Do cheaters prosper? Effect of externally supplied momentum during resistance training on measures of upper body muscle hypertrophy

For correspondence:
*brad.schoenfeld@lehman.cuny.edu

Francesca Augustin[1], Alec Piñero[1], Alysson Enes[1, 2], Adam E. Mohan[1], Max Sapuppo[1], Max Coleman[1], Milo Wolf[1], Patroklos Androulakis Korakakis[1], Paul A. Swinton[3], Jeff Nippard[4], *Brad J. Schoenfeld[1]

1. Department of Exercise Science and Recreation, Applied Muscle Development Lab, CUNY Lehman College, Bronx, NY
2. Metabolism, Nutrition and Strength Training Research Group (GPMENUTF), Federal University of Paraná (UFPR), Curitiba, PR, Brazil
3. Department of Sport and Exercise, School of Health Sciences, Robert Gordon University, Aberdeen, United Kingdom
4. STRCNG Incorporated OA Jeff Nippard Fitness, Oakville, ON L6L 1W4, Canada

Please cite as: Augustin, F., Piñero, A., Enes, A., Mohan, A.E., Sapuppo, M., Coleman, M., Wolf, M., Androulakis Korakakis, P., Swinton, P.A., Nippard, J., Schoenfeld, B.J. (2024). Do cheaters prosper? Effect of externally supplied momentum during resistance training on measures of upper body muscle hypertrophy

All authors have read and approved this version of the manuscript. This article was last modified 12/2024.

ABSTRACT

This study examined the effects of externally applied momentum on resistance training-induced muscular adaptations in the upper extremities. Thirty young adults were recruited to participate in a within-participant design, with one limb randomly allocated to perform biceps curls and triceps pushdowns using strict form (STRICT) and the other using external momentum (CHEAT). Participants completed four sets of each exercise with 8-12 repetitions until momentary muscular failure, twice a week for eight weeks. We obtained pre-post proximal and distal measures of muscle thickness for the elbow flexors and extensors, and assessed circumference changes in the upper arms. Data were analyzed in a Bayesian framework including both univariate and multivariate mixed effect models with random effects. Differences between conditions were estimated as average treatment effects, with inferences based on posterior distributions and Bayes Factors (BFs). Results showed similar between-conditions increases for all muscle thickness sites as well as circumference measures, generating consistent support for the null hypothesis (BF = 0.06 to 0.61). Volume load was markedly greater for CHEAT compared to STRICT across each week of the intervention. In conclusion, the use of external momentum during single-joint RT of the upper extremities neither helped nor hindered hypertrophy of the target muscles.

Keywords: exercise technique; cheat repetitions; exercise form; muscle growth

INTRODUCTION

Structured resistance training (RT) is a primary intervention for enhancing muscle growth [1]. Research suggests the manipulation of specific RT variables including volume and proximity to failure can help to further augment adaptations [23]. Exercise technique, defined as “the controlled execution of bodily movements to ensure an exercise effectively targets specific muscle groups while minimizing the risk of injury,” is another variable frequently highlighted as a critical aspect of successful RT programs, with proper technique suggested to play a role in maximizing muscle development [4].

Key components of exercise technique, such as body positioning, range of motion and repetition tempo, have been individually studied [567]. Moreover, exercise technique guidelines are frequently based on biomechanical principles and applied anatomy, yet research directly examining the impact of these variables on hypertrophy is limited [4]. More specifically, an aspect of RT technique that lacks direct research is the use of external momentum during repetitions. External momentum, which often accompanies non-strict or "cheat" repetitions, involves ancillary muscle groups contributing to the movement. In contrast, strict repetitions aim to isolate the target muscle by minimizing momentum and additional muscle involvement. For instance, performing a biceps curl with strict form limits hip or leg drive use, while cheat repetitions allow such contributions.

Cheat repetitions are frequently regarded as less effective than strict repetitions in promoting muscular adaptations. To assess this hypothesis, Arandjevićlo [8] developed a biomechanical model that simulated the use of external momentum during the shoulder lateral raise exercise. Results from the computer simulation suggested that use of a moderate amount of momentum during the beginning of a repetition (initial angular velocities ~$57.5° s^{-1}$) heightened abduction torque of the target muscles irrespective of increases in load. Moreover, results indicated that torque was further increased when external momentum was applied with a 25% increase in load. Based on a hypothesized interaction between the absolute magnitude of muscular tension and the duration of this tension in optimizing hypertrophy, the model suggested that incorporating moderate momentum at the beginning of each repetition provides the best balance between safety and stimulation of the target musculature. Despite these findings, excessive momentum could conceivably diminish the hypertrophic stimulus by reducing target muscle engagement or time spent at long muscle lengths, which could limit hypertrophic adaptations given the suggested importance of training at long muscle lengths for hypertrophy [9].

To date, no longitudinal studies have directly examined the effect of strict versus cheat repetitions on muscle hypertrophy. While theoretical and biomechanical perspectives provide some rationale for the use of strict or cheat repetitions, the practical implications of these approaches for optimizing muscular adaptations remain to be determined. Therefore, this study aimed to investigate the effect of externally applied momentum on resistance training-induced muscle hypertrophy of the upper body extremities in untrained men and women. We hypothesized that the use of external momentum would have a detrimental effect on muscular adaptations due to a reduction in stimulus to the target musculature [4].

METHOD

Participants

Participants included 30 male and female volunteers recruited from a university population. Sample size determination was made based on considering the analysis approach (Bayesian analyses considering strength of evidence), previous research, the within participant design, and pragmatic considerations of ability to recruit between twenty to thirty participants. We employed a modified version of the workflow suggested by [10] to quantify likely precision in our average treatment effect estimate across our potential sample sizes by investigating the width of the 95% credible intervals. We also performed simulation-based calibration of Bayes factors to assess whether the correct hypothesis was likely to be supported based on sample size and study design [11]. 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 results from meta-analyses investigating distribution of effects in strength and conditioning [12][13]. Priors were set on a standardized scale and included a distribution describing typical improvement $N(0.44,0.40^2)$, an average treatment effect $N(0.30,0.27^2)$, a heterogeneous response $N(0,0.15^2)$ and measurement error $N(0,0.20^2)$. The fitting priors used an average treatment effect prior of $N(0,0.40^2)$. Simulation based calibration of Bayes factors assumed equal prior probabilities for the null (H_0) and alternative (H1) hypotheses. Simulation and fitting was conducted with the neutral prior $N(0,0.40^2)$ and with the average treatment effect set to zero on half the iterations. Calibration was performed by examining the average posterior model probability (and determining if this matched the true 50%), and the average percentage of posterior allocated to the true hypothesis. Models were fit across m=500 iterations for sample sizes n=20,25, and 30, with results presented in the supplementary material (Table S1).

To qualify for inclusion in the study, male and female participants were required to be: (a) between the ages of 18-40 years; (b) free from existing cardiorespiratory or musculoskeletal disorders and answer "no" to all items of the Physical Activity Readiness Questionnaire; (c) untrained, defined as not having performed resistance-exercise for their upper body in the past year, and; (d) self-reported as free from consumption of anabolic steroids or any other illegal agents known to increase muscle size for the previous year. Participants were asked to refrain from consuming creatine products throughout the course of the study period since creatine has been shown to positively impact muscle growth when combined with resistance training (RT) [14].

The participants were randomly assigned to 1 of 2 experimental within-subject conditions involving unilateral performance of a traditional (STRICT: n=30) or an applied external momentum (CHEAT: n=30) for the elbow flexors and elbow extensors. Randomization into groups was carried out using block randomization, with two limbs per block, via online software (www.randomizer.org.). Approval for the study was obtained from the college's Institutional Review Board. Written informed consent was obtained from all participants before beginning the study. The methods for this study were preregistered (https://osf.io/5w3z9) prior to recruitment.

Resistance training procedures

The resistance exercise protocol included 2 exercises: unilateral supinated dumbbell biceps curl and unilateral pronated cable triceps pushdown. The protocol was performed on two non-consecutive days per week for 8 weeks. Each session consisted of 4 sets of 8-12 repetitions for each exercise. The resistance load was adjusted to ensure that participants stayed within the recommended repetition range. Research assistants supervised the participants during each session and provided verbal encouragement to perform sets until momentary muscular failure (the inability to perform another concentric repetition). Participants were instructed to abstain from performing any additional upper body RT outside of the study for the entire duration. To prevent non-localized fatigue from affecting limb performance, participants were given a 1-minute rest period between each arm when performing a given exercise and a 2-minute rest period when transitioning to the next exercise. Exercise order was not standardized, but participants completed all 4 sets of the first exercise before starting the next.

Before the training intervention, the participants underwent a 10-repetition maximum (RM) test for the biceps curl and triceps pushdown to determine the starting loads and familiarize them with the prescribed technique outlined in the study. To further aid visual learning, participants were provided with instructional videos to enhance their understanding (the videos can be viewed in the supplemental material). The RM testing was conducted according to the guidelines established by the National Strength and Conditioning Association (NSCA) [15].

The exercise instruction for the STRICT condition was consistent with guidelines provided by NSCA's Exercise Technique Manual for Resistance Training [16]. While this book provides instructions on specific aspects of exercise technique, it does not specify a prescriptive repetition tempo. We standardized the eccentric actions between conditions using a tempo of ~2 seconds as visually determined by the supervising researcher, which is consistent with general recommendations for the eccentric phase as well as for training to optimize muscle hypertrophy [17]. Given the research question, concentric tempo was specific to the condition, with STRICT performing controlled repetitions of ~1 second and CHEAT performing repetitions as explosively as possible.

STRICT resistance training instruction

Participants adhered to the following performance guidelines for the STRICT condition. For the dumbbell biceps curl, participants began by positioning their unilateral arm alongside their torso, with palms supinated while standing with their feet shoulder – or hip width apart and their knees slightly flexed. Each repetition was executed through a full range of motion, consisting of complete extension and flexion at the elbow. Participants were instructed to maintain a stationary body position and to avoid swinging the torso (i.e., hyperextending the hips and spine), shrugging the shoulders, hyperextending the neck, extending the knees, or rising on the toes to assist in the concentric action.

For the cable triceps pushdown (Freemotion Fitness, Logan, UT, USA), participants maintained a pronated grip, upright torso, and 0 degrees of shoulder flexion/abduction ensuring elbow extension was the only movement occurring during the exercise.

CHEAT resistance training instruction

For the CHEAT condition, participants performed exercises with the use of external momentum during the concentric actions. As such, participants began the biceps curl movement by swinging the weight from full elbow extension at the bottom position to full elbow flexion at the top of the movement. To reinforce prescribed performance, they were verbally encouraged to utilize external momentum to lift the weight as often as possible until they reached failure.

For the triceps extensions, participants were instructed to use external momentum throughout the set until they could not fully extend the elbow. This included allowing the elbows to flare during each repetition, employing leg drive by bending the knees to assist in the downward motion, and assuming a forward lean to facilitate the completion of a full repetition.

Measurements

Muscle thickness (MT) was measured using ultrasound imaging as previously described [18]. In brief, a trained technician used a B-mode ultrasound imaging apparatus (Model ECO 3 Expert, CHISON Medical Technologies Co., Ltd., Wuxi, China) and applied a water-soluble transmission gel (Aquasonic 100 Ultrasound Transmission Gel, Parker Laboratories Inc., Fairfield, NJ) to a 4-12 MHz linear array ultrasound probe for all measurement sites. The probe was placed perpendicular to the tissue interface taking care not to depress the skin. Once a satisfactory image quality was achieved, the technician saved the image to a hard drive and measured MT by determining the distance from the subcutaneous adipose tissue-muscle interface to either the aponeurosis or the muscle-bone interface. Multiple measurements were taken at different points on the anterior and posterior upper arm because various sites have been suggested to be included when assessing muscle change [19]. Measurements of the elbow flexors and elbow extensors were taken at 55% (proximal) and 65% (distal) of the distance from the acromion process of the scapula to the lateral epicondyle of the humerus.

To ensure that muscle swelling from training did not obscure muscle thickness results, an image was obtained at least 48 hours after the participants' training sessions for both the pre-and post-study assessments. This protocol is consistent with research indicating that an acute increase in muscle thickness returns to baseline within 48 hours following a resistance training session [20]. We determined the intraclass correlation coefficients (ICC) and coefficients of variation (CV) in a cohort of 8 subjects for the assessed sites on 2 separate occasions separated by 24-48 hours; values for ICC and CV in these sites ranged from 0.97-0.99 and 1.19%-4.19%, respectively.

Anthropometry

To reduce the potential for confounding from lifestyle factors, participants were told to refrain from eating 12 hours before testing, eliminate alcohol consumption for 24 hours, and void their bladder immediately before anthropometric testing. Each participant's height was measured using a stadiometer, and assessments of initial body mass and percent body fat was obtained by multifrequency bioelectrical impedance analysis (Model 770, InBody Corporation, Seoul, South Korea) as per the instructions of the manufacturer.

A three-dimensional optical scanner was then used to assess muscle circumferences of the upper arms. Participants stood on a rotating scale that performed a 360-degree scan of their body. This scan estimated circumferences, with a focus on the combined girth of the elbow flexors and extensors.

Volume Load

Volume load, calculated as (sets x repetitions x load [kg]), was manually recorded during each session. The values were transcribed to a spreadsheet and reported for each condition in both the biceps curl and triceps pushdown exercises.

Dietary Adherence

Participants were advised to maintain their customary nutritional regimen to avoid potential dietary confounding of results. Dietary adherence was assessed by self-reported 5-day food records (including at least 1 weekend day) using the MacroFactor mobile application (https://macrofactorapp.com/). Nutritional data were collected twice during the study: 1 week before the first training session (i.e., baseline) and during the final week of the training protocol. Participants were instructed to record all food items and the respective portion sizes consumed for the designated period of interest. Each food item was individually entered into the program, and the program provided relevant information as to total energy consumption, as well as the amount of energy derived from proteins, fats, and carbohydrates for each time period analyzed.

Blinding

To minimize potential bias, the researcher who obtained the MT measurements was blinded to group allocation, and the statistician performed blinded analyses for all outcomes. Moreover, group allocation was concealed from the researcher who determined whether a participant was eligible for inclusion.

Statistical procedure

All analyses were conducted in R (version 4.4.0) within a Bayesian framework. Bayesian statistics represents an approach to data analysis and parameter estimation based on Bayes' theorem and can provide several advantages over frequentist approaches including formal inclusion of information regarding likely differences between intervention conditions based on knowledge from previous studies (e.g., through informative priors); and presentation of inferences based on intuitive probabilities [21]. Inferences were not drawn on within-condition change as this was not the focus of our research question [22], although we descriptively presented within-group changes to help contextualize our findings. The effect of condition (STRICT vs CHEAT) on outcome variables were estimated using linear mixed models with random effect structures included to account for the within participant design [23].

All inferences were made from posterior distributions of model parameters describing estimates of the effect of intervention allocation and strength of evidence for the existence of a difference through Bayes factors. Informative prior distributions were used based on meta-analysis data on the specific research question and general strength and conditioning literature [13]. All analyses were performed using the R wrapper package brms interfaced with Stan to perform sampling [24]. A complete Bayesian workflow was adopted [11] that included prior predictive checks, posterior predictive checks, and simulation-based calibration of Bayes factors. To improve accuracy, transparency and replication of the analyses, the WAMBS-checklist (When to worry and how to Avoid Misuse of Bayesian Statistics) was used and reported [25]).

Results

Twenty-five of the initial 30 volunteers completed the protocol (see Table 1). Reasons for drop-out are presented in Supplementary figure S1. The average session attendance for participants who completed the protocol was 92%.

Table 1 presents the descriptive characteristics of participants. Table 2 presents a summary of pre- and post-intervention values for all outcomes. Table 3 presents estimates of average treatment effects (ATEs) between groups. Table 4 presents the raw weekly volume load data. Figure 1 presents standardized mean differences illustrating within-intervention changes.

Table 1: Descriptive characteristics of the participants

Variable	Men (n = 11)	Women (n = 14)
Height (cm)	172.2 ± 6.4	160.3 ± 6.4
Body mass (kg)	75.8 ± 17.5	61.9 ± 15.7
Age (yr)	20.2 ± 4.1	21.3 ± 3.6
Bodyfat%	23.5 ± 11.8	32.6 ± 10.2

Several participants complained of a fast heart rate during performance of the CHEAT condition, presumably attributed to the cardiorespiratory component associated with swinging the weights, but these complaints subsided as they became acclimated to the technique. The majority of participants complained of muscle soreness during the initial weeks of the intervention but, consistent with the repeated bout effect [26], this symptom did not persist after acclimation to the RT program. No other adverse events were reported during the intervention.

Table 2: Descriptive summary of pre- and post-intervention values for all outcomes

	STRICT (n=25)			CHEAT (n= 25)		
Variable	Pre	Post	Δ%	Pre	Post	Δ%
Biceps brachii 55 (mm)	26.0 ± 5.0	27.5 ± 5.1	5.8%	26.1 ± 4.9	28.2 ± 5.3	8.0%
Biceps brachii 65 (mm)	30.2 ± 4.9	31.9 ± 5.2	5.6%	30.3 ± 5.7	32.1 ± 5.7	5.9%
Triceps brachii 55 (mm)	29.3 ± 6.1	32.2 ± 6.3	9.9%	28.4 ± 6.4	31.4 ± 6.7	10.5%
Triceps brachii 65 (mm)	21.7 ± 5.2	24.9 ± 5.6	14.7%	21.5 ± 5.1	24.5 ± 4.9	14.0%
Circumference (cm)	31.6 ± 5.3	32.1 ± 4.9	1.6%	32.0 ± 4.9	32.6 ± 4.9	1.9%

Muscle Thickness

Results for both the elbow flexors and extensors were consistent with evidence supporting the null hypothesis. For the elbow flexors the support was 'anecdotal' at 55% (Bayes factor = 0.61) and 'moderate' at 65% (Bayes factor = 0.13) of the distance between the lateral epicondyle of the humerus and the acromion process of the scapula (Table 3). Multivariate analysis of the two regions of the elbow flexors provided 'strong' evidence supporting the null hypothesis (Bayes factor = 0.07). Univariate analyses for the elbow extensors provided 'moderate' support (Bayes factor = 0.24 and 0.25) for the null hypothesis at 55% and 65% of the distance between the lateral epicondyle of the humerus and the acromion process of the scapula, respectively (Table 3). Multivariate analysis of the two regions of the elbow extensors provided 'strong' evidence supporting the null hypothesis (Bayes factor = 0.06).

Within-condition analyses using standardized mean difference estimates indicated that interventions were likely to produce small to medium increases in muscle thickness for the elbow flexors and medium to large increases for the elbow extensors (see figure3). Output from the WAMBS checklist presented in the supplementary file identified no concerns with the analyses.

Arm Circumference

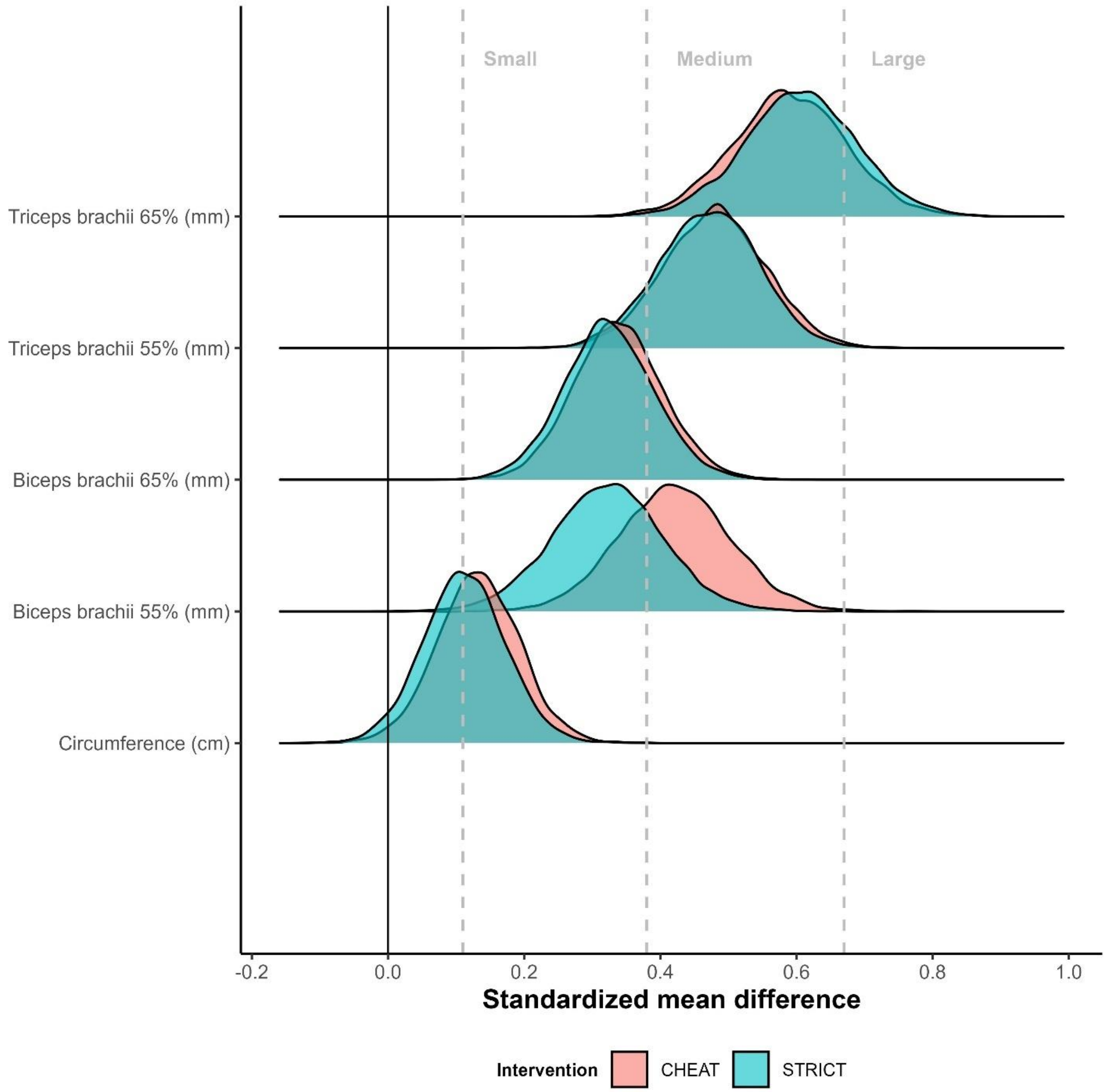
Results for measurement of arm circumference provided 'moderate' support (Bayes factor = 0.18) for the null hypothesis (Table 3). Within-condition analyses using standardized mean difference estimates indicated that interventions were likely to produce small increases in arm circumference (see figure 3). Output from the WAMBS checklist presented in the supplementary file identified no concerns with the analyses.

Table 3: Univariate and multivariate analyses of potential group pre to post differences for hypertrophy outcomes.

Variable	Univariate Group Difference STRICT:CHEAT (95%CrI)	Bayes factor for univariate analysis with interpretation	Bayes factor for multivariate analysis with interpretation
Biceps brachii 55% (mm)	0.49 (-0.08 to 1.1)	0.61 (Anecdotal support of H_0)	0.07 (Strong support of H_0)
Biceps brachii 65% (mm)	0.08 (-0.46 to 0.60)	0.13 (Moderate support of H_0)	
Triceps brachii 55% (mm)	0.06 (-1.1 to 1.2)	0.24 (Moderate support of H_0)	0.06 (Strong support of H_0)
Triceps brachii 65% (mm)	-0.08 (-1.1 to 0.96)	0.25 (Moderate support of H_0)	
Circumference (cm)	0.11 (-0.60 to 0.79)	018 (Moderate support of H_0)	-

Positive values of group differences favor the CHEAT condition. CrI: Credible interval

Figure 1: Standardized mean differences illustrating within-intervention changes.



Volume Load

Total volume load at the beginning of the intervention was nearly double in the CHEAT condition compared to STRICT (Table 4). Total volume load increased for both conditions over the 8-week program, with CHEAT demonstrating greater increases in weekly volume (70.9% [95%CrI: 53.6 to 88.4]) compared to STRICT (35.7% [95%CrI: 18.3 to 53.0]; Supplemental Figure S2).

Table 4: Weely volume load for each condition (kg)

	BiCheat	TriCheat	BiStrict	TriStrict
Week1	22751	16879	11641	9097
Week 2	22339	18630	10850	9702
Week3	21866	19260	11159	10586
Week4	20354	17166	11613	8469
Week5	24680	21834	12822	10030
Week6	24852	22215	12675	11200
Week7	24558	21552	13131	10786
Week8	18228	16365	9872	8070

Discussion

To our knowledge, this is the first longitudinal study to directly investigate the effects of external momentum during RT on muscle hypertrophy. Our findings indicate that incorporating external momentum had no discernible effect on MT or upper arm circumference when performing an 8-week program of biceps curls and triceps pushdowns compared to the same exercises performed with strict technique. Results were consistent between conditions across all outcomes, providing support for the null hypothesis. However, within-condition analyses showed that both interventions led to improvements over the training period. We hypothesized that the use of external momentum would reduce the stimulation of target muscles, thereby attenuating hypertrophic adaptations. However, this hypothesis was not supported, as hypertrophy outcomes were comparable between conditions.

Our findings are at odds with those of Arandjevićlo [8], whose biomechanical model suggested the use of momentum during shoulder abduction heightened torque of the deltoid, conceivably promoting a greater hypertrophic stimulus in this muscle. Discrepancies between the two studies can be attributed to the limitations of extrapolating results of a biomechanical model into practice. By nature, a model is only as good as its underlying assumptions. It is therefore possible that some of the assumptions in Arandjevićlo's model [8] may not accurately approximate the complexity and variability of in vivo biological systems [27], which could have influenced the ability to draw conclusions. Moreover, Arandjevićlo's model [8] was specific to humeral abduction for targeting the deltoid; it is possible that this model may not translate to the use of external momentum in other joint actions and skeletal muscles. Alternatively, even though our study had sufficient statistical power to detect probabilistic differences between conditions with reasonable confidence, we cannot rule out the possibility of a type II error. Thus, replication of our methods as well as investigation of the use of external momentum in other muscles is required to draw stronger inferences on the topic.

As expected, volume load was substantially greater when employing external momentum, with weekly values generally more than double that of STRICT. Volume load has been proposed to be a contributing factor in hypertrophy [28], although this theory remains controversial [29]. On the surface, our results would seem to refute the effects of volume load on muscle development. However, given that the use of external momentum involves body segments other than the agonists, it is likely that some, if not much, of the muscular stress during training was redirected away from the target musculature. Thus, no strong conclusions can be drawn in this regard.

Of note, volume load continued to increase over the course of the first 7 weeks of the study for both conditions but decreased precipitously in the final week. The volume load drop-off can largely be attributed to the need for several of the participants to post-test before they completed their final training session due to scheduling conflicts and the impending holiday break.

From a practical standpoint, our findings can be interpreted in several ways. On one hand, the lack of difference in measures of hypertrophy between conditions conflicts with the claim that strict technique is crucial to optimizing muscle development [4]. This could be taken to mean that trainees can simply focus on lifting weights with little regard to generally accepted kinematic principles. Conceivably, the ability to use heavier loads when performing cheat repetitions may offset the dispersion of forces to other body segments, ultimately inducing similar levels of mechanical tension in the target muscles as when training with strict technique. If true, this would help to explain the similar adaptations between conditions. We only measured hypertrophy of the upper arm muscles, but it is possible that other muscles involved in the CHEAT condition also may have hypertrophied from the ancillary stress. Future studies should investigate the effect of external momentum on adaptations of non-target muscles to determine if this strategy may represent a time-efficient approach for overall muscle development.

On the other hand, using external momentum throughout a training program may increase injury risk to soft tissue structures including muscles, tendons and ligaments [8]. Direct evidence investigating the effects of technique on injury rate remains scant due to the inherent issues associated with objectively investigating the topic. While no injuries were reported during the course of our study, the 8-week interventional period and limited number of participants may have been insufficient to adequately assess the topic. Although speculative, continually subjecting soft tissues to excessive external momentum could be deleterious to these structures. Factors such as the amount of external momentum used during exercise performance and the specific body segments involved (e.g., spine, hips, etc.) may play a role in the associated risk of the strategy. Thus, trainees should take into account the potential increased injury risk from a cost-benefit standpoint when deciding how to perform a given exercise.

While the present study provides novel insights into the effects of resistance training techniques on measures of muscle development, there are several limitations that must be considered when drawing practical inferences on the topic. First and foremost, this was a proof-of-principle study designed to isolate the effects of external momentum on muscular development. To exert maximal control over the training stimulus to the biceps and triceps, we limited exercise selection to elbow flexion and elbow extension as the performance of other upper body exercises (e.g., chest presses, rows, etc.) would have directly influenced hypertrophy of the target muscles. This necessitated the use of untrained individuals since those engaged in regular RT likely would not have consented to only perform exercises for the arms over the 8-week intervention. Therefore, our findings cannot necessarily be extrapolated to those with RT experience; future research should investigate the topic in this population under more ecologically valid protocols. Second, the CHEAT condition used external momentum throughout all repetitions. Conceivably, there may be a benefit to employing external momentum after performing strict repetitions at or close to failure as often performed by bodybuilders. This would essentially be a form of training “beyond” failure, which has been shown to be effective via the extended use of partial repetitions at longer muscle lengths after training to fatigue with a full range of motion [30]. This hypothesis warrants future investigation. Third, it was difficult to standardize form in CHEAT; therefore, we cannot rule out the possibility that between-participant differences in the amount of momentum and the kinematics associated with performance in this condition may have influenced results. Finally, our results are specific to hypertrophy of the elbow flexors and extensors when performing arm curls and triceps pushdowns; the findings cannot necessarily be extrapolated to multi-joint movements and other muscle groups.

Conclusion

The use of external momentum during single-joint RT of the upper extremities neither helped nor hindered hypertrophy of the target muscles. These results were observed even though the CHEAT condition performed approximately double the volume load of the STRICT condition. The potential increased injury risk associated with persistent use of excessive external momentum requires consideration when deciding on technique for a given exercise. Future research should investigate the use of external momentum to extend sets after fatiguing muscles with strict form, as well as assessing its effects in multi-joint exercises and with other muscle groups especially in resistance trained populations.

Contributions

BJS and PAK conceived of the idea for the study. BJS, FA, PAK, MW, PS and AP designed the methodology for the study. FA, AP, and AE assisted with data acquisition. PAS conducted the statistical analysis. All authors critically interpreted the data, drafted and/or revised the article, and approved the final version of the manuscript draft.

Conflict of interest

BJS formerly served on the scientific advisory board for Tonal Corporation, a manufacturer of fitness equipment. All other authors report no competing interests with the content of this manuscript.

Acknowledgements

We are grateful to Jean Rojas for his assistance in carrying out data collection. We also wish to thank Greg Nuckols for providing the use of the MacroFactor software platform for nutritional tracking. AE gratefully acknowledges the support by the Fulbright U.S. Student Program - Doctoral Dissertation Research Award, which is sponsored by the U.S. Department of State and Brazilian Fulbright Commission.

Funding information

This study was not funded.

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/jxaqn/files/osfstorage*

REFERENCES

1. Schoenfeld BJ. The mechanisms of muscle hypertrophy and their application to resistance training. *J Strength Cond Res*. 2010;24(10):2857–2872. doi: 10.1519/JSC.0b013e3181e840f3.

2. Robinson ZP, Pelland JC, Remmert JF, et al. Exploring the dose-response relationship between estimated resistance training proximity to failure, strength gain, and muscle hypertrophy: A series of meta-regressions. *Sports Med*. 2024. doi: 10.1007/s40279-024-02069-2.

3. Schoenfeld BJ, Ogborn D, Krieger JW. Dose-response relationship between weekly resistance training volume and increases in muscle mass: A systematic review and meta-analysis. *J Sports Sci*. 2017;35(11):1073–1082. doi: 10.1080/02640414.2016.1210197.

4. Androulakis Korakakis P, Wolf M, Coleman M, et al. Optimizing resistance training technique to maximize muscle hypertrophy: A narrative review. *J Funct Morphol Kinesiol*. 2023;9(1):9. doi: 10.3390/jfmk9010009. doi: 10.3390/jfmk9010009.

5. Kassiano W, Costa B, Kunevaliki G, et al. Greater gastrocnemius muscle hypertrophy after partial range of motion training performed at long muscle lengths. *J Strength Cond Res*. 2023;37(9):1746–1753. doi: 10.1519/JSC.0000000000004460.

6. Pearson J, Wadhi T, Barakat C, et al. Does varying repetition tempo in a single-joint lower body exercise augment muscle size and strength in resistance-trained men? *J Strength Cond Res*. 2022;36(8):2162–2168. doi: 10.1519/JSC.0000000000003953.

7. Nunes JP, Costa BDV, Kassiano W, et al. Different foot positioning during calf training to induce portion-specific gastrocnemius muscle hypertrophy. *J Strength Cond Res*. 2020;34(8):2347–2351. doi: 10.1519/JSC.0000000000003674.

8. Arandjelović O. Does cheating pay: The role of externally supplied momentum on muscular force in resistance exercise. *Eur J Appl Physiol*. 2013;113(1):135–145. doi: 10.1007/s00421-012-2420-y.

9. Wolf M, Androulakis-Korakakis P, Fisher J, et al. Partial vs full range of motion resistance training: A systematic review and meta-analysis. *International Journal of Strength and Conditioning.* 2023;2(3):1.

10. Wang F, Gelfand AE. A simulation-based approach to bayesian sample size determination for performance under a given model and for separating models. *Statistical Science*. 2002;1:193–208.

11. Schad DJ, Nicenboim B, Bürkner P, Betancourt M, Vasishth S. Workflow techniques for the robust use of bayes factors. *Psychol Methods*. 2023;28(6):1404–1426. doi: 10.1037/met0000472.

12. Swinton PA, Burgess K, Hall A, et al. Interpreting magnitude of change in strength and conditioning: Effect size selection, threshold values and bayesian updating. *J Sports Sci*. 2022;40(18):2047–2054. doi: 10.1080/02640414.2022.2128548.

13. Swinton PA, Murphy A. Comparative effect size distributions in strength and conditioning and implications for future research: A meta-analysis. *SportRxiv*. 2022:DOI: 10.51224/SRXIV.202.

14. Burke R, Piñero A, Coleman M, et al. The effects of creatine supplementation combined with resistance training on regional measures of muscle hypertrophy: A systematic review with meta-analysis. *Nutrients*. 2023;15(9):2116. doi: 10.3390/nu15092116. doi: 10.3390/nu15092116.

15. Baechle TR, Earle RW, eds. *Essentials of strength training and conditioning.* 3rd ed. Champaign, IL: Human Kinetics; 2008.

16. National Strength & Conditioning Association. *Exercise technique manual for resistance training.* 4th ed. Champaign, IL: Human Kinetics; 2022.

17. Helms E, Fitschen PJ, Aragon A, Cronin J, Schoenfeld BJ. Recommendations for natural bodybuilding contest preparation: Resistance and cardiovascular training. *J Sports Med Phys Fitness*. 2014. doi: R40Y9999N00A140056 [pii].

18. Coleman M, Burke R, Benavente C, et al. Supervision during resistance training positively influences muscular adaptations in resistance-trained individuals. *J Sports Sci*. 2023;41(12):1207–1217. doi: 10.1080/02640414.2023.2261090.

19. Nunes JP, Blazevich AJ, Schoenfeld BJ, et al. Determining changes in muscle size and architecture after exercise training: One site does not fit all. *J Strength Cond Res*. 2024;38(4):787–790. doi: 10.1519/JSC.0000000000004722.

20. Ogasawara R, Thiebaud RS, Loenneke JP, Loftin M, Abe T. Time course for arm and chest muscle thickness changes following bench press training. *Interventional Medicine and Applied Science*. 2012;4(4):217–220.

21. van de Schoot R, Depaoli S, King R, et al. Bayesian statistics and modelling. *Nature Reviews Methods Primers*. 2021;14(1):1–26.

22. Bland JM, Altman DG. Comparisons against baseline within randomised groups are often used and can be highly misleading. *Trials*. 2011;12:264–264. doi: 10.1186/1745-6215-12-264.

23. Magezi DA. Linear mixed-effects models for within-participant psychology experiments: An introductory tutorial and free, graphical user interface (LMMgui). *Front Psychol*. 2015;6:2. doi: 10.3389/fpsyg.2015.00002.

24. Bürkner P. Brms: An R package for bayesian multilevel models using stan. *J Stat Softw*. 2017;80(1):1–28.

25. Depaoli S, van de Schoot R. Improving transparency and replication in bayesian statistics: The WAMBS-checklist. *Psychol Methods*. 2017;22(2):240–261. doi: 10.1037/met0000065.

26. Hyldahl RD, Chen TC, Nosaka K. Mechanisms and mediators of the skeletal muscle repeated bout effect. *Exerc Sport Sci Rev*. 2017;45(1):24–33. doi: 10.1249/JES.0000000000000095.

27. Hicks JL, Uchida TK, Seth A, Rajagopal A, Delp SL. Is my model good enough? best practices for verification and validation of musculoskeletal models and simulations of movement. *J Biomech Eng*. 2015;137(2):020905. doi: 10.1115/1.4029304.

28. Nóbrega SR, Scarpelli MC, Barcelos C, Chaves TS, Libardi CA. Muscle hypertrophy is affected by volume load progression models. *J Strength Cond Res*. 2022;Published ahead-of-print(doi: 10.1519/JSC.0000000000004225).

29. Hammert WB, Kataoka R, Yamada Y, et al. Progression of total training volume in resistance training studies and its application to skeletal muscle growth. *Physiol Meas*. 2024;45(8):10.1088/1361–6579/ad7348. doi: 10.1088/1361-6579/ad7348.

30. Larsen S, Swinton PA, Sandberg NØ, et al. Resistance training beyond momentarily failure: The effects of lengthened supersets on muscle hypertrophy in the gastrocnemius. *SportRχiv*. . doi: https://doi.org/10.51224/SRXIV.414.