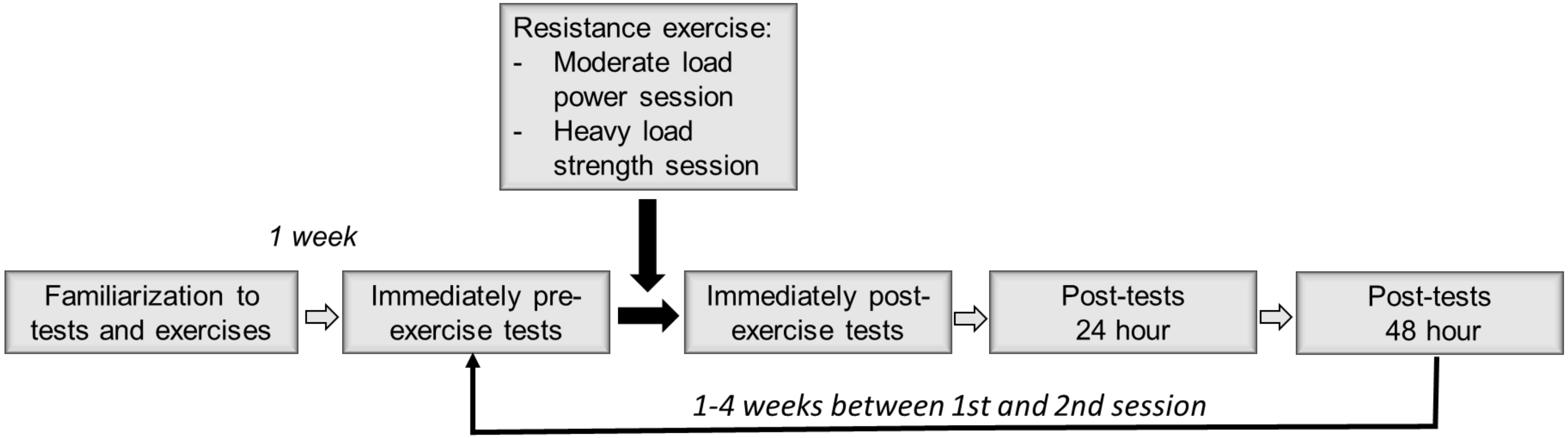
Resistance exercise:
- Moderate load power session
- Heavy load strength session
1 week
Familiarization to tests and exercises
Immediately pre-exercise tests
Immediately post-exercise tests
Post-tests 24 hour
Post-tests 48 hour
1-4 weeks between 1st and 2nd session

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 2

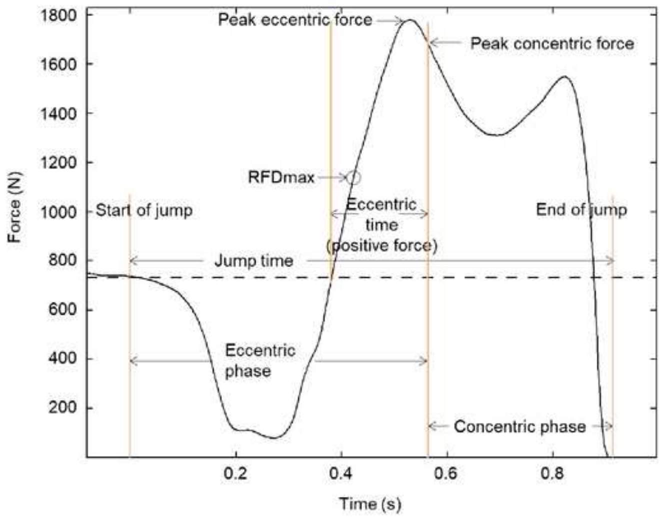

Figure 3

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 3

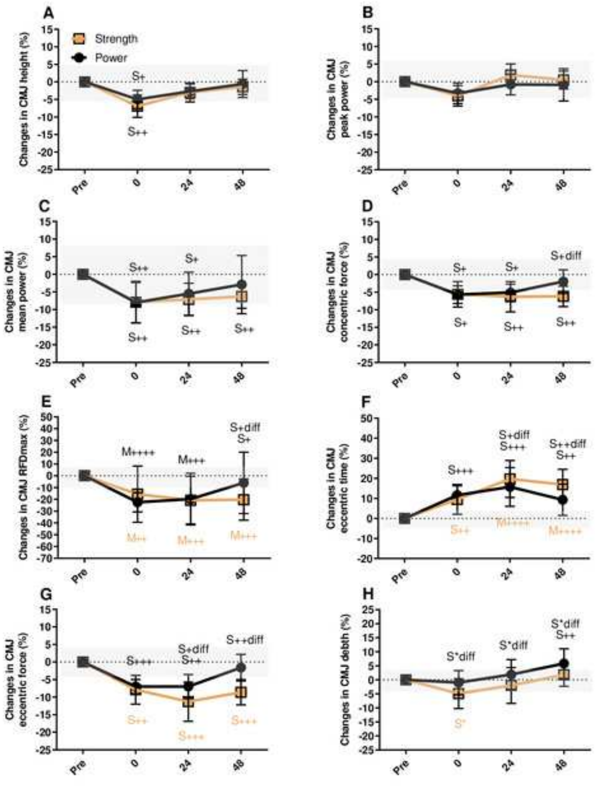

Figure 4

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.

Figure 4

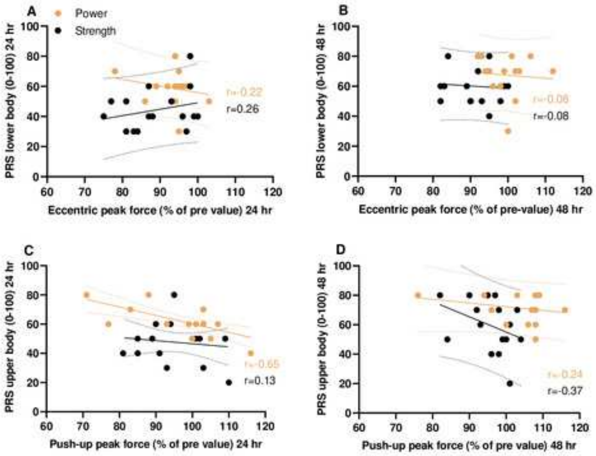

Table 1(on next page)

The exercises applied

Exercises for each of the two training sessions

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.

Table 2(on next page)

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

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.

Table 3(on next page)

Changes and recovery over time

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

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

2

Table 4(on next page)

Differences between the training sessions

Percent differences between the power and the heavy strength session.

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