Turkish Journal of Sports Medicine
Spor Hekimliği Dergisi

Turk J Sports Med. DOI: 10.47447/tjsm.0948

RESEARCH ARTICLE / ARAŞTIRMA MAKALESI

The Effect of Acute Multiple Set Complex Training with Different Intensities on Jump Performance in Trained Women

Antrenmanlı Kadınlarda Farklı Şiddette Akut Çoklu Set Kompleks Antrenman Uygulamasının Sıçrama Performansına Etkisi

Çisil Sönmez[1], Mehmet Gören Köse[1], Taylan Aytaç[2], Ayşe Kin İşler[1]

[1]*Department of Exercise and Sport Sciences, Faculty of Sport Sciences, Hacettepe University, Ankara, Türkiye*
[2]*Department of Exercise and Sport Sciences, Faculty of Health Sciences, Başkent University, Ankara, Türkiye*

ABSTRACT

Objective: Complex training (CT) involves performing resistance exercises of maximal or high intensity before a lighter resistance plyometric movement with similar biomechanical properties. This study aimed to investigate the effect of different intensities of acute multi-set CT on counter movement jump (CMJ) height in trained female athletes.

Materials and Methods: Fourteen trained female athletes (age = 25.2 ± 5.2 years) with a regular menstrual cycle (26.1 ± 1.8 days) and experience in strength and plyometric training (3.79 ± 1.57 years) were randomized to two different intensities (90% 1RM and 65% 1RM) at the same time of day (15:30–17:00 h), with a 48-hour interval, during the late follicular phase of their menstrual cycle (days 7–12). CT was performed in 3 sets, each consisting of 3 repetitions of back squats at the specified intensity, followed by 3 countermovement jumps (CMJ) as explosive exercises. Participants performed 2 CMJs before CT, and the acute effect of two different CT intensities on CMJ height was assessed with CMJ tests conducted at 1 and 3 min after 3 sets of CT. Data were analyzed using a 2 × 3 repeated-measures two-way ANOVA, with intensity (65% vs. 90%) and time (pre, 1 min, and 3 min post) as within-subject factors.

Results: The results indicated no significant main effect of intensity on CMJ height when values were averaged across time points ($F_{(1,13)}$ = 3.23; p = 0.096; ηp^2 = 0.199). The intensity × time interaction was also not statistically significant ($F_{(2,12)}$ = 1.088; p = 0.352; ηp2 = 0.077). However, a significant main effect of time on CMJ height was observed ($F_{(2,12)}$ = 4.638; p = 0.019; ηp^2 = 0.263).

Conclusion: The main finding of this study was that CMJ height did not change significantly in trained female athletes following CT at different intensities. However, CMJ height was significantly lower at 1 min post-CT compared with baseline. No significant differences were observed between baseline and 3 min post-CT, or between the 1- and 3-min post-CT measurements.

Keywords: Complex training, post-activation performance enhancement, plyometric exercise, female athletes

ÖZ

Amaç: Kompleks antrenman (KA), benzer biyomekanik özelliklere sahip daha hafif dirençli bir pliometrik hareket gerçekleştirmeden önce maksimum veya yüksek şiddetli direnç egzersizlerini içerir. Bu çalışmanın amacı antrenmanlı kadın sporcularda farklı şiddette akut çoklu set KA uygulamasının CMJ yüksekliği üzerine etkisinin incelenmesidir.

Gereç ve Yöntem: Düzenli menstrüel döngüye sahip (26,1 ± 1,8 gün) ve kuvvet ile pliometrik antrenman deneyimi bulunan (3,79 ± 1,57 yıl) 14 gönüllü kadın sporcu (yaş: 25,2 ± 5,2 yıl) çalışmaya dahil edilmiştir. Tüm testler menstrüel döngünün geç foliküler fazında (7–12. gün), günün aynı saatinde (15:30–17:00) ve 48 saat arayla, 1TM'nin %65'i ve %90'ı iki farklı şiddette randomize bir düzende gerçekleştirilmiştir. Kompleks antrenman protokolü, 3 tekrar sırt skuat egzersizini takiben uygulanan 3 CMJ egzersizinden oluşmuş ve toplam 3 set olarak uygulanmıştır. Katılımcılar her KA uygulaması öncesinde iki referans CMJ gerçekleştirmiş; KA uygulamasının ardından 1. ve 3. dakikada tekrarlanan CMJ

Received: 06.07.2025 · **Accepted:** 13.01.2026 · **Published:** 21.07.2026

Correspondence: Ayşe Kin İşler · Department of Exercise and Sport Sciences, Faculty of Sport Sciences, Hacettepe University, Ankara, Türkiye · aysekin@gmail.com

Cite as: Sönmez Ç, Köse MG, Aytaç T, Kin İşler A. The effect of acute multiple set complex training with different intensities on jump performance in trained women. *Turk J Sports Med*. 2026; https://doi.org/10.47447/tjsm.0948

testleri ile KA'nın CMJ yüksekliği üzerindeki akut etkisi değerlendirilmiştir. Veriler, şiddet (65% ve 90%) ve zaman (önce, 1. ve 3.dk) faktörlerini içeren 2 × 3 tekrarlı ölçümlü çift yönlü varyans (ANOVA) ile analiz edilmiştir.

Bulgular: Zaman noktaları üzerinden ortalaması alınan CMJ yüksekliği açısından, şiddetin ana etkisinin istatistiksel olarak anlamlı olmadığını göstermiştir ($F_{(1,13)}$ = 3,23; p = 0,096; ηp^2 = 0,199). Ayrıca, şiddet × zaman etkileşimi de istatistiksel olarak anlamlı bulunmamıştır ($F_{(2,12)}$ = 1,088; p = 0,352; ηp2 = 0,077). Buna karşın, zamanın ana etkisi CMJ yüksekliği üzerinde istatistiksel olarak anlamlı bulunmuştur ($F_{(2,12)}$ = 4,638; p = 0,019; ηp^2 = 0,263).

Sonuç: Bu çalışmanın temel bulgusu, antrenmanlı kadın sporcularda farklı şiddette uygulanan akut CT protokolü sonrasında CMJ yüksekliğinin anlamlı düzeyde değişmediğini göstermektedir. CMJ yüksekliği, CT sonrası 1. dakikada başlangıç değerine kıyasla istatistiksel olarak anlamlı derecede daha düşük bulunurken, CT sonrası 3. dakikada başlangıç değeri ile anlamlı bir fark göstermemiştir. Ayrıca, CT sonrası 1. ve 3. dakikada ölçülen CMJ yüksekliği arasında istatistiksel olarak anlamlı bir fark gözlenmemiştir.

Anahtar Sözcükler: Kompleks antrenman, aktivasyon sonrası performans artışı, pliometrik egzersiz, kadın sporcu

INTRODUCTION

Complex Training (CT) is a training method designed to develop both strength and power within the same session [1]. CT involves performing a heavy resistance exercise followed by a lighter plyometric movement that shares similar biomechanical characteristics [2]. The heavy resistance exercise, referred to as the conditioning activity (CA), combined with a plyometric exercise, forms a complex pair [3]. The performance enhancement observed in the plyometric exercise performed following the CA is explained by PAPE (Post-Activation Performance Enhancement) [4]. PAPE refers to the acute enhancement of muscle force output following a prior contractile activity and constitutes the physiological basis of CT [5]. The proposed mechanisms underlying PAPE, such as increased muscle temperature, elevated cellular water content, and enhanced neuromuscular activation, are believed to facilitate strength improvements over extended durations [4].

The magnitude of PAPE depends on the balance between fatigue and potentiation. Enhanced performance occurs when the effects of activation and potentiation outweigh fatigue [6]. This relationship is influenced by individual factors, such as athletes' physiological characteristics, training background, sex, age, muscle fiber distribution (i.e., fast- and slow-twitch fibers), maximal power, power-to-strength ratio, and overall training status [1]. Additionally, the CT intended to elicit the PAPE effect is influenced by variables such as exercise type and intensity, the number of complex pairs , and the rest intervals between sets [7]. The literature indicates that each factor plays a significant role, with the greatest PAPE effect observed following high-intensity (85-90% of 1RM (one-repetition maximum)) back squats after 3-5 min of rest [1]. High-intensity activities are more effective than low-intensity ones in activating high-threshold motor units and increasing neural firing rates [8]. For example, Fukutani et al. [9] reported that a heavy back squat protocol performed at 90% of 1RM resulted in greater improvements in jump performance compared to a protocol performed at 75% of 1RM. Similarly, a bench press CA at 87% of 1RM was more effective in enhancing subsequent upper-body ballistic performance than a ballistic bench press at 30% of 1RM [10].

The effect of PAPE also appears to depend on an individual's relative strength level [7]. Studies have shown that athletes who can back squat 1.7-2.0 times their body weight exhibit greater potentiation in vertical jump height [11]. In particular, squatting 2.0 times body weight results in a greater potentiation effect on vertical jump height [7]. Specifically, the PAPE effect is greater in strong individuals following a 1RM load (effect size; ES = 0.60 vs. 0.36), whereas submaximal loads appear to be more effective for weaker individuals (ES = 0.35 vs. 0.28). For example, fifteen elite volleyball players performed three repetitions of back squats followed by three unloaded CMJ exercises, for 10 sets at either 65% or 87% of 1RM, respectively. The control group performed ten repetitions of three CMJ sessions. Using the back squat as a CA resulted in a notable enhancement in CMJ regardless of the intensity level employed. Additionally, the increase in CMJ height of participants with greater relative strength was higher after CA was applied at 87% of 1RM [12].

When designing training programs for athletes, it is important that coaches and sports scientists consider whether the selected protocol is effective for both male and female participants [1]. One study reported that the proportion of type II muscle fibers is higher in males than in females, and that these fibers have a larger cross-sectional area in males compared to females [13]. Given that type II fibers are more likely to generate potentiation than type I fibers, force development in response to a stimulus may be greater in males than in females [13]. Nevertheless, analysis of the existing literature reveals a disparate set of findings. Some researchers reported no statistically significant differences between genders in lower extremity strength development [14]. However, other researchers reported greater strength development in males compared to females [13, 15]. In a separate study examining the impact of gender on changes in counter movement jump (CMJ) height following isometric back squat activity in trained adults, the protocol enhanced CMJ height in both females and males, with performance improvements observed at 3 min post-activation. However, a decline in performance was observed in females over the subsequent six minutes, while males maintained performance [16].

Several studies have compared the efficacy of different training methods, including resistance training, plyometric exercises, and CT protocols, in improving CMJ height [17, 18]. However, a review of the existing literature shows that studies investigating the influence of multiple sets of different-intensity exercises on strength performance in trained female athletes are scarce [12]. If such an effect can be sustained throughout an entire weight training session, it can provide a greater training stimulus [12]. This may lead to enhanced adaptation over time and, consequently, improved performance. The topic of CT and its underlying mechanism, PAPE, has been of significant interest within sports science. Moreover, the increasing number of trained female athletes in our country, as in the rest of the world, highlights the need for scientific studies focusing on trained female athletes. There is a notable gap in the scientific literature regarding the training responses and performance of females compared to males. Findings from this study will provide important contributions to training and competition planning and help maximize performance outcomes of trained female athletes, especially those involved in team and individual sports that emphasize strength and jumping performance. It also helps strength and conditioning coaches design warm-ups that can enhance sport-specific exercises (e.g., jumps and sprints) before training or recommed preload exercises during CT sessions. Therefore, this study aimed to investigate the effect of different intensities of acute multi-set CT on CMJ height in trained female athletes.

MATERIAL AND METHODS

Participants

Fourteen volunteer trained female athletes aged 19-32 years, with regular menstrual cycles (26.1 ± 1.8 days), and experience in strength and plyometric training from team sports (volleyball) and individual sports (CrossFit), participated in this study. Participants reported their menstrual cycle dates for at least three consecutive cycles prior to testing to confirm cycle regularity. The sample size for this study was calculated a priori by using the G*power program (version 3.1.9.7) (36). The alpha value (α) was set at 0.05 and the power (1-β error probability) was set at 0.80. Sample size was estimated as 15 to be sufficient for this study. Ethical approval was obtained from the university institutional ethics committee (2022/13-42), and the study was conducted in accordance with the Declaration of Helsinki (2013). Participants were provided with comprehensive information regarding the nature of the study and signed written informed consent forms. Participants were instructed to refrain from high-intensity physical activity for 24 h before testing and to avoid alcohol, coffee, or other caffeinated beverages on the night before testing.

Procedures

A randomized crossover design with one familiarization and two experimental sessions was used in this study

(Figure 1). Participants were assigned to the experimental sessions in a simple random order, and the allocation was concealed from the investigators until the beginning of each session. At least 48 h before the familiarization session, participants attended the laboratory for preparatory procedures. These procedures included anthropometric measurements, a 1RM back squat test using a plate-loaded barbell, and a CT trial.The experimental protocols consisted of CT performed at 65% and 90% of 1RM, with three sets of three CMJ. All primary tests were conducted during the late follicular phase (days 6-12) to minimize potential interference from other menstrual cycle phases (19). Each participant was tested at the same time of the day to control for the circadian rhythm effect (4).

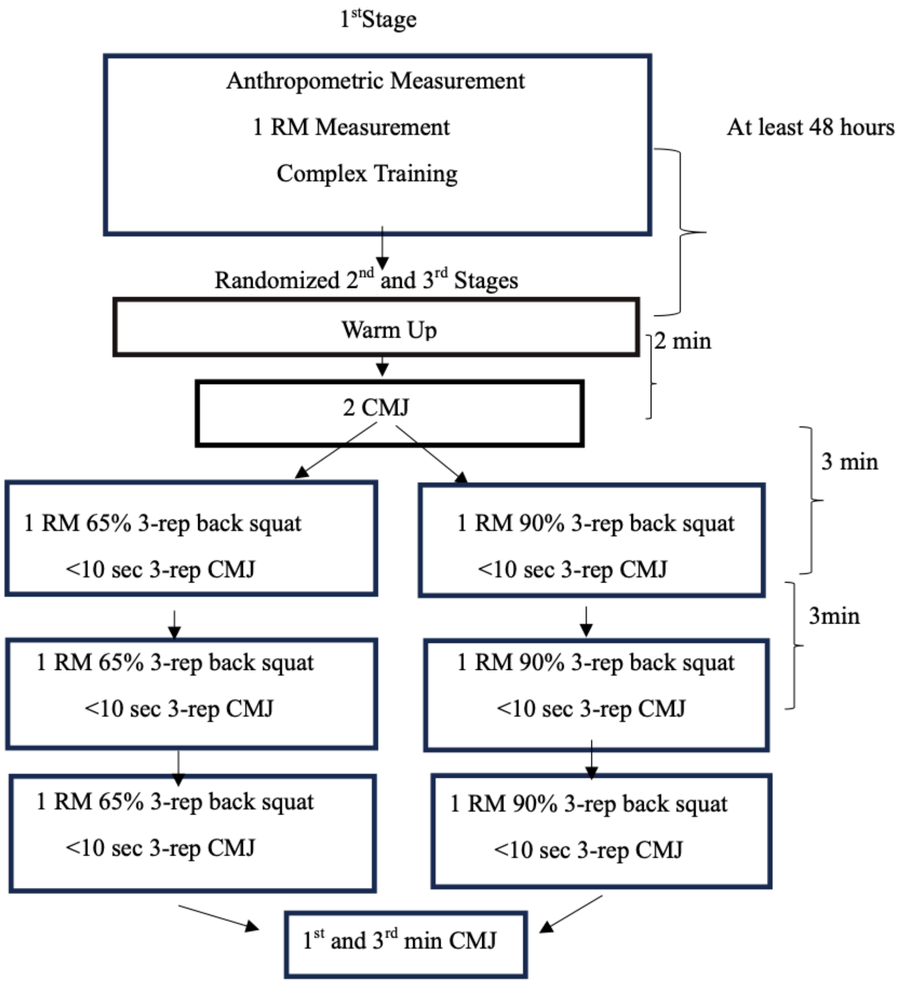

Figure 1. Research Design

Initially, participants attended a familiarization session during which the study protocol was explained and they were instructed on how to perform the CT protocol correctly. Subsequently, anthropometric measurements were obtained, and three CMJ and the back squat exercise were performed. During the experimental sessions, participants first completed a 5-min jogging bout followed by a 5-min dynamic warm-up targeting the lower extremities. Following a 2-min rest interval, participants performed two preliminary CMJ to establish baseline CMJ height, with the best jump recorded. A subsequent 3-min rest period was provided. Participants then performed the CT, consisting of three repetitions of the back squat at 65% or 90% of 1RM, followed by three repetitions of CMJ. A 3-min rest interval was allocated between sets, and a 10-s rest interval was provided between complex pairs. Following the CT protocol, participants performed CMJ at 1 and 3 min.

Anthropometric and Body Composition Measurements

Participants' height was measured using a stadiometer with an accuracy of ±1 mm (Holtain, England), and body mass and body composition were assessed using an electronic scale (Tanita TBF 401A, Japan) with an accuracy of ±100 g. Subsequently, body fat percentage (%BF) and lean body mass (LBM) were calculated.

Menstrual Phase Measurement

Menstrual cycle phases were identified using a calendar-counting method. All training assessments were conducted during the late follicular phase, when estrogen levels are typically at their peak (19).

1 Repetition Maximum (RM) Measurement

The 1RM protocol developed by Earle was used to determine the maximum squat load that participants could lift in a single repetition(20). Olympic bars, Olympic weight plates (Werksan, Turkey), and standard squat racks were used for both the 1RM and CT protocols. Following a standardized 10-min warm-up, participants rested for 2-min before commencing the 1RM protocol. Participants performed 7-10 repetitions in the initial set using a load determined jointly by the participants and the researcher. After a 1-min rest interval, the load was increased for the second set, allowing participants to complete 3-5 repetitions. Subsequently, participants rested for 2-min, after which a load that could be lifted for 2-3 repetitions was used in the third set. Participants were then given a 4-min rest period before commencing the fourth set, during which they attempted one repetition with an increased load. In the event of an unsuccessful attempt, the load was reduced after a 4-min rest period. Participants were then allowed one additional attempt, and the load successfully lifted in the final set was recorded. If the fourth set was successful, the load was increased again based on the participant's willingness to continue. If another successful attempt was achieved, this load was also recorded. The test was concluded in either the fourth or fifth set, and the participants' 1RM load was determined.

Complex Training

First, participants completed a general and specific warm-up, followed by the assessment of baseline CMJ, which was later compared with post-CT values. Following a 3-min rest period, the participants proceeded with the CT protocol. The CT protocol was performed on separate days in a randomized order using back squat exercises at loads of 65% and 90% of 1RM. A 48-h period separated the back squat trials performed at the two different intensities. Immediately following the back squat exercise, participants performed three repetitions of CMJ within 10 s. Participants completed three sets of CT with 3-min rest intervals and performed CMJ at 1 and 3 min following the completion of all sets to assess the effects of CT on CMJ height (21).

Counter Movement Jump (CMJ) Measurement

CMJ was assessed using a jump mat integrated system on a tartan track in an indoor athletics facility (Fusion Sport, Australia). Prior to data collection, participants received standardized instructions and a practical demonstration of the CMJ technique. To minimize lateral and horizontal displacement and eliminate the influence of arm swing, participants performed the CMJ with their hands on their hips, feet shoulder-width apart, and a knee flexion angle of approximately 90°, landing and taking off from the same marked position (22). Participants performed CMJ trials as follows: two repetitions at baseline (prior to CT), three consecutive repetitions immediately following the back squat exercise within each CT set, and two repetitions at 1 and 3 min following the completion of the CT protocol. A 2-min rest interval was provided between CMJ attempts, and the best CMJ from each time point was used for analysis.

Back Squat Excercise

As part of the CT intervention, participants performed the back squat exercise at loads of 65% and 90% of 1RM for three repetitions. Each participant performed the back squat exercise, descending from full knee extension to approximately 90° of knee flexion in a shoulder-width stance. For safety reasons, two experienced strength-training spotters were present during all back squat trials.

Statistical analysis

Descriptive statistics were calculated for all variables, and data normality was assessed using the Shapiro-Wilk test ($n < 50$). All variables were normally distributed ($p > 0.05$). A two-way repeated-measures analysis of variance (ANOVA) was performed with two within-subject factors: intensity (65% and 90% of 1RM) and time (baseline, 1 min, and 3 min). Bonferroni-adjusted post hoc tests were applied for pairwise comparisons when appropriate. Mauchly's test of sphericity indicated that the assumption of sphericity was met for all effects-intensity ($p = 1.000$), time ($p = 0.382$), and the intensity × time interaction ($p = 0.277$); therefore, no correction was applied. Effect sizes were calculated using partial eta square (ηp^2) and interpreted as small (0.01), medium (0.06), and large (0.14). All statistical analyses were conducted using SPSS (version 23.0; IBM Corp., Armonk, NY, USA), with the level of statistical significance set at $p < 0.05$.

RESULTS

Descriptive characteristics of the participants are presented in Table 1.

Table 1 shows that the mean age of the 14 trained female athletes was 25.21 ± 5.25 years, with a mean height of 161.93 ± 5.30 cm, mean body mass of 58.80 ± 8.80 kg, and mean lean body mass of 46.28 ± 4.43 kg. In addition, the participants' 1RM load was 82.14 ± 14.40 kg, sport age was 6.29 ± 2.60 years, plyometric training experience was 3.79 ± 1.57 years, and strength training experience was 3.95 ± 1.61 years.

Results of the two-way repeated-measures ANOVA are presented in Table 2. The analysis revealed no significant main effect of intensity on CMJ height ($F_{(1,13)} = 3.23$, $p = 0.096$, $\eta p^2 = 0.199$), indicating that mean CMJ height did not differ between the 65% and 90% 1RM conditions. A significant main effect of time on CMJ height was observed ($F_{(2,12)} = 4.638$, $p = 0.019$, $\eta p^2 = 0.263$). No significant intensity × time interaction effect was found ($F_{(2,12)} = 1.088$, $p = 0.352$, $\eta p^2 = 0.077$; Figure 2). The intra-set CMJ values are presented in Table 3 and individual CMJ height values before and after CT at 65% and 90% 1RM loads are presented in Figure 3.

Table 1. The participants' physical and training characteristics

Variables	Mean	Sd
Age (years)	25.5	5.25
Height (cm)	161.93	5.34
Weight (kg)	58.86	8.80
BFP (%)	21.09	4.33
LBM (kg)	46.28	4.43
1RM (kg)	82.14	14.47
Relative 1RM	1.26	0.06
Training age (years)	6.29	2.67
Strength training (years)	3.95	1.61
Plyometric training (years)	3.79	1.57

BFP: Body Fat Percentage, LBM: Lean Body Mass, RM: Repetition Maximum

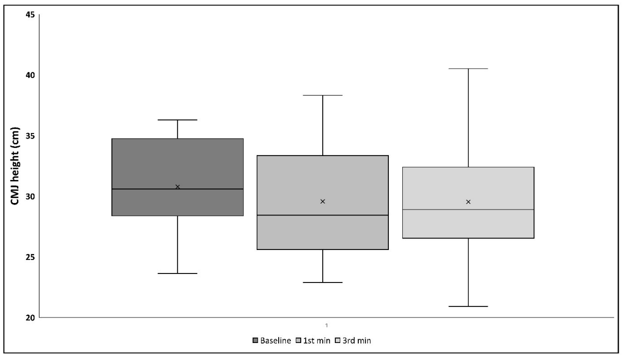

Figure 2. CMJ height at baseline and 1st and 3rd min following complex training

Table 2. CMJ heights before and after complex training at different intensities with ANOVA results

	Baseline	1st min	3rd min	F	p	ηp^2
Intensity effect	Mean ± SD	Mean ± SD	Mean ± SD	3.23	0.096	0.199
%65intensity(cm)	30.78 ± 1.04	29.57 ± 1,27	29.54 ± 1.43	4.638	**0.019***	0.263
%90 intensity(cm)	29.96 ± 0.98	28.63± 1.17	29.39± 1.19	1.088	0.352	0.077

Table 3. Intra-set CMJ Height (cm) (Mean ± SD)

Intensity (%)	Set	Baseline CMJ (cm)	CMJ 1 (cm)	CMJ 2 (cm)	CMJ3(cm)	1st min CMJ (cm)	3rd min CMJ (cm)
65	1	30.78 ± 3.76	26.08 ± 3.94	26.38 ± 3.80	26.28 ± 3.61	29.57 ± 4.60	29.54 ± 5.18
65	2	30.78 ± 3.76	26.40 ± 3.80	26.03 ± 4.28	26.42 ± 4.28	29.57 ± 4.60	29.54 ± 5.18
65	3	30.78 ± 3.76	26.30 ± 4.02	26.25 ± 3.87	26.09 ± 4.44	29.57 ± 4.60	29.54 ± 5.18
90	1	29.96 ± 3.54	26.12 ± 2.92	26.21 ± 3.37	26.49 ± 3.62	28.63 ± 4.23	29.39 ± 4.30
90	2	29.96 ± 3.54	25.92 ± 3.27	25.88 ± 3.68	26.35 ± 3.78	28.63 ± 4.23	29.39 ± 4.30
90	3	29.96 ± 3.54	25.61 ± 3.31	25.77 ± 3.08	26.25 ± 3.68	28.63 ± 4.23	29.39 ± 4.30

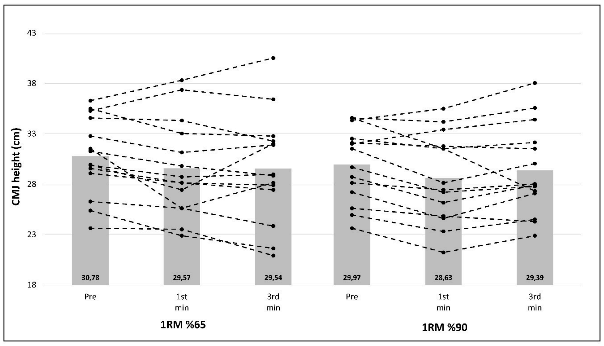

Figure 3. Intra-set CMJ Height (cm) (Mean ± SD)

DISCUSSION

The objective of this study was to examine the effects of acute multiple-set CT performed at different intensities (65-90% of 1RM) on CMJ height in trained female athletes. The primary finding was that CMJ height following CT did not differ significantly between intensity conditions. CMJ height measured 1 min post-CT was lower than baseline values, whereas CMJ height at 3 min post-CT was comparable to baseline.

Among the factors influencing the PAPE response, training intensity has been identified as a key determinant.Loads between 65% and 80% of 1RM are typically classified as submaximal, whereas loads of ≥85% 1RM are considered high intensity (7). Although meta-analytic evidence suggests that high-intensity conditioning activities may elicit greater PAPE responses than moderate-intensity protocols, the present study did not demonstrate intensity-dependent differences in CMJ performance (7). These findings are consistent with those reported by Reardon et al.(23), who applied either a moderate-intensity back squat protocol (3 sets × 10-rep at 75% 1RM) or a high-intensity protocol (3 sets × 3-rep at 90% 1RM) with a 3-min recovery period in trained male athletes and observed no differences in PAPE responses. Collectively, these results suggest that higher loading intensity alone may not be sufficient to induce acute performance enhancement, particularly when other moderating factors are present (7). Although our study involved trained female athletes, their relative strength levels were not very high, which may explain why most participants did not show improvements in jump performance (1). In addition, despite 5 out of 14 participants having a relative strength greater than 1.5, no PAPE effect was observed. In our study, 90% of the participants' 1RM corresponded to an average load of approximately 80 kg. This may have been insufficient to induce a strong PAPE effect at high intensity (%90 1RM). Furthermore, although the literature suggests that submaximal loads are effective in eliciting PAPE in weaker individuals, no PAPE effect was observed under submaximal conditions (%65 1RM) in our study.

An important factor in eliciting the PAPE effect is the number of sets and repetitions, along with strategies to increase total training volume. Wilson et al. (1) reported that multiple sets of CA may enhance PAPE more effectively than a single set; however, responses vary depending on relative strength levels. In our study, the low number of repetitions within sets in the multi-set CT protocol may have resulted in a low training volume, which could have been insufficient to provide adequate neuromuscular stimulation. Increasing the number of repetitions may enhance motor unit recruitment; however, it also increases fatigue levels. Therefore, optimizing both the number of sets and the total training volume is crucial for maximizing neuromuscular adaptations.

The observation of a potentiation effect in individuals possessing greater relative strength highlights the critical importance of individualized assessment. For example, a study examining the individual effects of high- and low-intensity CT interventions on upper-body performance reported greater variability in responses under the lower-intensity condition, with some individuals responding positively while others did not (24). Similarly, a study evaluating athletes with homogeneous muscle strength and training status using force platform measurements during squat jumps reported that some participants demonstrated performance improvements, whereas others exhibited performance decrements. The authors concluded that, due to substantial individual variability, a single CT intervention cannot be considered optimal for all athletes (25). However, Aytaç et al. (26) investigated the effects of a back squat protocol consisting of 3 sets × 3 repetitions at 90% 1RM with a 2-min rest interval on 505 test and T-test performance and reported no significant changes in individual PAPE responses. Similarly, in our study, no changes in individual PAPE responses were observed.

Another important factor in achieving a PAPE effect during CT protocol is the rest interval between the heavy resistance exercise and the subsequent plyometric exercise (27). In our study, a 10-s intra-set rest and a 3-min inter-set rest did not result in significant changes in jump performance. NCAA Division I female volleyball players performed vertical jumps following a 5RM back squat with subsequent rest intervals of 10 s, 1 min, 2 min, 3 min, and 4 min. Similar to our findings, no significant effects on CMJ height or ground reaction forces were observed at any time point following the back squat exercise (28). In contrast to our study, a complex training protocol performed at 90% 1RM with approximately 10 seconds of rest increased strength and CMJ height in high-level amateur football players. (29). However, Jensen and Ebben (28) examined vertical jump responses in a group of 11 males and 10 females following a 5RM back squat with rest intervals of 10 s, 1 min, 2 min, 3 min, and 4 min. They reported that a 10-s rest interval resulted in reduced vertical jump performance. Based on the available literature, rest intervals should be evaluated on an individual basis, with optimal rest durations between complex pairings generally ranging from 3 to 5 min (7). For example, Guo et al. (30) reported that peak performance occurred 3 min after the application of a PAPE protocol in studies employing rest intervals of 3 min or longer. An individual's strength level influences the required rest interval, with stronger individuals exhibiting PAPE effects after shorter rest periods, whereas weaker individuals may require longer rest durations. In our study, considering the strength levels of our participants, the short 10-second intra-set rest period may have allowed fatigue to predominate.

Limitations and Recommendations

Our data demonstrated that no positive effect was observed within the first 3 minutes post-CT, and potential effects beyond this time window remain unknown. This limits the ability to fully assess the evolution of PAPE effects over time. It is recommended that CMJ height be assessed at later time points to more accurately evaluate potential PAPE effects beyond the initial period. The menstrual cycle phase was determined solely based on calendar-based estimations, without hormonal verification. We recommend that future studies use hormonal verification methods to more accurately determine the menstrual cycle phase.

CONCLUSION

The main finding of this study was that CMJ height did not change significantly in trained female athletes following CT at different intensities. CMJ height was significantly lower at 1 min post-CT compared with baseline, whereas no significant difference was observed between baseline and 3 min post-CT. No significant differences were observed between the 1-min and 3-min post-CT CMJ height measurements. These findings indicate that no positive effect of CT on CMJ height was observed within the first 3 minutes post-CT. However, since longer recovery intervals (e.g., 4-8 minutes) were not examined, the present results cannot rule out the possibility of a delayed PAPE response.

Ethics Committee Approval / Etik Komite Onayı

The approval for this study was obtained from Hacettepe University Non-invasive Clinical Research Ethics Committee, Ankara, Türkiye (Decision no: 2022/13-42, Date: 06/09/2022).

Conflict of Interest / Çıkar Çatışması

The authors declared no conflicts of interest with respect to authorship and/or publication of the article.

Financial Disclosure / Finansal Destek

The authors received no financial support for the research and/or publication of this article.

Author Contributions / Yazar Katkıları

Consept: ÇS, AKİ; design: ÇS, MGK, TA, AKİ; supervison: AKİ; materials: ÇS, MGK, TA, AKİ; data collection and/or processing: ÇS, MGK, TA; analysis and interpreta-tion: ÇS, MGK, AKİ; literature review: ÇS; writing manuscript: ÇS, MGK, AKİ; critical reviews: MGK, AKİ. All authors contributed to the final version of the manuscript and discussed the results and contributed to the final manuscript.

REFERENCES

1. Wilson JM, Duncan NM, Marin PJ, Brown LE, Loenneke JP, Wilson SM,et.al. Meta-analysis of postactivation potentiation and power: effects of conditioning activity, volume, gender, rest periods, and training status. *J Strength Cond Res*. 2013;27(3):854-9.
2. Carter J, Greenwood M. Complex training reexamined: Review and recommendations to improve strength and power. *Strength Cond J*. 2014;36(2):11-9.
3. Batista MA, Roschel H, Barroso R, Ugrinowitsch C, Tricoli V. Influence of strength training background on postactivation potentiation response. *J Strength Cond Res*. 2011;25(9):2496-502.
4. Blazevich AJ, Babault N. Post-activation potentiation versus post-activation performance enhancement in humans: historical perspective, un-derlying mechanisms, and current issues. *Front Physiol*. 2019; 10:1359.
5. Scott DJ, Ditroilo M, Marshall PA. Complex training: the effect of exercise selection and training status on postactivation potentiation in rugby league players. *J Strength Cond Res*. 2017;31(10):2694-703.
6. Thomas K, Brownstein C, Dent J, Parker P, Goodall S, Howatson G. Neuromuscular fatigue and recovery after heavy resistance, jump, and sprint training. *Med Sci Sports Exerc*. 2018;50(12):2526-35.
7. Seitz LB, Haff GG. Factors modulating post-activation potentiation of jump, sprint, throw, and upper-body ballistic performances: A systematic review with meta-analysis. *Sports Med*. 2016; 46:231-40.
8. Krutki P, Mrówczyński W, Bączyk M, Łochyński D, Celichowski J. Adaptations of motoneuron properties after weight-lifting training in rats. *J Apply Physiol*. 2017;123(3):664-73.
9. Fukutani A, Takei S, Hirata K, Miyamoto N, Kanehisa H, Kawakami Y. Influence of the intensity of squat exercises on the subsequent jump per-formance. *J Strength Cond Res*. 2014;28(8):2236-43.
10. West DJ, Cunningham DJ, Crewther BT, Cook CJ, Kilduff LP. Influence of ballistic bench press on upper body power output in professional rug-by players. *J Strength Cond Res*. 2013;27(8):2282-7.
11. Berning JM, Adams KJ, DeBeliso M, Sevene-Adams PG, Harris C, Stamford BA. Effect of functional isometric squats on vertical jump in trained and untrained men. *J Strength Cond Res*. 2010;24(9):2285-9.
12. Poulos N, Chaouachi A, Buchheit M, Slimani D, Haff GG, Newton RU. Complex training and countermovement jump performance across multi-ple sets: Effect of back squat intensity. *Kinesiology*. 2018;50(1):75-89.
13. Terzis G, Spengos K, Karampatsos G, Manta P, Georgiadis G. Acute effect of drop jumping on throwing performance. *J Strength Cond Res*. 2009;23(9):2592-7.
14. McCann MR, Flanagan SP. The effects of exercise selection and rest interval on postactivation potentiation of vertical jump performance. *J Strength Cond Res*. 2010;24(5):1285-91.
15. Tsolakis C, Bogdanis GC, Nikolaou A, Zacharogiannis E. Influence of type of muscle contraction and gender on postactivation potentiation of upper and lower limb explosive performance in elite fencers. *J Sports Sci Med*. 2011;10(3):577.
16. Koźlenia D, Domaradzki J. The sex effects on changes in jump performance following an isometric back squat conditioning activity in trained adults. *Front Physiol*.2023; 14:1156636.
17. Gourgoulis V, Aggeloussis N, Kasimatis P, Mavromatis G, Garas A. Effect of a submaximal half-squats warm-up program on vertical jumping ability. *J Strength Cond Res*. 2003;17(2):342-4.
18. Pagaduan J, Pojskic H. A meta-analysis on the effect of complex training on vertical jump performance. *J Hum Kinet*. 2020;71(1):255-65.
19. Kissow J, Jacobsen KJ, Gunnarsson TP, Jessen S, Hostrup M. Effects of follicular and luteal phase-based menstrual cycle resistance training on muscle strength and mass. *Sports Med*. 2022;52(12):2813-9.

20. Baechle TR, Earle RW. Essentials of strength training and conditioning. 3rd ed. Champaign (IL): *Human Kinetics*; 2008.
21. Till KA, Cooke C. The effects of postactivation potentiation on sprint and jump performance of male academy soccer players. *J Strength Cond Res*. 2009;23(7):1960-7.
22. Archer DC, Brown LE, Coburn JW, Galpin AJ, Drouet PC, Leyva WD, et al. Effects of short-term jump squat training with and without chains on strength and power in recreational lifters. *Int J Kinesiol Sports Sci*. 2016;4(4):18-24.
23. Gołaś A, Maszczyk A, Zajac A, Mikołajec K, Stastny P. Optimizing post activation potentiation for explosive activities in competitive sports. *J Hum Kinet*. 2016;52(1):95-106.
24. Reardon D, Hoffman JR, Mangine GT, Wells AJ, Gonzalez AM, Jajtner AR, et al. Do changes in muscle architecture affect post-activation potentiation? *J Sports Sci Med*. 2014;13(3):483.
25. Ruben RM, Molinari MA, Bibbee CA, Childress MA, Harman MS, Reed KP, et al. The acute effects of an ascending squat protocol on performance during horizontal plyometric jumps. *J Strength Cond Res*. 2010;24(2):358-69.
26. Duthie GM, Young WB, Aitken DA. The acute effects of heavy loads on jump squat performance: An evaluation of the complex and contrast methods of power development. *J Strength Cond Res*. 2002;16(4):530-8.
27. Matthews M, O'Conchuir C, Comfort P. The acute effects of heavy and light resistances on the flight time of a basketball push-pass during upper body complex training. *J Strength Cond Res*. 2009;23(7):1988-95.
28. Sygulla KS, Fountaine CJ. Acute post-activation potentiation effects in NCAA division II female athletes. *Int J Exerc Sc*. 2014;7(3):212.
29. Weber KR, Brown LE, Coburn JW, Zinder SM. Acute effects of heavy-load squats on consecutive squat jump performance. *J Strength Cond Res*. 2008;22(3):726-30.
30. Aytac T, Esatbeyoglu F, Kin-Isler A. Post-activation performance enhancement on change of direction speed: Effects of heavy back-squat exercise. *Sci Sports*. 2024 ;39(2): 196-205.
31. Dobbs CW, Gill ND, Smart DJ, McGuigan MR. Relationship between vertical and horizontal jump variables and muscular performance in athletes. *J Strength Cond Res*. 2015;29(3):661-71.
32. Jensen RL, Ebben WP. Kinetic analysis of complex training rest interval effect on vertical jump performance. *J Strength Cond Res*. 2003;17(2):345-9.
33. Faude O, Roth R, Di Giovine D, Zahner L, Donath L. Combined strength and power training in high-level amateur football during the competitive season: a randomised-controlled trial. *J Sports Sci*. 2013;31(13):1460-7.
34. Guo H, Dong X, Zhang J. Hormone levels at different menstrual cycle phases and changes of athletic performance in female athletes. *Chin J Tissue Eng Res*. 2005;188-90.
35. Bogdanis GC, Tsoukos A, Veligekas P, Tsolakis C, Terzis G. Effects of muscle action type with equal impulse of conditioning activity on postactivation potentiation. *J Strength Cond Res*. 2014;28(9):2521-8.
36. Faul F, Erdfelder E, Buchner A, Lang AG. Statistical power analyses using G* Power 3.1: Tests for correlation and regression analyses. *Behav Res Methods*. 2009, 41(4), 1149-1160.