Warming up to improved performance? Effects of different specific warm-up protocols on neuromuscular performance in trained individuals

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ABSTRACT

Warm-up strategies are often performed to enhance resistance training (RT) performance from a psychophysiological standpoint. However, it remains unclear whether the number of sets or the loading scheme used during a specific warm-up (SWU) influences neuromuscular performance in multiple-set RT performed to concentric failure. Therefore, this study investigated the effects of varying the set number and loads in SWU protocols on RT session performance. Using a crossover design, twenty-nine participants (RT experience of 4.5 ± 3.9 years) were randomized to the following experimental conditions: 1 set of 3-4 repetitions at 75%10RM (1SET), 2 sets of 3-4 repetitions at 55% and 75%10RM (2SET) and no warm-up (CON). The SWU protocols were performed before the working sets (4 sets at 10RM load to concentric failure) on each exercise (Smith-machine bench press and 45º leg press). For neuromuscular and perceptual responses, we assessed repetition performance, fatigue index, and volume load, as well as exercise readiness and rating of perceived exertion, respectively. Analyses were completed using linear mixed models within a Bayesian framework. Condition comparisons were expressed as standardized mean differences (SMDs), with posterior distributions and evidence ratios used to assess support for the superiority of SWU and the ordered hypothesis that CON < 1SET < 2SET, respectively. SMDs comparing 1SET and 2SET to CON indicated negligible to small potential differences for all outcomes. Posterior probabilities of SWU conditions being superior to CON remained relatively low for the bench press and 45° leg press, with evidence ratios generally providing strong evidence against the ordered hypothesis. Our findings indicate that SWU protocols are similar to CON regarding RT performance and perceptual responses. The results suggest it is possible to achieve greater time efficiency in RT sessions by forgoing a SWU when training at ~10RM loads.

Keywords: resistance training; strength training; rating of perceived exertion; volume load; fatigue index.

INTRODUCTION

Resistance training (RT) is considered a primary interventional strategy for inducing improvements in muscle strength, power, and size. RT programming variables, including load and volume, can influence the extent of these adaptations[1]. Coaches and practitioners often seek strategies to improve RT session performance to maximize neuromuscular adaptations[1]. In turn, it is commonly believed that warm-up strategies can enhance RT session performance from a psychophysiological standpoint[2].

Current guidelines for strength and conditioning recommend a general (GWU) and specific warm-up (SWU) prior to RT sessions to prepare individuals for intense training, arguing this strategy will enhance performance and reduce injury risk[3–5]. The GWU is a low intensity activity unrelated to the task (e.g. walking or cycling before RT) that aims to increase body and muscle temperature[6]. Alternatively, the SWU is an analogous task to the exercise that will be performed, but carried out at a reduced intensity of effort compared to the targeted training intensity (e.g. lifting with a low level of effort before performing the same lift at higher %1-repetition-maximum [RM] with a greater effort)[7]. The general recommendation for warming-up before an RT session is based on physiological effects such as increased body and muscle temperature, enhanced blood flow to the working muscles, improvements in neural drive (i.e. increased action potential conduction rate), reduced muscle stiffness, and augmented metabolic efficiency (i.e. oxygen and substrate delivery to muscles)[8–10]. These physiological alterations are collectively theorized to improve RT session performance, especially for strength and power outcomes.

Research regarding the effects of resistance training warm-up strategies are somewhat conflicting[10]. Moreover, when reconciling studies that compared a GWU to a SWU, no statistical differences were found for RT performance in single or multiple sets to failure[6,7,11]. Although the type (i.e. general or specific) of warm-up seems to lead to similar performance outcomes, time constraints can limit practitioners' ability to employ both strategies. In turn, incorporating only a SWU might be more beneficial for those with time restrictions, as this strategy involves performing similar movements to the exercises in the RT session. However, whether SWU protocols are necessary, and if so, how they can be tailored to improve the submaximal RT performance, remains unclear.

Research that has investigated the effects of different SWU protocols on submaximal RT performance in recreationally-trained individuals indicates similar performance metrics compared to a control condition (i.e., no warm-up)[11–13]. Curiously, a caveat amongst studies that did not detect meaningful effects from SWU protocols is that they employed just 1-2 sets in the warm-up protocol with low-to-moderate loads (40-60% of 1-repetition maximum (1RM)), which might not be sufficient to increase neuromuscular output in the subsequent exercise, performed as a single-set with submaximal loads. It is well established that relative intensity (i.e. %1RM) plays a role in the effects induced by conditioning activities (e.g. postactivation performance enhancement, PAPE) for RT performance, and worth noting that single-set performance may not reflect performance across a multiple-set RT session[1,2,14].

To date, several studies[11,15–18] have investigated the effect of SWU protocols on performance of multiple sets of an exercise involving medium repetition ranges; some reported no statistical differences in beginners[11,15] and others reported improvements in neuromuscular performance in recreationally-trained individuals[16–18]. Of note, the studies that observed an advantage of SWU protocols employed 1-2 warm up sets, with at least one of them performed at higher loads (ranging from 80 to 90%1RM), progressively increasing the load[16–18]. Conversely, other studies that did not observe an advantage of SWU protocols employed just a single set at low-to-moderate loads (50% of 8RM load[15] and 50% of 80%1RM load[11]). Nonetheless, Ribeiro et al.[16] detected improvements in force output after a single set (6 reps at 80% of training load) for barbell back squat and 2 sets at increasing loads (6 reps at 40% and 80% of training load) for bench press. Therefore, it is unclear if these findings were elicited by progressing the SWU loads or the set number.

Considering the conflicting evidence, the purpose of this study was to investigate the effects of varying the set number and loads in SWU protocols on RT session performance and perceptual responses. We hypothesized that a higher set number at higher loads will enhance submaximal multi-set RT session performance, as these factors are determinants of priming effects.

METHOD

Study design

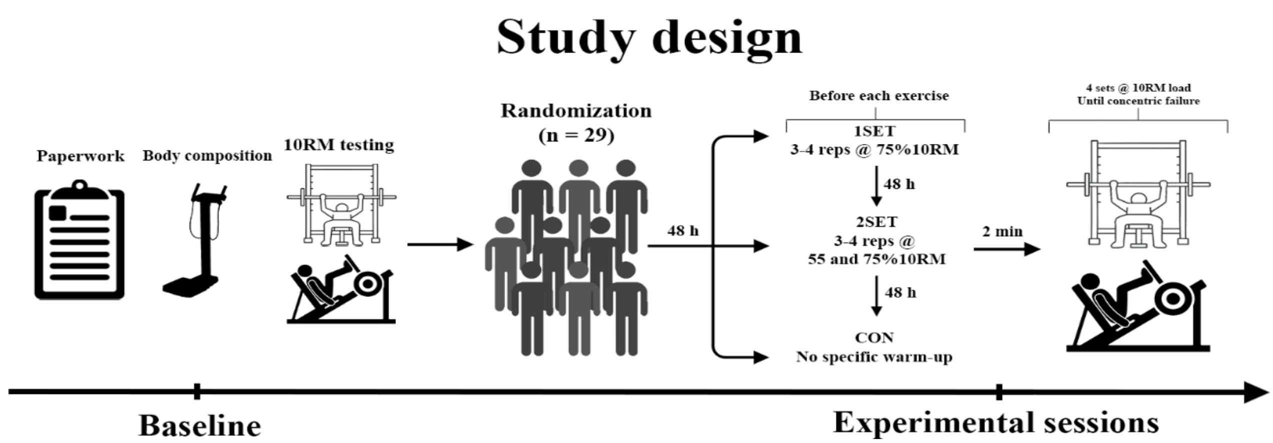
This study employed a crossover repeated-measures design, with each participant performing all experimental conditions. Participants were required to visit the laboratory 4 times, with visits separated by at least 48 hours. After signing the written consent form, participants were asked to visit the lab for an anthropometric assessment in a fasted state (at least 8 hours with no meals, no fluids, and no alcohol). Participants were given the choice as to whether to eat after the anthropometric assessment. Then, we conducted 10RM testing in the Smith machine bench press and 45º leg press to determine the loads for the working sets. The

10RM test was performed according to the guidelines established by the National Strength and Conditioning Association[5].

Afterwards, the experimental conditions were randomized for each participant, ensuring the same likelihood for the testing order in every experimental condition. The experimental conditions were as follows: a) 1 SWU set at 75%10RM (1SET); b) 2 SWU sets at 55 and 75% of 10RM load (2SET); and c) a control condition (CON) that did not perform a SWU before the working sets. To avoid fatigue effects, the SWU sets employed a target range of 3 to 4 repetitions. Participants were afforded a 120-second rest interval between all the SWU and working sets and exercises. Figure 1 provides an overview of the experimental design.

Participants' rating of perceived exertion (RPE) was assessed after each set, both in the SWU and for working sets. Exercise readiness was assessed before every experimental condition and after the 1SET and 2SET protocols. We also assessed repetition performance, fatigue index, and volume load for each experimental session. To reduce the potential for dietary confounding, participants were instructed to keep their regular meal schedule throughout the study. In blinded fashion, a member of the research staff uninvolved in written consent and 10RM testing performed the randomization procedures for the conditions (1SET, 2SET, CON) using Research Randomizer (randomizer.org). The methods for this study were preregistered prior to data collection (https://osf.io/f6w9b).

Figure 1. Experimental design overview.



Participants

To be considered for inclusion, participants had to meet the following criteria: a) men and women between 18-40 years of age; b) answer "no" to all Physical Activity Readiness

Questionnaire items; c) have at least 1-year previous RT experience without training cessation for more than 2 weeks within the past year, as well as previous experience performing the bench press and leg press for at least 4 weeks; d) self-report to be free from chronic use of anti-inflammatory drugs, painkillers, and anabolic steroids for the previous year. To avoid potential negative effects of withdrawal, participants were allowed to consume their usual pre-workout supplements and listen to their preferred music; if so, the pre-workout supplement and music had to remain constant across all conditions. In addition, participants were asked to refrain from alcohol consumption and moderate-to-vigorous activity in their daily routine for at least 48 hours prior to the experimental sessions. Participants were instructed to consume their breakfast or breakfast and lunch if they attended the experimental sessions in the morning or afternoon, respectively, with the last meal consumed at least 2 hours prior the training session. The participants were excluded from the sample if they self-reported to: a) suffer a musculoskeletal injury during the course of the study; b) consume a substantial amount of alcohol 48 hours prior to an experimental session as well c) perform moderate-to-vigorous activity outside the study in the 48 hours prior to an experimental session. Moreover, participants were excluded if they failed to attend one of the lab visits. Approval for the study was obtained from the Lehman College Institutional Review Board (#2025-0055-Lehman).

Sample Size Justification

A power analysis was conducted to determine an appropriate sample size. We employed a modified version of the workflow suggested by Wang and Gelfand[19] to quantify likely precision in our average treatment effect estimate across our potential sample sizes by investigating the width of the 95% credible intervals and posterior probabilities. To assess likely precision, we first simulated prior predictive data for samples of size n using informative priors (sampling priors). These priors were based on the individual participant results from Abad et al.[7], and the calculated main effect of different warm-up conditions and variation of difference scores. Priors were set on a standardized scale with participant random intercept $N(0,1^2)$, main effect of 1SET ~ $N(0.3,0.1^2)$, main effect of 2SET~ $N(0.5,0.1^2)$, measurement error $N(0,0.1^2)$, and a single participant random "slope" from control to both 1SET and 2SET $N(0,0.3)$. Main effects were sampled from a bivariate normal distribution with correlation equal to 0.9. Default weakly informative priors were used to fit the models across m=500 iterations for sample sizes n=10, 15, and 20, with results presented in the supplementary file (Table S1). Based on the width of the credible intervals and posterior probabilities a sample size of 15 was selected; however, we recruited additional participants to account for the possibility of dropouts.

Resistance training procedures

Participants performed 10RM testing to determine the initial loads for Smith machine bench press and 45° leg press. After 10RM testing, the experimental condition order was randomized for each participant.

The research staff directly supervised all training sessions. The load was the same for every working set according to 10RM testing with a 120-second rest interval provided among the SWUs, working sets and exercises. The participants were instructed to perform the concentric phase of each repetition as fast as possible and take 2 seconds for the eccentric action with no pause between muscle actions or repetitions; however, when sets approached concentric failure, the concentric repetition cadence necessarily slowed despite participants attempting to exert maximal force. All working sets were carried out to the point of momentary concentric muscular failure, i.e., the inability to perform another concentric repetition while maintaining proper exercise form, as many repetitions as possible.

Measurements

Anthropometry

Anthropometric assessments were conducted during the first visit. Height was measured using a stadiometer (Cardinal Scale Manufacturing Company, Webb City, MO). Body composition (body mass and body fat percentage) was assessed using multifrequency bioelectrical impedance (Model 770, InBody Corporation, Seoul, South Korea). Participants were asked to abstain from food and fluid intake for 8 hours, avoid alcohol consumption 48 hours prior to anthropometric assessments, and empty their bladder immediately before testing.

Neuromuscular performance

Neuromuscular performance was assessed via repetition performance (RP, the total of repetitions performed for each exercise), volume load (VL, the product of repetitions * sets * load (kg)), fatigue index (FI, the index of performance decline on the product of load by repetitions between the first and last working set). The FI was calculated as proposed by Sforzo and Touey[20] with the following formula: $FI = [(S_{(last\ set)} - S_{(first\ set)})/(S_{(first\ set)})]*100$, where S represents the product of load and number of repetitions performed in the respective set.

Instructions for specific warm-up sets

Since a primary purpose of SWU is to increase neuromuscular output, we employed a lower repetition range (3-4 reps) for SWU sets compared to working sets (~8-12 reps). We instructed the participants to stop SWU sets when they felt adequately warmed up, to avoid any residual fatigue that might impair performance. Participants were given the following instructions: a) "*when you feel warmed-up, stop the set*"; b) "*you should stop the set before you feel fatigued*"; c) "*these specific warm-up sets are to prepare your muscles to the working sets, stop the set when you feel ready to perform your working sets*". We did not use words mentioning "*effort*", "*failure*" or "*discomfort*" to avoid any influence in the anchoring on the RPE scale and for readiness to working sets.

Perceptual measurements

For the RPE, we used the resistance-exercise specific scale[21], which has anchors from 1-2 to 10. In this scale, a rating of 1-2 represents little to no effort and 10 represents maximum effort (i.e., neither additional repetitions nor increases in load can be implemented). At the end of each set, participants were asked to provide an RPE value according to the scale, first choosing a verbal anchor (e.g. "maximal effort" as indicated in the scale) and then giving the respective number for the anchoring. Participants were introduced to the scale and its anchors during their first lab visit and reminded not to confuse discomfort (e.g., muscle burning) with exertion when providing their ratings.

Exercise readiness was assessed before and 1 min after the SWU protocol as well as before the experimental session in the CON condition. The participants were asked "Based on your past performance, how ready are you to exercise right now?", and indicate on a 7-point, bipolar Likert scale ranging from -3 to +3, according to how they expected to perform in the working sets after the SWU protocols, based on their general performance. The bipolar Likert scale anchors were as follows: -3 = strongly decrease; -2 = moderately decrease; -1 = slightly decrease; 0 = no effect; 1 = slightly increase; 2 = moderately increase; 3 = strongly increase[22]. Participants were instructed not to confuse motivation with readiness when providing their ratings.

To account for the potential influence of sleep patterns, we used the Karolinska Sleepiness Scale (KSS)[23]. In short, this is a 10-point Likert scale that measures the level of sleepiness at specific times of the day (i.e. the times of the experimental sessions). In the present study, it was assessed before the experimental sessions. In the KSS, participants indicated which level reflected the psychophysical state experienced in the last 10 minutes.

The anchors were as follows: 1 = extremely alert; 2 = very alert; 3 = alert; 4 = rather alert; 5 = neither alert nor sleepy; 6 = some signs of sleepiness; 7 = sleepy, but no effort to keep awake; 8 = sleepy, but some effort to keep awake; 9 = very sleepy, great effort to keep awake, fighting sleep; 10 = extremely sleepy, can't keep awake.

Statistical Analysis

A statistician, blinded to the allocation of conditions, conducted all analyses in R (version 4.4.0) within a Bayesian framework. The primary analysis employed univariate linear mixed models, including random intercepts for participants. Posterior distributions of the parameters comparing mean differences between warm-ups were standardized by the CON standard deviation (SMD), and also included posterior distribution p-values for the superiority of SWU to draw inferences. These p-values represented the probability that the 1SET or 2SET conditions outperformed CON based on the posterior samples. To formally evaluate the hypothesis that $\mu_{2SET} > \mu_{1SET} > \mu_{CON}$, we calculated the evidence ratio from the posterior draws of the estimated condition effects, dividing the probability of this ordered hypothesis by the probability of all other orderings. The strength of evidence for or against the ordered hypothesis was assessed using standard criteria[24]. Given the limited prior research in this area, weakly informative priors were employed to regularize estimates while allowing the data to drive inference.

Results

Table 1 presents the participants' descriptive characteristics. Of the 29 participants, 16 (~55%) did not employ a SWU during their usual training routine, 11 (~40%) regularly employed a SWU and 2 (~5%) reported sporadic use of SWU.

Table 1. Descriptive characteristics of the sample (n = 29; 22 males, 7 females).

Variables	Mean ± SD
Age (years)	22.9 ± 3.6
Height (cm)	167.6 ± 1.0
Body mass (kg)	79.1 ± 15.0
Body fat (%)	19.9 ± 9.1
RT experience (years)	4.5 ± 3.9
Previous chest press volume (sets.week^{-1})	11 ± 6
Previous leg press volume (sets.week^{-1})	6 ± 3
10RM load at smith machine bench press (kg)*	47.8 ± 22.8
10RM load at 45° leg press (kg)*	175.9 ± 64.5

Abbreviations: cm = centimeter; kg = kilogram; SD = standard deviation. * = without the bar and platform mass.

Analyses for the primary outcomes of VL, RP, and FI are presented in Table 2. For the bench press, SMDs comparing each warm-up condition to control were generally modest, with central estimates ranging from negligible to small in magnitude. The posterior probabilities that either warm-up condition was superior to control remained relatively low across all outcomes ($0.089 \leq P \leq 0.726$). Furthermore, the evidence consistently provided “strong” to “very strong” support against the hypothesis of a strictly ordered effect (i.e., CON < 1SET < 2SET), indicating limited support for a dose-response relationship based on the number of warm-up sets. Similar results were observed for the primary outcomes during the leg press, with relatively low posterior probabilities that either warm-up condition was superior to control ($0.067 \leq P \leq 0.855$). However, in contrast to the bench press, the evidence against a strictly ordered effect (CON < 1SET < 2SET) was classified as “anecdotal” for both VL and RP, and “strong” for the FI.

Table 2. Comparison of warm-up set conditions on bench press and leg press performance outcomes.

Exercise/Outcome	1SET compared to CON (SMD [95%CrI])	Probability 1SET superior to CON	2SET compared to CON (SMD [95%CrI])	Probability 2SET superior to CON	Evidence ratio of ordered effect (CON < 1SET < 2SET)
Bench Press					
Repetitions Performance	-0.02 [-0.34 to 0.30]	*P* = 0.459	-0.21 [-0.53 to 0.10]	*P* = 0.089	0.01: "Very strong" evidence against
Fatigue Index	0.13 [-0.30 to 0.57]	*P* = 0.726	-0.12 [-0.55 to 0.33]	*P* = 0.297	0.06: "Strong" evidence against
Volume load	0.04 [-0.12 to 0.20]	*P* = 0.701	-0.07 [-0.23 to 0.10]	*P* = 0.212	0.03: "Strong" evidence against
45º Leg Press					
Repetitions Performance	0.08 [-0.33 to 0.50]	*P* = 0.642	0.22 [-0.20 to 0.63]	*P* = 0.853	0.75: "Anecdotal" evidence against
Fatigue Index	-0.26 [-0.59 to 0.08]	*P* = 0.067	0.00 [-0.33 to 0.33]	*P* = 0.508	0.05: "Strong" evidence against
Volume load	0.00 [-0.22 to 0.22]	*P* = 0.499	0.12 [-0.11 to 0.34]	*P* = 0.855	0.62: "Anecdotal" evidence against

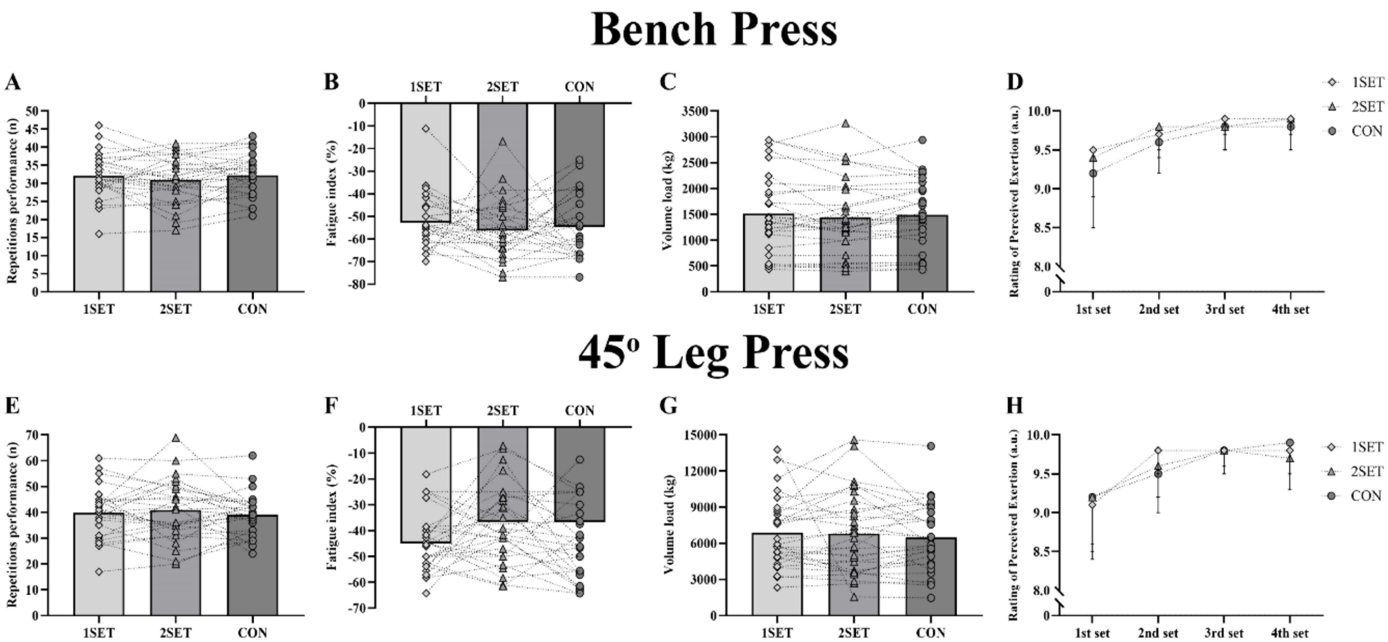
CrI: Credible interval; SMD: Standardized mean difference effect size; S&C Specific threshold of 0.15, 0.30, and 0.50 for small, medium, and large were used for interpretation[25]. Probabilities were calculated from the proportion of the posterior distribution indicating superiority.

Figure 2 depicts the descriptive data for the outcomes across all conditions and exercises. The KSS scores before the 1SET, 2SET and CON experimental sessions were 3.4 ± 1.5, 3.9 ± 1.8, and 3.5 ± 1.7, respectively. The Exercise Readiness scores before and after bench press SWU were 1.1 ± 1.4 and 1.4 ± 1.1 for 1SET and 1.3 ± 1.2 and 1.6 ± 0.9 for 2SET, respectively, and 1.4 ± 1.2 before the working sets for CON. The Exercise Readiness scores before and after the 45º leg press SWU were 1.3 ± 1.0 and 1.4 ± 1.0 for 1SET, and 1.5 ± 1.0 and 1.4 ± 1.1 for 2SET, respectively, and 1.3 ± 1.1 for CON. The RPE after the first SWU set was 3.0 ± 1.0 for 1SET and 2.7 ± 0.8 for 2SET on bench press and 3.4 ± 1.3 for 1SET and 3.0 ± 0.9 for 2SET on leg press; values after the second SWU set were 3.8 ± 1.3 on bench press and 3.8 ± 1.0 on leg press for 2SET.

A visual overview of RPE across the 4 sets, and the potential for warm-up conditions to moderate this change, is presented in Figures 2D and 2H. There was limited evidence of an interaction effect for both the bench press and leg press. For each additional set, the estimated change in RPE relative to CON was small: bench press – 1SET: β = -0.07 [95% CrI: -0.15 to 0.01], 2SET: β = -0.05 [95% CrI: -0.13 to 0.03]; leg press – 1SET: β = -0.05 [95% CrI: -0.15 to 0.05], 2SET: β = -0.06 [95% CrI: -0.16 to 0.04].

No adverse events were reported by any participant during the training sessions.

Figure 2. Descriptive data of the outcomes. The repetitions performance (A and E), fatigue index (B and F), volume load (C and G) and rating of perceived exertion (D and H) were depicted for Bench Press (at the top, from Panel A to D) and 45º Leg Press (at the bottom, from Panel E to H). Note: n = number of repetitions; kg = kilogram; a.u. = arbitrary units. Data are depicted as mean and individual responses.



To explore whether strength influenced the extent to which SWU affected total repetitions, we examined how the effect of each condition varied across participants with different strength levels, as quantified by load used. We found little to no evidence of an interaction effect for either the bench press or leg press. For each one SD increase in strength, the estimated increase in repetitions (relative to control) was: bench press – 1SET: β = 1.5 [95%CrI: -0.43 to 3.4], 2SET: β = 0.8 [95%CrI: -1.1 to 2.7]; leg press – 1SET: β = -1.8 [95%CrI: -5.2 to 1.6], 2SET: β = 0.5 [95%CrI: -2.9 to 3.9].

Discussion

This study investigated the effects of varying the set number and loads in SWU protocols on RT session performance and perceptual responses in resistance-trained individuals. We hypothesized that a higher SWU set number at higher loads would enhance submaximal multi-set RT session performance. However, our findings did not support this hypothesis, since the multi-set RT session performance was relatively similar among different

SWU set numbers and loading schemes compared to no warm-up at all. Therefore, our main finding was that varying the SWU protocol, as set number or load, neither appreciably enhanced nor impaired RT session performance in resistance-trained individuals.

A primary purpose of employing specific warm-up protocols is to increase neuromuscular output in the subsequent exercise. Some previous research on the topic provides uncertainty regarding SWU protocols. For instance, Viveiros et al.[18] investigated different SWU protocols consisting of 15 repetitions at 40%, 10 repetitions at 60% and 5 repetitions at 80% of the 10RM load before 3 sets of the bench press, inclined leg press, and wide grip lat pulldown in men with at least 6 months of RT experience. The SWU protocols were performed before each exercise. The 80% SWU protocol elicited a greater combined volume load compared to lower intensities; however, when scrutinizing results for each exercise, the 80% protocol elicited greater volume load and repetition performance only for the bench press compared to 60%, but not to 40%, with no other differences in volume load or FI within exercises or between protocols. Importantly, the authors did not employ a control condition (i.e., no SWU). Similarly, Garbisu-Hualde et al.[26] investigated 2 experimental conditions in resistance-trained individuals. For both experimental conditions, the participants performed a standardized GWU (i.e. 5-min cycling) and SWU consisting of 10, 4, 2 and 1 repetitions at 40%, 60%, 70%, and 80%1RM, respectively. After the standardized GWU and SWU, participants performed either a set to failure on the bench press at 80%1RM (control) or 1 repetition at 93%1RM followed by a set to failure on the bench press at 80%1RM (PAPE protocol). The authors observed a positive effect induced by the conditioning activity (1 rep at 93%1RM) on repetition performance (mean difference ~1 repetition) and a slower mean propulsive velocity in the last repetition. Of note, both conditions performed the standardized warm-up consisting of a GWU and SWU, which can be considered a confounder. In addition, although both studies suggest a performance-related benefit to SWU, these effects can be considered small in magnitude.

Alternatively, Lisboa et al.[27] compared the effects of SWU, static stretching, and a control condition preceding 2 sets of a variety of upper- and lower-body exercises performed to volitional concentric failure in older women. The SWU protocol consisted of a set lasting 45s at ~30-50% of the working set weight (8–12 repetitions) while participants remained seated for the same 45s in the control condition. Curiously, the SWU protocol elicited similar performance to the control and static stretching conditions, but upper-body performance was impaired after the SWU protocol compared to control and static stretching. Although the study by Lisboa et al.[27] involved older females rather than resistance-trained individuals, their finding of no performance improvement following a SWU protocol aligns with our findings and those of other studies conducted in resistance-trained individuals using multiple-set protocols[11,28].

It could be argued that SWU improves the subsequent performance only in specific activities such as jumps, sprints, or RT sets performed at intensities above ~80%[14,29]. It can be speculated that in resistance training carried out in medium to higher repetition ranges (e.g., 10+RM), the initial several repetitions of each set function as a SWU by priming the neuromuscular system to the movement pattern, thereby obviating the need for a SWU prior to performance. In addition, although some research suggests that stronger participants can benefit more from SWU protocols[29,30], theoretically due to higher levels of potentiation and greater muscle volume, our regression analysis showed that initial strength did not influence the SWU effects.

Our study is not without limitations. First, our findings are specific to healthy, young, resistance-trained individuals and should not be extrapolated to other populations such as untrained, older individuals, or elite athletes. Second, although we aimed to make our study design as ecologically valid as possible and to avoid any influence from pre-training assessments (e.g., isometric testing)[14], resource and logistical constraints limited our ability to include additional neuromuscular (e.g., isometric dynamometry, countermovement jump, velocity-based assessments), biochemical (e.g., blood lactate analysis) and perceptual (e.g., Session-RPE) measurements that could help to contextualize our findings. Third, to maintain consistency, the exercise order was the same across all experimental sessions; however, randomizing the exercise order could potentially reduce bias on the order and learning effect. Fourth, our findings are specific to performing the Smith machine bench press and 45^{o} leg press with a 10RM load and 120-second rest intervals, and inferences cannot necessarily be extrapolated to different exercises, order, repetitions range (e.g. 1-3RM), or rest intervals between SWU and working sets. Fifth, although no participants experienced adverse events in any of the conditions during the intervention, our study was not designed to assess the effect of SWU on injury risk, which is often cited as a rationale for employing the strategy[31]. This topic requires future investigation. Finally, our findings are specific to acute performance and perceptual responses and thus caution should be used when attempting to extrapolate implications to neuromuscular adaptations such as strength, power, and muscle hypertrophy.

Conclusion

Our findings indicate that performing 1 or 2 sets of 3–4 repetitions at 55% and 75% of 10RM load elicits similar effects on upper- and lower-body performance as well as on perceptual responses compared to no SWU. Moreover, individual strength capacity did not influence the effects of SWU on performance.

Given that lack of time is one of the principal barriers to resistance-training adherence, coaches and practitioners with time constraints do not necessarily need to employ SWU sets when training with ~10RM loads, thus saving ~2-5 minutes per exercise. Nonetheless, given that our study did not show any detriments to performing a SWU, its implementation should be considered on an individual basis, especially for those without time constraints who objectively or perceptually feel the strategy better prepares them for their working sets.

Contributions

AE and BJS conceived the idea for the study; AE, AEM, AP, TH, MS, MC, PAK, MW, TPSJ, PAS and BJS assisted in study design; AE, AEM, AP, TH, MS assisted with data collection; PAS conducted the statistical analysis. All authors critically interpreted the data, revised the manuscript and approved the final version.

Conflict of interest

BJS formerly served on the scientific advisory board for Tonal Corporation, a manufacturer of fitness equipment. The other authors report no conflicts of interest with this manuscript.

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Data and Supplementary Material Accessibility

Data can be requested from the corresponding author. Supplementary material are available on the Open Science Framework project page: https://osf.io/s42mw/

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