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INTER-INDIVIDUAL VARIABILITY IN STRENGTH ADAPTATIONS TO A 12-WEEK STANDARDIZED RESISTANCE-TRAINING PROGRAM: A PILOT STUDY

INTERINDIVIDUALNA VARIJABILNOST U PRILAGODBAMA SNAGE NAKON 12-TJEDNOG STANDARDIZIRANOG PROGRAMA TRENINGA SNAGE: PILOT-STUDIJA

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ABSTRACT

Inter-individual variability in adaptations to resistance training is a well-documented and expected phenomenon, particularly in previously untrained individuals. Consequently, the present investigation was conceived as a pilot study, with the primary aim of characterizing the magnitude and pattern of individual strength responses under tightly standardized training and nutritional conditions.

Five healthy adults with no previous exposure to structured resistance training - three males and two females from 25 to 30 years with an average body mass index of 25 participated in this research. The training program consisted of four weekly sessions with an upper/lower body split, performed on commercial machines and free weights. All sessions were supervised by the same researcher to minimize execution-related variability. Additionally, all participants adhered to a eucaloric diet with a standardized protein intake (1.8 g/kg body mass) to reduce potential nutritional confounding. Muscular strength was assessed with six-repetition maximum (6RM) testing across 11 exercises at baseline and after 12 weeks of training.

As anticipated, all participants exhibited meaningful increases in strength; however, the magnitude of these improvements differed substantially between individuals. Notably, inter-individual variability was most pronounced in single-joint isolation exercises, whereas compound lower-body movements demonstrated more homogeneous strength gains across participants. As a pilot investigation, the

SAŽETAK

Interindividualna varijabilnost u prilagodbama na trening s otporom dobro je dokumentiran i očekivan fenomen, osobito kod prethodno netreniranih osoba. Posljedično, ovo je istraživanje osmišljeno kao pilot-studija, s primarnim ciljem karakterizacije veličine i obrasca individualnih odgovora snage u uvjetima strogo standardiziranog treninga i prehrane.

U istraživanju je sudjelovalo pet zdravih odraslih osoba bez prethodnog iskustva sa strukturiranim treningom s otporom – tri muškarca i dvije žene u dobi od 25 do 30 godina, s prosječnim indeksom tjelesne mase od 25. Program treninga sastojao se od četiri tjedna treninga s podjelom na gornji i donji dio tijela, provedenog na komercijalnim spravama i sa slobodnim utezima. Sve treninge nadzirao je isti istraživač kako bi se smanjila varijabilnost povezana s izvođenjem vježbi. Dodatno, svi su sudionici slijedili eukaloričnu prehranu sa standardiziranim unosom proteina (1,8 g/kg tjelesne mase) kako bi se smanjio mogući nutritivni utjecaj. Mišićna snaga procijenjena je testiranjem šest-ponavljajućeg maksimuma (6RM) u 11 vježbi na početku istraživanja i nakon 12 tjedana treninga.

Kako je i očekivano, svi su sudionici pokazali značajna povećanja snage; međutim, veličina tih poboljšanja znatno se razlikovala među pojedincima. Posebno je izražena interindividualna varijabilnost uočena kod jednozglobnih izolacijskih vježbi, dok su višezglobni pokreti donjeg dijela tijela pokazali homogenije dobitke u snazi među sudionicima. Kao pilot-istraživanje, ovi rezultati pružaju present results provide a detailed descriptive foundation for future studies aiming to explore mechanistic determinants of individual responsiveness using larger samples and inferential designs.

Keywords: *inter-individual variability, resistance training, muscular strength, training adaptations, six-repetition maximum (6RM), isolation and compound exercises*

detaljnu deskriptivnu osnovu za buduća istraživanja usmjerena na proučavanje mehanističkih odrednica individualne responzivnosti uz primjenu većih uzoraka i inferencijalnih istraživačkih dizajna.

Ključne riječi: *interindividualna varijabilnost, trening snage, mišićna snaga, adaptacije na trening, šestponavljajući maksimum (6RM), izolacijske i složene vježbe*

INTRODUCTION

Resistance training is a well-established method for improving neuromuscular function through increases in muscular strength[24]. These adaptations result from a combination of neurological and morphological changes that occur in response to mechanical loading of the musculoskeletal system[5,11,31,32]. In untrained persons, the initial increases in strength are attributed to neurological adaptations such as increased motor unit recruitment, improved synchronization, and higher firing frequency, where muscular hypertrophy emerge later in the adaptive process[7,9,29]. These neurological changes manifest within the first 2 to 4 weeks of training and play an important role in the early increases in strength[7].

Strength is a fundamental prerequisite for performing daily activities, while power is crucial for dynamic and explosive movements [1,11]. Resistance training induces neurological adaptations which result in improved motor unit recruitment, better synchronization, and increased firing frequency[4,24]. These neurological adaptations explain why in the early weeks of training, untrained people experience an increase in strength even before meaningful muscular hypertrophy occurs[20,29]. Studies using high-density surface electromyography and transcranial magnetic stimulation have shown increased corticospinal excitability, reduced intracortical inhibition, and substantial changes in motor unit behavior following short-term strength training[7,8,30]. These results show that the nervous system adapts to training stimuli, especially in people without prior experience in structured physical activity[2]. As training progresses, these neurological changes are complemented or replaced by structural adaptations such as muscle fiber hypertrophy - both myofibrillar and sarcoplasmic[13], changes in muscle architecture, and improved tendon stiffness[26].

Factors that may contribute to variability in these adaptations include genetic predisposition, baseline neuromuscular function, muscle fiber composition, hormonal status, sleep habits, psychological readiness, and nutritional status[10,18,22]. Although the present study did not directly assess neural or molecular mechanisms, these pathways are discussed to provide physiological context for the magnitude and variability of the observed strength adaptations. Particular attention should be given to dietary control, as caloric surplus or deficit can modify training-induced adaptations[27]. For this reason, many studies aim to isolate the effects of resistance training often implement eucaloric dietary protocols[14,15]. Machine-based exercises and free weights produce different levels of muscle activation and stability demands[25]. Identical equipment is important for standardizing mechanical loading and minimizing variability resulting from differences in movement patterns and resistance profiles[25]. Cable systems provide continuous tension and a stable linear load that depends solely on the moment arm of the human anatomy. Bands and machines have different resistance profiles, ranging from being heaviest at the beginning to heaviest at the end of the movement. The application of these different tools enables a gradual progression from controlled and fixed conditions toward more complex, dynamic movements, thereby improving motor coordination, stability, and strength[3].

Also, genetic factors are important for the individual response to resistance training, with variability observed in the magnitude of strength and muscle mass gains across different individuals[17]. The expression of specific microRNA molecules is associated with heightened skeletal muscle responsiveness to training stimuli, suggesting the possibility of a molecular predisposition for more efficient adaptation[6]. Gene polymorphisms such as those in ACE and ACTN3 have been identified as important biological determinants of explosive strength and performance in high-intensity activities[19].

Standardization of dietary intake is an important component when examining adaptations to resistance training, as protein intake and caloric balance directly affect muscle protein synthesis and hypertrophy [27]. Gains in strength and muscle mass have been shown to be greater in groups with higher protein intake, even when training protocols are identical[16], stressing the importance of nutritional control in interpreting adaptations [21]. A regular intake of 20-25 g of protein per meal optimizes muscle protein synthesis, and consuming protein within 1-2 hours post-exercise further improves activation of anabolic pathways[21,27,28].

Subjects and methods

Five healthy adults (3 males, 2 females; 25-30 years) without prior structured resistance-training experience were recruited. Inclusion criteria required absence of musculoskeletal, neurological, metabolic, or endocrine disorders, BMI within clinically normative ranges, no use of ergogenic, anabolic, or pharmacological agents capable of affecting neuromuscular adaptation and full availability to comply with the 12-week supervised protocol. All baseline characteristics, including anthropometrics, training history, and health status, were documented to ensure homogeneity of the sample.

Research design

This study employed a prospective, exploratory interventional design to examine inter-individual variability in strength adaptations following a 12-week standardized resistance-training program in previously untrained adults. The intervention was implemented under tightly controlled conditions, including standardized exercise selection, training frequency and progression, continuous supervision, and controlled dietary intake, in order to reduce external sources of variability. Testing procedures and training sessions were conducted using uniform equipment and protocols to ensure consistency across participants. The study was designed to enable a detailed descriptive assessment of individual response patterns rather than population-level inference.

Training intervention

A highly standardized 12-week hypertrophy-oriented training program was implemented, consisting of four weekly sessions arranged in an upper/lower body split (Monday-Tuesday; Thursday-Friday). All sessions were fully supervised by the principal investigator to minimize deviations in execution, tempo, range of motion, and effort level, but also to be consistent with volume and frequency[31].

The intervention consisted of 11 multi-joint and isolation exercises, performed on identical commercial machines and free-weight equipment to avoid mechanical variability. The exercise order, machine type, and loading characteristics were fixed across the entire intervention. A double-progression model was used within a 6-10 repetition range. Participants increased load when achieving ≥10 repetitions to maintain effort within the prescribed zone and ensure continuous progressive overload. From week 2 onward, all working sets were performed to volitional failure, aligning with evidence-based hypertrophy recommendations.

Standardization of external variables

All sessions were conducted at the same time of day, in the same facility, with identical environmental conditions. Warm-up protocols, rest intervals for the testing (2–3 min between sets; up to 10 min between exercises), and movement tempo were precisely controlled.

Nutritional control

To eliminate dietary confounding, participants followed a strictly controlled, individualized eucaloric diet throughout the intervention. Energy intake was calculated from pre-intervention food-intake logs and adjusted (+300 kcal/day) to account for training demands while maintaining weight stability. Daily macronutrient targets were standardized: Protein: 1.8 g/kg body mass, fat: 1.0 g/kg body mass, carbohydrates: remaining caloric needs. All participants used the same brand of whey protein; no other performance-improving supplements were permitted. Compliance was verified through daily logs, weekly check-ins, and continuous body-mass monitoring.

Biomechanical and equipment standardization

All resistance exercises were performed using identical plate-loaded machines, weight-stack machines, cables, and branded dumbbells. Joint angles, moment arms, and line-of-force characteristics were kept consistent to reduce equipment-related variability. Machine settings (seat height, backrest, handle positions) were fixed and recorded for each participant.

Monitoring of external factors

Sleep quantity/quality, psychological readiness, and general well-being were monitored weekly with structured self-report interviews to control for factors known to influence training performance.

Strength assessment protocol

Muscular strength was evaluated using a 6-repetition maximum (6RM) assessment across all 11 exercises pre- and post-intervention. The same machines, loads, procedures, and supervisory personnel were used at both assessments to ensure maximal test–retest reliability. Testing included a standardized 5-minute cycling warm-up, two submaximal familiarization sets per exercise, two maximal attempts to determine 6RM with ≥5 minutes rest between attempts, fixed testing order and same time-of-day testing for both assessment points. Upper-body and lower-body assessments were conducted on separate days to avoid acute fatigue interference. A 6RM was defined as the maximal load lifted six times through a strict, full range of motion without compensatory movement or external assistance. This protocol was intended to provide a reliable, descriptive measure of individual strength responses under tightly standardized conditions.

Statistical analysis

Given the very small sample size (n = 5), all analyses were conducted with a descriptive and exploratory focus, emphasizing individual response patterns rather than population-level inference. Absolute and relative changes in strength (kg and %) were calculated for all exercises to document pre–post differences at both the individual and group level.

Inter-individual variability was described using standard deviation, coefficient of variation (CV%), and Cohen's *d*. These metrics were included solely as descriptive indices to illustrate within-sample change and dispersion and were not interpreted as stable estimates of effect magnitude or used for inferential comparisons. Inferential statistical testing was intentionally avoided, as the primary aim of the study was to characterize variability in strength responses under standardized conditions rather than to test hypotheses or estimate generalizable effects.

All analyses followed commonly reported descriptive procedures in resistance-training research, and results are presented in detail in the accompanying tables and figures.

RESULTS

Table 1 shows the six-repetition maximum (6RM) strength values prior to the start of the intervention for each participant across all selected resistance exercises. These values serve as descriptive baseline measures of individual strength levels before the implementation of the training program and illustrate the heterogeneity in initial performance within the small sample size.

Table 2 shows the six-repetition maximum (6RM) strength values following completion of the intervention,

Table 1. 6 Repetition maximum in kilograms pre-intervention
Tablica 1. Šestponavljajući maksimum (6RM) u kilogramima prije intervencije

Exercise	P1	P2	P3	P4	P5
Leg extension	43.5	49	33.5	23.5	29
Hack squat	20	40	30	5	20
Seated leg curl	39	60	29.5	19.5	23.5
Leg press	40	39	50	20	30
Standing calf raises	35	90	60	40	40
Chest press	10	25	20	10	10
Chest supported machine row	15	25	20	5	12.5
Lat pulldown	25	50	30	20	25
Machine shoulder press	10	20	15	5	10
Dumbel preacher curls	5	12.5	7.5	4	4
Cable pressdown	12.5	20	15	7.5	5

Table 2. 6 Repetition maximum in kilograms post intervention
Tablica 2. Šestponavljajući maksimum (6RM) u kilogramima nakon intervencije

Exercise	P1	P2	P3	P4	P5
Leg extension	93.5	99	69	49.5	53.5
Hack squat	105	120	70	65	70
Seated leg curl	83.5	89	63.5	43.5	49
Leg press	120	93.5	120	80	100
Standing calf raises	140	160	120	100	100
Chest press	60	80	50	25	30
Chest supported machine row	45	60	35	20	25
Lat pulldown	50	80	50	45	50
Machine shoulder press	30	40	30	15	20
Dumbel preacher curls	15	20	12.5	10	10
Cable pressdown	30	40	25	20	20

showing improvements in every participant. All participants demonstrated increases in strength across all exercises. These post-intervention values are presented descriptively to document individual changes relative to baseline.

Table 3 shows the average percentage increase in strength for each exercise, along with the standard deviation, which reflects the inter-individual variability resulting from the training intervention. Given the untrained status of participants, large relative percentage changes are expected and are strongly influenced by low baseline values. Accordingly, percentage changes are reported for descriptive purposes only and should not be interpreted as indicators of exceptional adaptive capacity or comparative responsiveness between exercises.

Table 4. presents the mean absolute increase in strength (kg) and corresponding standard deviation across participants for each exercise. Cohen's *d* values are reported as descriptive indices of pre–post change. Given the very small sample size, these effect size estimates are highly sensitive to individual variability and should not be interpreted as stable indicators of effect magnitude or used for comparisons between exercises.

Figure 1 depicts standardized descriptive estimates of pre–post strength changes across exercises following the 12-week intervention. Large magnitudes of change were observed, consistent with expected adaptations in previously untrained individuals. These values are presented for descriptive comparison only and reflect both training-induced adaptations and inter-individual heterogeneity in baseline strength and early neuromuscular responsiveness.

Figure 2 Figure 2 presents the coefficient of variation for strength changes across exercises, illustrating differences in response dispersion under identical training conditions. In the present pilot sample, CV% values should be viewed as descriptive indicators rather than measures of response consistency or uniformity.

Table 3. Average percentage increase in strength and inter-individual variability.
Tablica 3. Prosječno postotno povećanje snage i interindividualna varijabilnost

Exercise	Average %	Standard deviation in %
Leg extension	103.61	11.74
Hack squat	441.66	437.48
Seated leg curl	101.85	30.36
Leg press	202.61	67.65
Standing calf raises	155.55	86.69
Chest press	244	146.38
Chest supported machine row	163	89.97
Lat pulldown	90.33	26.78
Machine shoulder press	140	54.77
Dumbel preacher curls	105.33	43.49
Cable pressdown	154.66	89.74

Table 4. Average strength increase, standard deviation, and Cohen's d (in kilograms).
Tablica 4. Prosječno povećanje snage, standardna devijacija i Cohenov d (u kilogramima)

Exercise	Average	Standard deviation	Cohen's d (kg)
Leg extension	37.2	12.42	2.99
Hack squat	63	19.23	3.27
Seated leg curl	31.4	8.27	3.79
Leg press	66.9	9.9	6.75
Standing calf raises	71	19.49	3.64
Chest press	34	17.81	1.90
Chest supported machine row	21.5	10.24	2.09
Lat pulldown	25	3.53	7.07
Machine shoulder press	15	5	3
Dumbel preacher curls	6.9	1.94	3.53
Cable pressdown	15	3.95	3.79

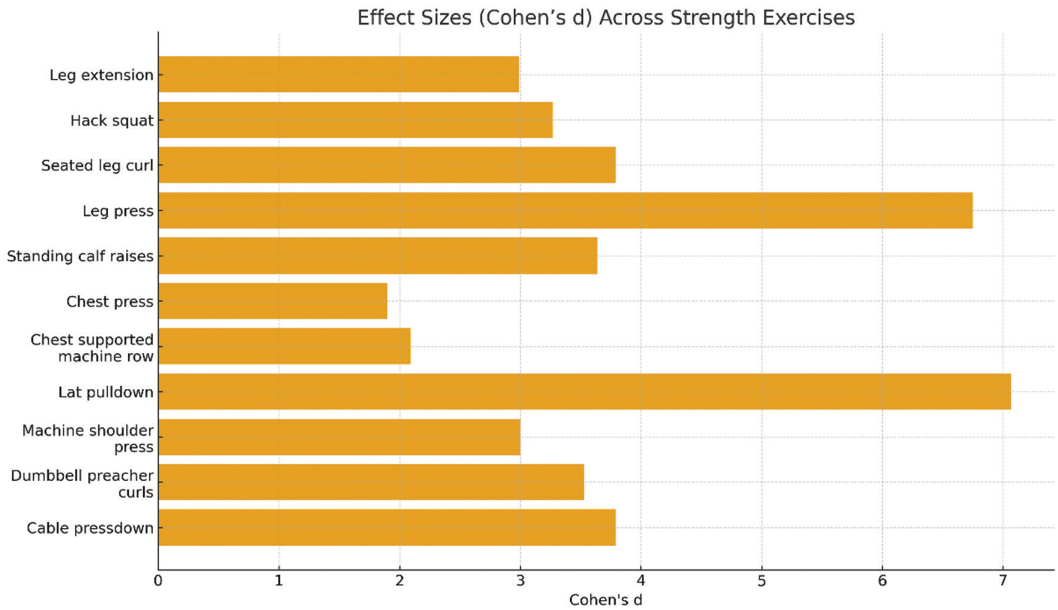

Figure 1. Effect sizes (Cohen's d) for strength adaptations across resistance exercises.
Slika 1. Veličine učinka (Cohenov d) za prilagodbe snage kroz različite vježbe s otporom

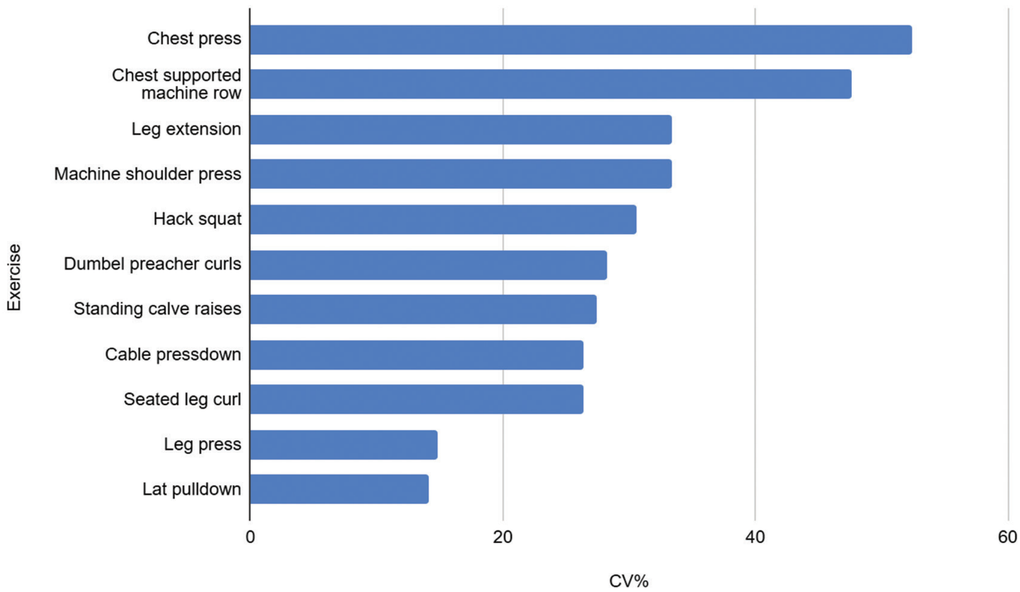

Figure 2. Coefficient of variation of strength improvements across different exercises.
Slika 2. Koeficijent varijacije poboljšanja snage kroz različite vježbe

Table 5. Individual absolute (kg) and relative (%) changes in total strength across the 11 exercises.
Tablica 5. Individualne apsolutne (kg) i relativne (%) promjene ukupne snage kroz 11 vježbi

Participant	Total strength (kg) pre	Total strength (kg) post	Absolute change (kg)	Relative change (%)
P1	270.5	642.5	+372.0	+137.6%
P2	432.5	796.5	+364.0	+84.2%
P3	339.5	587.5	+248.0	+73.1%
P4	165.5	422.5	+257.0	+155.2%
P5	220.5	457.5	+237.0	+107.5%

Table 5 presents individual pre–post changes in cumulative strength output (sum of 6RM values across all exercises), expressed as both absolute (kg) and relative (%) changes. These data illustrate the divergence of individual response trajectories under tightly standardized training and nutritional conditions and form the primary descriptive evidence of inter-individual variability in this pilot investigation.

DISCUSSION

This study aimed to evaluate individual responses to a standardized resistance training program targeting hypertrophy in previously untrained participants. Over the 12-week intervention period, all participants demonstrated improvements in 6RM strength across upper- and lower-body exercises. Despite identical training conditions, supervision, and dietary protocols, the magnitude of these improvements varied considerably among participants, indicating the presence of inter-individual variability even under tightly controlled conditions.

Across exercises, the dispersion of individual responses differed, as reflected by variation in CV% values. Some exercises, such as the leg press and lat pulldown, exhibited lower CV% values (14.8% and 14.1%, respectively), suggesting less dispersion of responses within the present sample. In contrast, greater dispersion was observed in exercises such as the chest press and chest-supported row (52.4% and 47.7%, respectively). In a very small sample, however, CV% values are highly sensitive to individual responses and should be interpreted descriptively rather than as indicators of response consistency or uniformity.

Differences in response dispersion across exercises may reflect a combination of factors, including task familiarity, coordination demands, and baseline performance differences. In addition, the inclusion of both male and female participants without stratified analysis may have contributed to variability in upper-body exercises, where known sex-related differences in absolute strength exist[23]. Importantly, the present data do not allow separation of sex-based effects from individual variability, and such interpretations should therefore remain cautious.

Hecksteden et al.[15] demonstrated that a considerable proportion of the variability in individual training responses can arise from normal fluctuations in performance-based testing rather than true differences in adaptive capacity. Their work emphasizes that single pre–post assessments may misclassify individuals as non-responders, which is particularly relevant for strength outcomes such as 6RM testing.

Noone et al.[22] highlight that inter-individual variation in response to the same exercise protocol results from a complex interplay of intrinsic factors (e.g., genetics, age, hormonal status) and extrinsic factors (e.g., training dose, sleep, nutrition). Their work underscores that universal exercise prescriptions may overlook individual adaptive potential, a consideration directly relevant when interpreting variability in strength outcomes such as 6RM improvements.

Harmon et al.[12] found that specific variants in CCL2 and CCR2 genes were significantly associated with both baseline muscle strength and the magnitude of strength gains following a 12-week resistance training program, indicating a genetic component to both initial strength and trainability. Their results suggest that inflammatory and muscle-repair signalling pathways may contribute to inter-individual variability in adaptation to resistance training.

Erskine et al.[10] demonstrated that after a 9-week progressive resistance training protocol, changes in muscle force, cross-sectional area and specific tension varied widely between individuals — with some showing minimal gains and others substantial improvements. Their findings support the view that inter-individual variability in strength adaptation is genuine and may arise from differences in both hypertrophy and change in intrinsic muscle quality, a concept directly relevant to our 6RM strength data.

Aslam et al.[2] report that neuromuscular adaptations to resistance training — including alterations in motor unit recruitment, neural drive, and muscle architecture — differ substantially between individuals due to factors such as training status, sex, age, and genetic predisposition. Importantly, they emphasize that these differences have practical implications for exercise prescription, highlighting that standardized training programs may not elicit optimal adaptations in all individuals and that tailoring load, volume, and progression to the individual's neuromuscular characteristics can enhance strength gains. These insights are directly relevant to the present study, as they provide a mechanistic and practical framework for understanding the substantial inter-individual variability observed in 6RM strength improvements.

Limitations

Although this study employed a non-randomized design, this approach was intentionally chosen to maintain strictly controlled and uniform training and dietary conditions, allowing for focused observation of individual response patterns. Nevertheless, the small sample size (n = 5) substantially limits generalizability, and all findings should be interpreted as exploratory.

The inclusion of both men and women without stratified analysis may have contributed to baseline differences in strength and influenced descriptive variability metrics, particularly in upper-body exercises. Additionally, the 12-week intervention primarily captures early-phase strength adaptations and may not reflect long-term response patterns that could emerge over extended training periods.

While continuous supervision maximized adherence and effort, such conditions may not reflect real-world training environments, particularly in recreational, clinical, or injured populations. Factors such as pain, limited range of motion, reduced motivation, and psychological barriers may substantially influence training outcomes in applied settings. Furthermore, findings derived from young, healthy participants cannot be directly extrapolated to older adults, whose recovery capacity, hypertrophic potential, neuromuscular plasticity, and injury risk differ markedly.

CONCLUSION

This study provides preliminary insight into the extent of inter-individual variability in strength adaptations following a 12-week resistance training program designed to promote hypertrophic adaptations in previously untrained adults. By strictly controlling external variables—including dietary intake, exercise equipment, training supervision, and program structure—the intervention sought to minimize external sources of variation and allow descriptive observation of individual response patterns under standardized conditions.

All participants demonstrated improvements in 6RM strength across the intervention period. Consistent with expectations in untrained individuals, these gains were generally more pronounced in multi-joint lower-body exercises, reflecting early-phase strength adaptations. However, the magnitude of improvement varied substantially between individuals, even under identical training and dietary conditions, highlighting the presence of inherent inter-individual variability in response to resistance training.

Notably, certain single-joint exercises, such as triceps extensions and preacher curls, exhibited smaller or more variable improvements in some participants. These exercise-specific differences suggest that early strength adaptations may not manifest uniformly across all movement patterns. In the present pilot sample, such variability may reflect differences in baseline performance, task familiarity, and coordination demands, although mechanistic explanations cannot be determined from the available data.

Although the small sample size and the absence of sex-stratified analyses limit generalizability, the findings underscore the importance of setting realistic expectations for strength development in untrained individuals. Even under highly controlled and supervised conditions, individual responses to resistance training may differ markedly. This variability should be considered by coaches, clinicians, and practitioners when interpreting short- and long-term training outcomes and when designing individualized progression strategies.

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