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ORIGINAL RESEARCH

The comparison of the effects of post-activity performance enhancement on foot plantar pressure and vertical jump in traditional set and cluster set training configurations

Mehmet Kale[1,*], Abdurrahman Boyacı[2], Ali Berkay Tolalı[2], Yeliz Yol[3], Ezgi Ayaz[2], Murat Tutar[4], Umut Davut Başoğlu[5]

[1] Department of Coach Training in Sports, Faculty of Sport Sciences, Eskisehir Technical University, 26555 Eskisehir, Turkey
[2] Department of Coaching Education, School of Physical Education and Sports, Istanbul Nisantası University, 34398 Istanbul, Turkey
[3] Department of Exercise and Sport Sciences, Faculty of Hamidiye Life Sciences, Health Sciences University, 34668 Istanbul, Turkey
[4] Department of Exercise and Sport Sciences, Faculty of Sport Sciences, Istanbul Gedik University, 34365 Istanbul, Turkey
[5] Department of Recreation, School of Physical Education and Sports, Istanbul Nisantası University, 34398 Istanbul, Turkey

***Correspondence**
mkale@eskisehir.edu.tr
(Mehmet Kale)

Abstract

Background: There is no study about the effects of post-activity performance enhancement on foot plantar pressure and vertical jump in different set configurations. This study aimed to compare the effects of post-activity performance enhancement on foot plantar pressure and vertical jump in traditional set and cluster set training configurations. **Methods**: The study included 27 volunteer university students (age: 20.0 ± 1.2 year, height: 180.2 ± 6.9 cm, body weight: 76.0 ± 11.8 kg). Static foot plantar pressure (SFPP), countermovement jump (CMJ), and squat jump (SJ) were performed as pre-tests 8 min after the half-squat 1 repetition maximum (HS 1RM) test. After pre-tests, 12 reps of training were performed with 70% of the HS 1RM by varying the training configurations of 1 × 12 reps traditional set (TS) on the 4th day, 3 × 4 reps cluster set 1 (CS1) with 30 s rest on the 8th day, and 6 × 2 reps cluster set 2 (CS2) with 10 s rest on the 12th day. Post-tests were performed in the following of each configuration. Repeated Measures Analysis of Variance (ANOVA) was used for the statistical comparison of the tests in four different time intervals. **Results**: There were no statistically significant SFPP differences in four different time periods, while statistically significant differences were found in the CMJ ($p < 0.001$) and SJ ($p = 0.002$). Pairwise comparisons showed that CMJ pre-test (CMJ_{PRE}) had statistically significant differences with CMJ_{TS}, CMJ_{CS1} and CMJ_{CS2}. There were also differences between SJ_{PRE} and SJ_{CS1}, SJ_{TS} and SJ_{CS2} for the SJ ($p < 0.05$). **Conclusions**: In conclusion, based on the results of the study, it is recommended to use any of the TS, CS1 and CS2 configurations to increase CMJ and to use the CS1 configuration to increase SJ as a performance enhancement at 8 min post-activity.

Keywords

Half-squat; Intensity; Plantar pressure; Countermovement jump; Squat jump

1. Introduction

Resistance training, especially free weight lifting, is an integral part of athletic performance development for many individuals of various ages and sports [1]. Increasing strength and power capacity is an important strategy for improving sports performance [2], and higher strength and power provide greater tolerance to training loads [3]. It can also be characterized by a systematic organization and manipulation of acute training variables consisting of external load, number of repetitions, movement speed, and rest intervals between sets, adjusted according to the resistance training goal involving free weights [4]. It was determined that the sets made until the unsuccessful lift had an acute negative effect on vertical jump and sprint performance compared to the sets with low-speed losses [5]. In this context, some set configurations, such as cluster set (CS), have been adopted to reduce the loss in neuromuscular performance by optimizing short- and long-term muscle adaptations [6]. From this point of view, resistance training with free weights, in which different set configurations are used by rearranging rests, seems to be an important strategy in terms of helping to maintain variable performance such as strength, power and velocity, as well as lower fatigue indicators [7].

Resistance training can provide potential benefits such as acute effects such as post-activation potentiation (PAP). However, it can also reduce anaerobic performance because of increasing physiological processes (creatine kinase levels, delayed-onset muscle soreness, kinematic change, energy expenditure, neural fatigue, and muscle glycogen depletion) [8]. PAP, defined as an enhanced contractile response of a muscle following its own contractile activity, influenced by the intensity and duration of the conditioning contraction, is a phenomenon that has been observed in laboratory studies on single twitches using electrical stimulation. It can be posited that PAP improves power performance after pre-conditioning activity [9, 10]. It has been suggested that post-activation performance enhancement (PAPE) be referred to for applied strength and conditioning research (jumps, sprints, and explosive actions) [11]. Potentiation continues for a short time after fatigue has normalized because potentiation can occur at some point during the recovery period as fatigue reduces at a faster rate than PAP [12]. While potentiation is dominant and fatigue is reduced, muscle performance may improve. If fatigue and potentiation are at the same level, it does not change but decreases if fatigue is higher than potentiation [13]. The PAP effect occurs more effectively in athletes who do resistance training with weight liftings or have a history of resistance training involving weight liftings [14]. It is known that these athletes recover faster after the high-intensity training protocol is applied to achieve the PAP effect [15]. In addition, squats using free weights with CS configurations are valid training strategies that can reduce muscle fatigue and correspondingly increase the PAPE effects [16].

CS, characterized by breaking sets into clusters with fewer repetitions with the addition of short intra-set rest or redistribution of rest between repetitions, allows for higher loads, leading to greater adaptation for performance. Therefore, it provides an increase in performance based on maintenance or improvement [17]. Several studies [6, 7, 18–22] in comparison to the TS configurations, the CS configurations facilitate a more pronounced maintenance of performance and a reduction in movement force, power, and velocity loss in mechanical and neuromuscular performance. This is achieved through the utilization of high contraction properties with fewer repetition sets and the incorporation of short, frequent rest periods between sets. As Dalton-Alves *et al*. [23] stated, a repeat block or recovery intervals between each rep characterizing two different CS configurations appears to be an effective strategy to increase volume without a significant reduction in velocity and power output over a set.

The human foot is responsible for maintaining body posture and ensuring the symmetrical distribution of plantar pressure, thereby providing support and flexibility for effective weight transfer and ankle stability during push-off. Additionally, the foot absorbs impact during loading response in activities such as walking and landing from a vertical jump [24]. Foot plantar pressure used to characterize dynamic foot function was based on the analysis of three anatomical regions (first and fifth metatarsal heads, heel) [25]. In foot plantar pressure analyses, results may vary due to basic factors such as time differences, balance protocols, foot position, device sampling frequencies, filtering methods, number of trials evaluated, and population groups. In particular, squats, which require a combination of functional movements and are known to be an important basic movement for resistance training, can cause changes in plantar pressure as a PAPE effect. Therefore, training and movement science needs to investigate how squat movements can affect the PAPE of foot plantar pressure and athletic performance such as vertical jump performance. A review of the literature reveals a lack of available studies examining the potential impact of PAPE on foot plantar pressure and vertical jump performance following resistance training. This is true for both cluster set configurations, which are characterized by short rest intervals within sets, and traditional set configurations, in which repetitions are performed continuously. Therefore, this study aimed to compare the effects of post-activity performance enhancement on foot plantar pressure and vertical jump in traditional set and cluster set training configurations.

2. Materials and methods

2.1 Participants

A total of 27 male students (Age: 20.0 ± 1.2 years, height: 180.2 ± 6.9 cm, body weight: 76.0 ± 11.8 kg) studying at the School of Physical Education and Sports, aged between 18–22 years, who have not done strength exercise for at least six months, who have not participated in strength exercise tests before, and who do not have any health problems, participated in the study voluntarily. The target sample number of 27 participants was determined by G*Power software (Version: 3.1.9.7, Heinrich-Heine-Universitat Dusseldorf, Dusseldorf, NRW, Germany) based on the data entered as power size (1 − β) 0.80, type I error or error level α = 0.05 and effect size (d) 0.80. The participants were assigned to the test protocols in accordance with a simple randomization method between December 01, 2023 and February 15, 2024. Istanbul Nisantası University Ethical Committee approval (Reference number: 2021/13) was obtained for the study.

2.2 Study design

The measurement and test devices were calibrated before starting the tests on the participants, who signed the informed consent form before the study. Trial measurements and tests were applied to the participants in order to adapt to laboratory conditions, anthropometric measurements, half-squats with free weights, static foot plantar pressure (SFPP), countermovement jump (CMJ), and squat jump (SJ) tests. Before starting half-squats, the participants applied a 10-min warm-up protocol consisting of jogging, dynamic stretching, and calisthenic movements in shorts, t-shirts and sports shoes as they wished. On the fourth day after the trial measurements and tests, all participants were given anthropometric measurements consisting of height and body weight measurements, and then tests of half-squat 1 repetition maximum (HS 1RM), SFPP, CMJ and SJ as pre-tests (PRE). After 4 min of the HS 1RM test, and the SFPP test with both feet was performed three times with 1-min rest intervals. After the foot plantar pressure test and 8 min after the HS 1RM test, the PRE was completed with the CMJ and SJ tests, which were performed three times at 30 s rest intervals. After PRE, the participants performed 12 reps of half squats with 70% intensity of the HS 1RM determined in the PRE with 1 × 12 reps traditional set (TS) on the 4th day, 3 × 4 reps cluster set (CS1) with 30 s rest intervals on the 8th day, and 6 × 2 reps cluster set (CS2) with 10 s rest intervals on the 12th day. The bar velocity was measured in all sets. After finishing the set, the participant completed the static plantar pressure with both feet, as well as CMJ and SJ tests as re-tests with the same procedure applied in the PRE. The experimental design is given in Fig. 1.

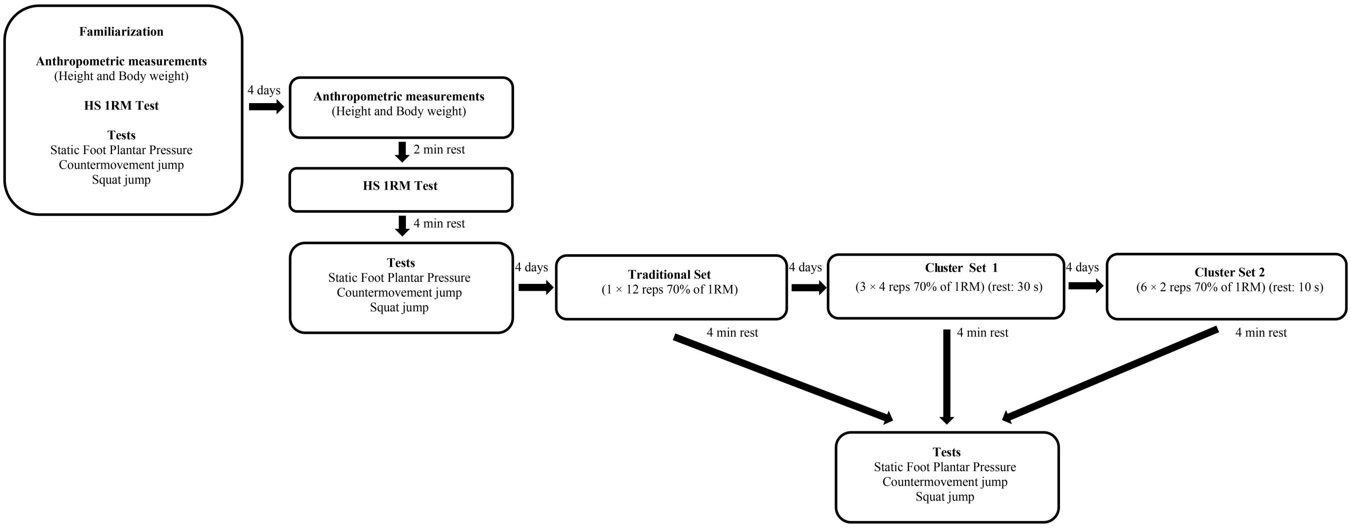

FIGURE 1. The experimental design of the study. HS 1RM: half-squat 1 repetition maximum.

2.3 Anthropometric measurements

Height measurements were made using a portable height meter with an accuracy of 0.1 mm (Seca 213, Vogel & Halke GmbH & Co, Hamburg, HH, Germany), and body weight measurements were made using an electronic laboratory scale with an accuracy of 0.1 kg (Seca 813, Vogel & Halke GmbH & Co, Hamburg, HH, Germany) as stated by Lohman *et al.* [26].

2.4 Half-squat 1 repetition maximum (HS 1RM)

For the HS 1RM tests, Olympic bars (Eleiko, Sweden) and free weights (Gainzmach, Turkey) were used. Safety control of the depth of the half-squat distance is ensured by the safety bars of the power rack (Gainzmach, Turkey). According to the 1RM protocol of Pallarés *et al.* [27], each participant descended to the ∼90° half-squat position with a controlled eccentric contraction while standing in an upright position and after waiting for 1.5 s with the contact of the Olympic bar on his shoulder with the safety bars of the power rack, he returned to the upright position by exhibiting concentric contraction at maximal speed. The test started with 10 min of warm-up with free jogging, dynamic stretches, and calisthenic movements, followed by ten reps of warm-up lifts with a 20 kg Olympic bar. Weights corresponding to an estimated 30% of 1RM were attached to the bar, and a 1RM half-squat lift was performed. After 2 min of rest, weights between 100 g and 20 kg were added, and the half-squat one rep was continued. The test was continued until the participant was unable to lift the weight without assistance (usually 4–6 attempts), and the maximum weight he could successfully lift was recorded as HS 1RM.

2.5 Static foot plantar pressure tests

For the SFPP test, the Zebris FDM platform and Zebris FDM 1.12 software (Zebris Medical GmbH, Isny im Allgaau, BW, Germany) were used, and the data were recorded on the computer at 100 Hz. Based on the recommendation of Scoppa *et al.* [28] that the recording time of posturographic parameters between 25 and 40 s is reliable, the test duration was determined as 30 s. During the test, the participants were asked to look at the target at a distance of 2 m for 30 s while standing with the arms on the sides of the torso, the feet shoulder-width apart and parallel to each other (standard standing posture), and SFPP applied to the platform was recorded during these 30 s. Each participant repeated the test three times with 1 min rest intervals, and the highest score was included in the statistical evaluation.

2.6 Vertical jump tests

For CMJ and SJ tests, OptoJump™ (Microgate, Bolzano/Italy) with 1 ms accuracy was used. The vertical jump heights of each participant in the CMJ and SJ tests were obtained depending on the flight time. Each vertical jump test was performed in three trials with 30 s rest intervals, and the highest vertical jump height was statistically evaluated. As stated by Bosco and Komi [29] for the CMJ test, the participants flexed the knees with their feet shoulder-width apart, bringing them to a knee angle of approximately 85° where they felt a comfortable starting position, and making a maximal vertical jump without waiting. For the SJ test, as stated by Bosco and Komi [29], the participants flexed the knees with their feet shoulder-width apart, felt a comfortable starting position, and reached the half-squat position, which is normally formed at a knee angle of about 85°, and made a maximal vertical jump without moving downwards after waiting for at least 2–3 s to prevent the pre-stretching in the muscles before the jump.

2.7 Bar velocity measurement

For the bar velocity measurement during the half-squat 12 repetitions of 1RM at 70%, a wireless velocity measurement device (VmaxPro VBT Tracker, Blaumann & Meyer Sports Technology, Magdeburg, ST, Germany) with a three-axis accelerometer, gyroscope and magnetometer was used, the validity and reliability of which was established by Held *et al.* [30] and Feuerbacher *et al.* [31]. The device was calibrated before each lift and then connected to a tablet computer (iPad

Pro, 11th inch (3rd generation), version 16.6.1; Apple, Inc., Cupertino, CA, USA) via Bluetooth 5.0. After the sensor of the device was placed at 1/4 point of the bar, it was monitored and tracked along the half-squats with the Enode Pro application (version 2.0.5, BM Sports Technology GmbH, Magdeburg, ST, Germany) compatible with the device and recorded at a sampling rate of 200 Hz. For the test to be accepted, the participant's half-squat descending distance was set to a minimum of 30 cm. Participants performed each half-squat repetition at maximum velocity.

2.8 Statistical analysis

The data obtained from the study were analyzed using the Jamovi statistical program (2.3.28.0, Stats Open Now). Skewness and Kurtosis and Shapiro-Wilk analysis were used for a normal distribution, and Mauchly's Sphericity Test was used to measure the sphericity of all variables. In Mauchly's Sphericality test, Greenhouse Geisser sphericity correction was preferred for the F value because the Epsilon value (ε) was less than 0.75 and the sample volume was low in the variables where the sphericity assumptions were not fulfilled. One-way analysis of Variance in Repeated Measurements (ANOVA) was used to compare the tests performed in four different time periods depending on three different strength training structures consisting of TS, CS1 and CS2. When the F statistics were significant for training-related changes, the Tukey Test was used in pairwise comparisons to determine which training variables caused the differences. Partial eta squared (η^2) was calculated for the size of the trial effect. As stated by Richardson [32], partial η^2; is classified as 0.01 = small, 0.06 = medium, and 0.14 = large impact. The statistical significance level was accepted as $p < 0.05$.

3. Results

The findings of the study are presented in Tables 1,2,3,4 and Figs. 2,3,4,5, which can be found below.

As seen in Table 1, statistically significant differences were found in CMJ and SJ values in the tests performed in 4 different time periods due to different training configurations ($F_{(3, 26)}$ = 7.55; $p < 0.001$, partial η^2 = 0.225 for CMJ and $F_{(3, 26)}$ = 6.90; p = 0.002, partial η^2 = 0.210 for SJ). The η^2 values showed that four different time periods due to different training configurations had significant impacts on the CMJ and SJ. As a result of the Tukey *Post Hoc* test, CMJ_{PRE} had statistically significant differences ($p < 0.05$) with variables CMJ_{TS}, CMJ_{CS1} and CMJ_{CS2} (Table 1 and Fig. 2A). There were statistically significant differences ($p < 0.05$) between SJ_{PRE} and SJ_{CS1}, and between SJ_{TS} and SJ_{CS2} for SJ (Table 1 and Fig. 2B).

As seen in Table 2 and Fig. 3A,B, no statistically significant differences were found in the variables FC_{avg} and FC_{max} in 4 different time periods.

As seen in the statistical results of the Friedman test in Table 3 and Fig. 4A,B, there were no statistically significant differences in 95% CEA and COPPL variables in 4 different time periods.

As seen in Table 4, statistically significant differences were found in BV_{avg}, BV_{peak} and BP_{peak} variables in TS, CS1 and CS2 configurations ($F_{(1, 26)}$ = 6.60; p = 0.003, partial η^2 = 0.202 for BV_{avg}, $F_{(1, 26)}$ = 8.01; p = 0.004, partial η^2 = 0.235 for BV_{peak}, and $F_{(1, 26)}$ = 4.51; p = 0.016, partial η^2 = 0.148 for BP_{peak}). The partial η^2 values showed that three different time periods due to different training configurations had significant impacts on BV_{avg}, BV_{peak} and BP_{peak}. As a result of the Tukey *Post Hoc* test, BV_{avgTS} had statistically significant differences ($p < 0.01$) with variables BV_{avgCS1} and BV_{avgCS2} (Table 4 and Fig. 5A). BV_{peakTS} had statistically significant differences ($p < 0.01$) with variables $\text{BV}_{peakCS1}$ and $\text{BV}_{peakCS2}$ (Table 4 and Fig. 5B). There was also a statistical difference ($p < 0.05$) between BP_{peakTS} and $\text{BP}_{peakCS1}$ (Table 4 and Fig. 5D).

4. Discussion

4.1 PAPE based on vertical jump due to TS and CS configurations

Regarding the different set configurations, Moreno *et al.* [33] reported that repetitive plyometric squat jumps performed with three different set configurations consisting of 2 × 10 reps of TS with 90 s rest between sets, 4 × 5 reps of CS1 with 30 s rest between sets, and 10 × 2 reps of CS2 with 10 s rest between sets allowed for greater maintenance of vertical jump power, take-off velocity and vertical jump height in CS, especially in CS2 compared to TS. In a similar study, Morales-Artacho *et al.* [34] found that a 3-week CMJ workout containing the CS configuration showed that the CMJ velocity and power adaptations specific to the training load were more effective in loading than the TS configuration. In the other study [18], resistance training, including squat lifting, was performed in 3 × 8 reps with 5 min rests and 6 × 4 reps with 2 min rests. CMJ decreased more in tests performed after 3 × 8 reps than after 6 × 4 reps. In the study of Asadi *et al.* [35], participants showed similar increases in CMJ in both groups after training 5 × 20 reps with 2 min rests as the TS configuration and 20 × (2 × 10 reps) with 1.5 min rest between each of 20 sets and 30 s rest between 2 sets as the CS configuration. However, the CMJ increase of CS was found to be higher than in TS. Although both training structures improved training performance at lower body maximal intensity, higher vertical jump adaptation occurred in the CS configuration. González-Hernández *et al.* [36] compared the mechanical, metabolic, and perceptual responses between two different TS (TS1 and TS2) and four different CS (CS1, CS2, CS3 and CS4) configurations. A balanced, randomized method was used to perform squat sessions with 30 reps, 5 min between sets, and a maximum of 10 reps. The set configurations were made equal as 3 × 10 reps with 5 min rests in TS1, 6 × 5 reps with 5 min rests in TS2, 3 × 10 reps with 10 s rests in CS1, 3 × 10 reps with 15 s rests in CS2, 3 × 10 reps with 30 s rests in CS3 and 1 × 30 reps with 15 s rests in CS4. Mechanical performance was tested by the average propulsive velocity during each rep and the change in CMJ after each set. In line with the average propulsive velocity results, the CMJ height showed the lowest reduction immediately after CS2 and CS3 compared to TS1. As a result of the increase in the

TABLE 1. Comparisons of CMJ and SJ variables in 4 different time periods depending on different training configurations (n = 27).

Variable	Mean ± Sd (cm)	*F*	*p*	Partial η^2	Pairwise comparisons
CMJ_{PRE}	35.5 ± 4.4	7.55	<0.001	0.225	CMJ_{PRE}–CMJ_{TS} CMJ_{PRE}–CMJ_{CS1} CMJ_{PRE}–CMJ_{CS2}
CMJ_{TS}	37.0 ± 4.5				
CMJ_{CS1}	37.8 ± 4.3				
CMJ_{CS2}	37.4 ± 4.4				
SJ_{PRE}	33.2 ± 4.1	6.90	0.002	0.210	SJ_{PRE}–SJ_{CS1} SJ_{TS}–SJ_{CS1}
SJ_{TS}	34.4 ± 3.9				
SJ_{CS1}	35.5 ± 4.1				
SJ_{CS2}	34.8 ± 4.3				

CMJ_{PRE}: CMJ height in PRE; CMJ_{TS}: CMJ height after TS; CMJ_{CS1}: CMJ height after CS1; CMJ_{CS2}: CMJ height after CS2; SJ_{PRE}: SJ height in PRE; SJ_{TS}: SJ height after TS; SJ_{CS1}: SJ height after CS1; SJ_{CS2}: SJ height after CS2; CMJ: countermovement jump; SJ: squat jump; TS: traditional set; CS1: cluster set 1; CS2: cluster set 2; PRE: pre-test; Sd: standard deviation.

TABLE 2. Comparisons of force curve (FC) variables of the static foot plantar pressure in 4 different time periods depending on different training configurations (n = 27).

Variable	Mean ± Sd (N)	*F*	*p*	Partial η^2
FC_{avgPRE}	757 ± 70	0.57	0.639	0.021
FC_{avgTS}	754 ± 69			
FC_{avgCS1}	756 ± 68			
FC_{avgCS2}	755 ± 68			
FC_{maxPRE}	772 ± 70	2.80	0.065	0.097
FC_{maxTS}	766 ± 70			
FC_{maxCS1}	766 ± 69			
FC_{maxCS2}	766 ± 68			

FC_{avgPRE}: Force curve average in PRE; FC_{avgTS}: Force curve average after TS; FC_{avgCS1}: Force curve average after CS1; FC_{avgCS2}: Force curve average after CS2; FC_{maxPRE}: Force curve maximal in PRE; FC_{maxTS}: Force curve maximal after TS; FC_{maxCS1}: Force curve maximal after CS1; FC_{maxCS2}: Force curve maximal after CS2; TS: traditional set; CS1: cluster set 1; CS2: cluster set 2; PRE: pre-test; Sd: standard deviation.

TABLE 3. Comparisons of 95% confidence ellipse area (95% CEA) and center of pressure path length (COPPL) variables of the static foot plantar pressure in 4 different time periods depending on different training configurations (n = 27).

Variable	Mean ± Sd	χ^2	*df*	*p*
95% CEA_{PRE} (mm^2)	215 ± 167	1.36	3	0.716
95% CEA_{TS} (mm^2)	204 ± 132			
95% CEA_{CS1} (mm^2)	179 ± 114			
95% CEA_{CS2} (mm^2)	206 ± 110			
$COPPL_{PRE}$ (mm)	198 ± 79	7.22	3	0.065
$COPPL_{TS}$ (mm)	214 ± 92			
$COPPL_{CS1}$ (mm)	209 ± 93			
$COPPL_{CS2}$ (mm)	211 ± 79			

95% CEA_{PRE}: 95% confidence ellipse area in PRE; 95% CEA_{TS}: 95% confidence ellipse area after TS; 95% CEA_{CS1}: 95% confidence ellipse area after CS1; 95% CEA_{CS2}: 95% confidence ellipse area after CS2; $COPPL_{PRE}$: Center of pressure path length in PRE; $COPPL_{TS}$: Center of pressure path length after TS; $COPPL_{CS1}$: Center of pressure path length after CS1; $COPPL_{CS2}$: Center of pressure path length after CS2; TS: traditional set; CS1: cluster set 1; CS2: cluster set 2; PRE: pre-test; Sd: standard deviation.

TABLE 4. Comparisons of BV and BP variables during the half-squat 12 reps of 1RM at 70% in 3 different time periods depending on different training configurations (n = 27).

Variable	Mean ± Sd	F	p	Partial η^2	Pairwise comparisons
BV_{avgTS} (ms^{-1})	0.493 ± 0.081				
BV_{avgCS1} (ms^{-1})	0.549 ± 0.088	6.60	0.003	0.202	BV_{avgTS}–BV_{avgCS1} BV_{avgTS}–BV_{avgCS2}
BV_{avgCS2} (ms^{-1})	0.540 ± 0.700				
BV_{peakTS} (ms^{-1})	0.549 ± 0.088				
$BV_{peakCS1}$ (ms^{-1})	0.865 ± 0.152	8.01	0.004	0.235	BV_{peakTS}–$BV_{peakCS1}$ BV_{peakTS}–$BV_{peakCS2}$
$BV_{peakCS2}$ (ms^{-1})	0.842 ± 0.124				
BP_{avgTS}	386 ± 110				
BP_{avgCS1}	433 ± 116	2.84	0.081	0.099	
BP_{avgCS2}	426 ± 102				
BP_{peakTS}	578 ± 175				
$BP_{peakCS1}$	685 ± 208	4.51	0.016	0.148	BP_{peakTS}–$BP_{peakCS1}$
$BP_{peakCS2}$	659 ± 175				

BV_{avgTS}: Average bar velocity during TS; BV_{avgCS1}: Average bar velocity during CS1; BV_{avgCS2}: Average bar velocity during CS2; BV_{peakTS}: Peak bar velocity during TS; $BV_{peakCS1}$: Peak bar velocity during CS1; $BV_{peakCS2}$: Peak bar velocity during CS2; BP_{avgTS}: Average bar power during TS; BP_{avgCS1}: Average bar power during CS1; BP_{avgCS2}: Average bar power during CS2; BP_{peakTS}: Peak bar power during TS; $BP_{peakCS1}$: Peak bar power during CS1; $BP_{peakCS2}$: Peak bar power during CS2; TS: traditional set; CS1: cluster set 1; CS2: cluster set 2.

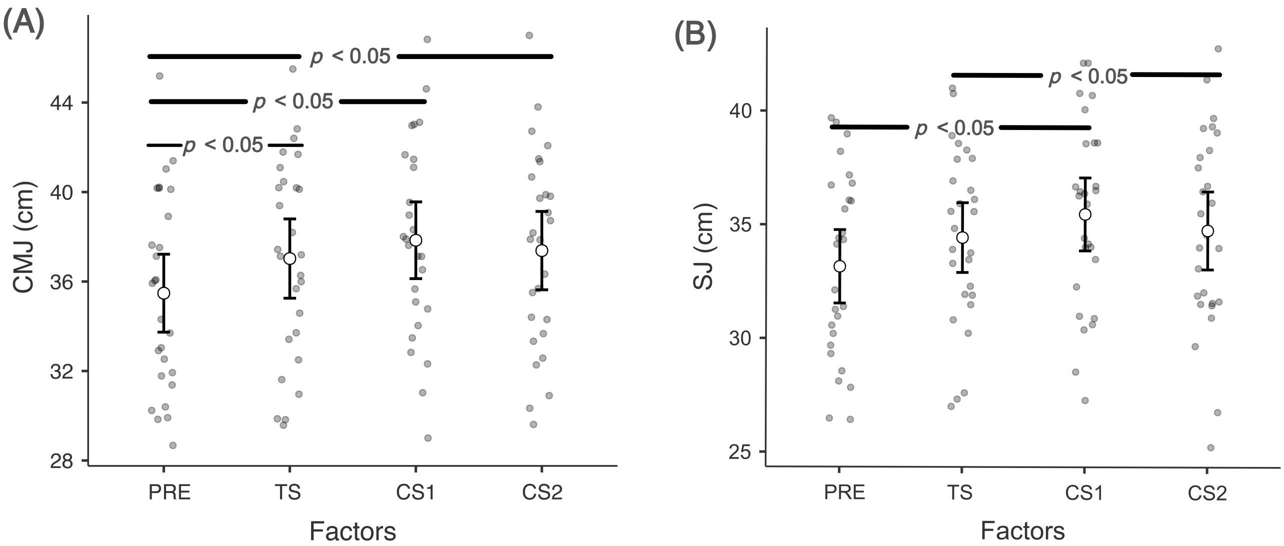

FIGURE 2. Comparisons of CMJ (A) and SJ (B) variables in 4 different time periods depending on different training configurations. CMJ: countermovement jump; SJ: squat jump; PRE: pre-test; TS: traditional set; CS1: cluster set 1; CS2: cluster set 2.

number of sets, after each training set, there was a decrease in CMJ. In conclusion, it was determined that mechanical, metabolic, and perceptual fatigue was significantly higher in the TS1 configuration than in the CS configuration, and the 2 set configurations that minimize mechanical fatigue were CS2 and CS3. In their study comparing the acute effects of TS and two different CS configurations on neuromuscular and perceptual fatigue, Cuevas-Aburto *et al*. [37] employed the following experimental groups: the TS group performed 3 × 6 repetitions with 3 min of rest between sets; the CS1 group performed 3 × 6 repetitions with 30 seconds of in-set rest between every two reps and 3 min of rest between sets; and the CS2 group performed 9 × 2 repetitions with 45 seconds of in-set rest between every two reps. The study determined that set configurations had a statistically significant effect on the bar velocity. It was found that the average velocity of the sets and CMJ were lower in the TS group than in the CS1 and CS2 groups. Pareja-Blanco *et al*. [38] evaluated the

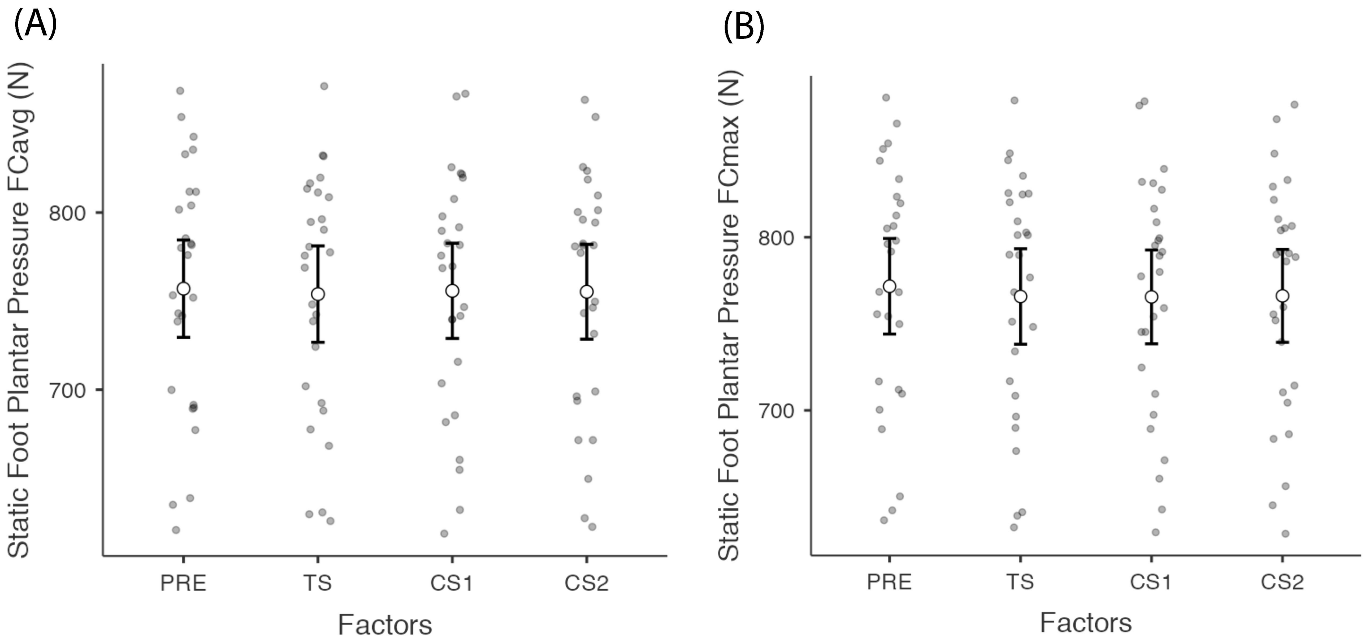

FIGURE 3. Comparisons of FC$_{avg}$ (A) and FC$_{max}$ (B) variables of the static foot plantar pressure in 4 different time periods depending on different training configurations. CEA: confidence ellipse area; COPPL: center of pressure path length; PRE: pre-test; TS: traditional set; CS1: cluster set 1; CS2: cluster set 2.

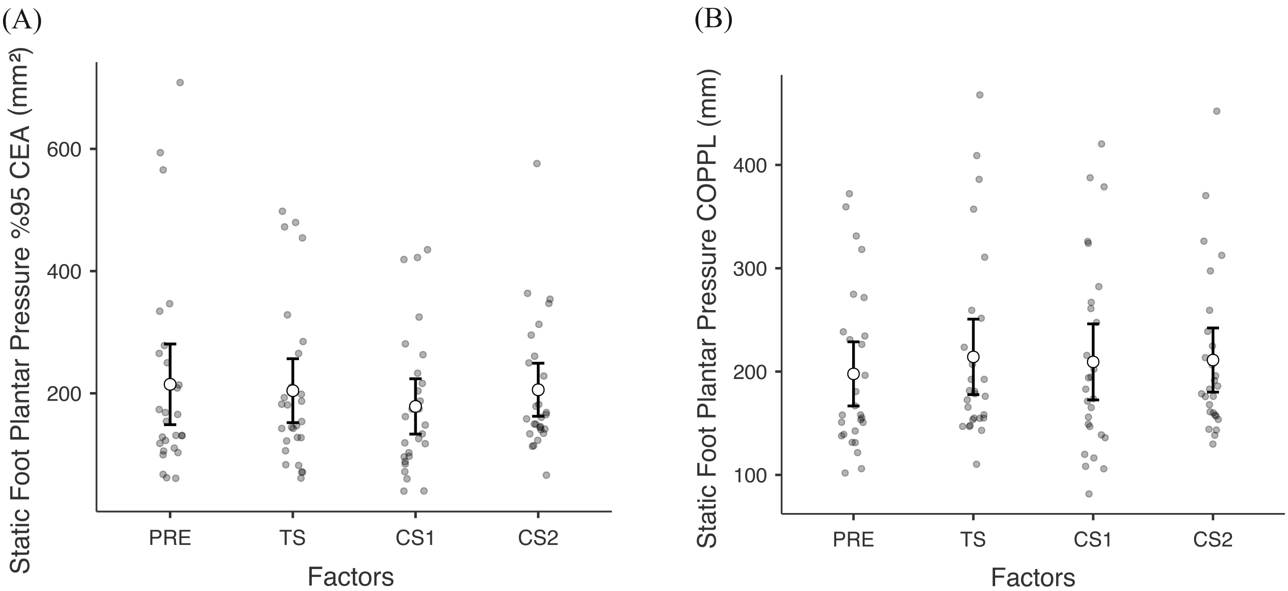

FIGURE 4. Comparisons of 95% CEA (A) and COPPL (B) variables of the static foot plantar pressure in 4 different time periods depending on different training configurations. FC$_{avg}$: Force curve average; FC$_{max}$: Force curve maximal; PRE: pre-test; TS: traditional set; CS1: cluster set 1; CS2: cluster set 2.

effect of 10 set configurations in the number of reps performed in each set with respect to the maximum predicted number. Three sets with 5 min interset rests were performed in each configuration in bench press and squat, on CMJ, which is a mechanical muscle function from 24 h before to 48 h after exercise, at various time periods. Set configurations with more reps caused more decreases in CMJ due to more fatigue accumulation. The present study supported the results of these studies which suggest that longer set configurations led to greater metabolic responses, along with greater impairments in jump height after squats. Also, CS configurations allow for greater absolute velocity and power outputs, which are highly effective at reducing lactate accumulation and perceived exertion during resistance training [39]. In addition, longer set configurations resulted in higher blood lactate [36], ammonia, growth hormone, cortisol, and creatine kinase levels [40]. Although physiological parameters and perceived exertion were not tested in this study, the higher movement speed and power results related to the bar displacement at half squat 12 reps of 1RM at 70% showed that CS configurations were

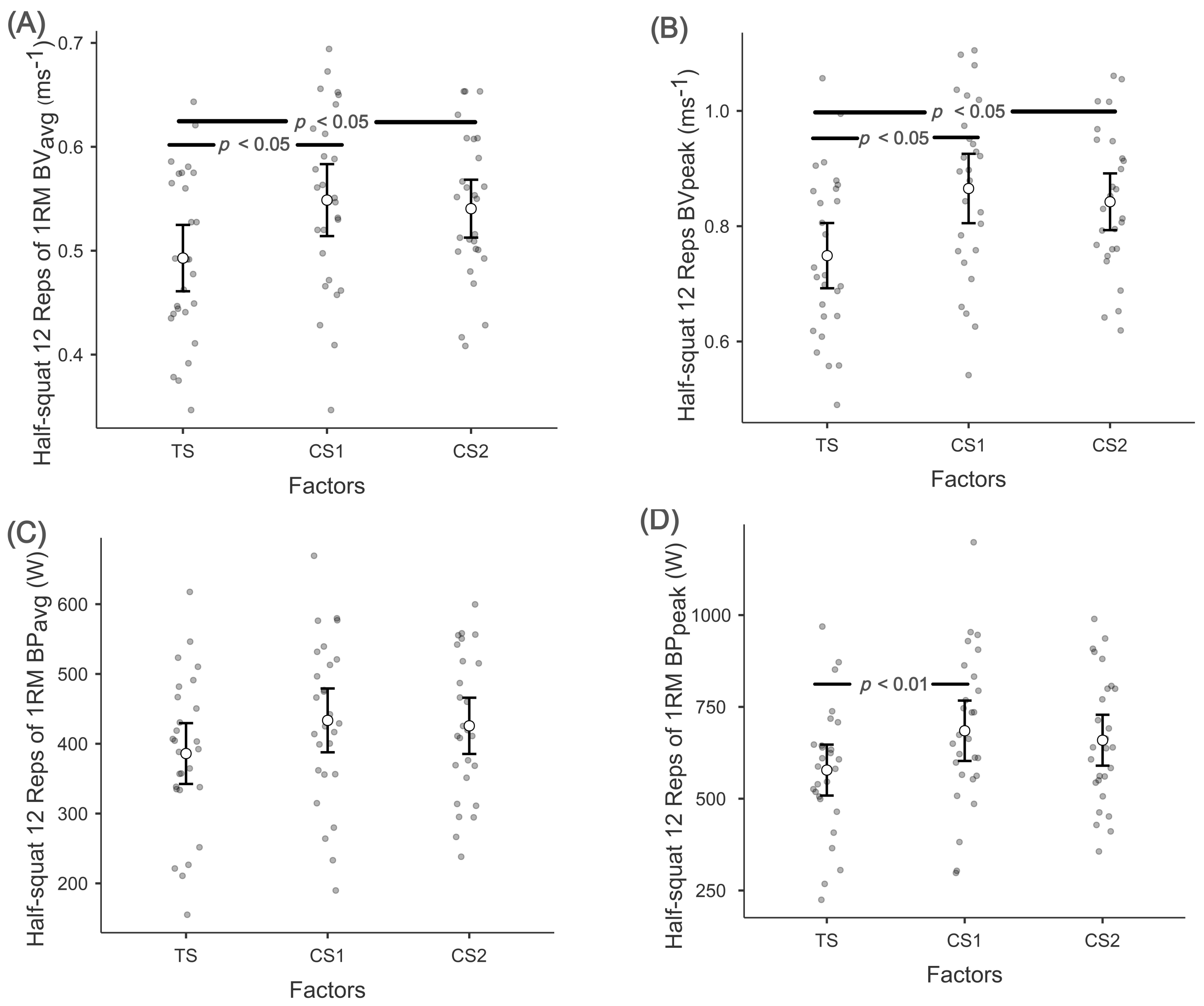

FIGURE 5. Comparisons of BV$_{avg}$ (A), BV$_{peak}$ (B), BP$_{avg}$ (C) and BP$_{peak}$ (D) variables during the half-squat 12 reps of 1RM at 70% in 3 different time periods depending on different training configurations. BV$_{avg}$: Average bar velocity; BV$_{peak}$: Peak bar velocity; BP$_{avg}$: Average bar power; BP$_{peak}$: Peak bar power; TS: traditional set; CS1: cluster set 1; CS2: cluster set 2; 1RM: 1 repetition maximum.

more effective lifting strategies for resistance training than TS. Therefore, it is thought that CS configurations may be very useful, especially in reducing mechanical fatigue, perceptual exertion, and metabolic stress. On the other hand, in the study conducted by Api *et al.* [7] to determine the effect of TS and CS configurations on mechanical and perceptual variables, squats were applied in the TS configuration including 3 × 8 reps with 225 s rest between sets, in the CS1 configuration including 3 × 2 × 4 reps with 30 s of in-set rests and 180 s rests between sets, and in the CS2 configuration including 3 × 4 × 2 reps with 30 s in-set rests and 90 s between sets. There was no statistically significant difference in CMJ after different set configurations. In the present study, the fact that all three of the TS, CS1 and CS2 configurations had statistically significant differences only with PRE supported the mentioned study. Iacono *et al.* [41] found a similar decrease in the CMJ performance of squats with TS and CS configurations with optimum power in the first 30 s, and an increase after 4 and 8 min. In addition, the CS configuration was found to produce higher CMJ compared to the TS configuration, which is similar to the results of the present study.

4.2 PAPE based on static foot plantar pressure due to TS and CS configurations

There is no study in the literature on the PAPE effect of resistance training using different set configurations with squat movements that can be exhibited at different joint angles on static foot plantar pressure variables. In this study, no statistically significant difference was found between the values of FC$_{avg}$, FC$_{max}$, 95% CEA and COPPL variables after three different resistance training set configurations consisting of TS, CS1 and CS2. This showed that the resistance training set configurations examined have similar effects on the variables of FC, 95% CEA, and COPPL. In the review study, Paillard [42] stated that static and dynamic activities increase the plantar pressure area. The plantar pressures of the feet during the spike jump showed that a certain sequence of foot contact correlated with performance [43]. However, in the study of Mora *et al.* [44], results were obtained that lower extremity fatigue during the free squat movement reduced plantar pressure. The results of the studies in the literature show differences regarding the changes in plantar pressure variables, which are thought to be due to the variability of the methods used. The fact that three different set configurations did not cause a difference in static foot plantar pressure variables suggested that these three different set combinations did not cause foot deformities and shape differences on the plantar surface of the foot. Therefore, results of the present study about FC_{avg}, FC_{max}, 95% CEA and COPPL can be an important reference point for the future research to compare the effects of different set methods on the plantar pressure variables when evaluating the training effect.

4.3 Effects of TS and CS configurations on the HS

In the present study, the BV_{avg} and BV_{peak} and BP_{avg} and BP_{peak} exhibited in half squat movement were significantly higher values in CS configurations than the TS configuration, indicating that the CS configurations are effective set configurations in resistance training to reduce fatigue and maintain mechanical performance (force, movement speed, and power output, *etc.*), as explained by Piqueras-Sanchiz *et al.* [18]. In another study [22], which supports the current study results, 6 set squats were applied as many as possible until they fell below the 90% BP_{peak} output. In the TS configuration, 2-min rest was made between sets, and in the CS configuration, 2 min rest was made between sets and 20 s rest after every two reps. The present study yielded similar results to those of previous studies, indicating that the CS configuration is an appropriate set configuration for augmenting the volume of velocity-based training. This approach involves the completion of sets when repetitions fall below the velocity or power threshold.

Tufano *et al.* [19] compared the effects between TS and 2 cluster sets (CS2 and CS4) configurations and found that CS configurations were more effective in terms of BV_{avg}, BV_{peak}, BP_{avg}, BP_{peak} than TS configuration. Jukic *et al.* [6] showed that 6 × 3 reps CS1 with 3 min rest between sets and 30 s rest between reps and 2 × 9 reps CS2 with 3 min rest between sets and 45 s rest between reps were more effective in reducing the overall decrease in repetition velocities compared to the 6 × 3 reps TS configuration without rest between reps. Therefore, it was suggested that both CS1 and CS2 configurations can be used to reduce fatigue. The present study results supported Jukic *et al.*'s [6] study in terms of the maintenance of neuromuscular fatigue. In the study of Wetmore *et al.* [20], it was determined that the CS configuration, which includes 3 min of rest between sets and 30 s between each rep in 3 × 5 reps of squats with 80% of 1RM, provides higher power output, speed, and force than the TS configuration with 3 min of rest between sets. In the study of García-Ramos *et al.* [21], bench press with a total of 30 reps with 5 min rest between sets was applied with five different set configurations (3 × 10 reps TS1, 6 × 5 reps TS2, 3 × 10 reps CS5 with 5 s rest between reps, 3 × 10 reps CS10 with 10 s rest between reps and 3 × 10 reps CS15 with 15 s rest between reps). A comparison of the first and last sets revealed a decrease in movement velocity in TS1, CS10 and CS15. Based on velocity loss, the set configurations are ranked as TS1 > CS5 > CS10 > TS2 > CS15. These results supported the use of TS2, CS10 and CS15 configurations for the maintenance of high mechanical outputs and showed that CS10 and CS15 configurations produced less metabolic stress than the TS2 configuration. Api *et al.* [7] determined that there was less decrease in mechanical performance in CS configurations even when the total rest interval was equal. Based on the studies [6, 7, 18–22] and the results of this study on BV and BP, the suggestion is more efficient to use a CS configuration with a high number of in-set rests.

5. Conclusions

In the present study, the effects of post-activity performance enhancement in TS and CS configurations on static foot plantar pressure and vertical jump were compared. No statistically significant differences in static foot plantar pressure were observed across the four time periods. However, statistically significant differences were observed in CMJ and SJ. In pairwise comparisons, it was determined that the source of difference was the statistically significant differences between CMJ_{PRE}–CMJ_{TS}, CMJ_{PRE}–CMJ_{CS1} and CMJ_{PRE}–CMJ_{CS2} for CMJ and the statistically significant differences between SJ_{PRE}–SJ_{CS1} and SJ_{TS}–SJ_{CS2} for SJ. Based on the findings of the study, which provided insight into how to achieve voluntary training adaptations by manipulating training variables, it is recommended to use any of the TS, CS1 and CS2 configurations to increase CMJ and CS1 configuration to increase SJ as a post-activity performance enhancement in the 8th min. Also, the study acknowledges the lack of significant findings about post-activity performance enhancement related to foot plantar pressure and that future research is necessary to focus on the effects of strength training set configurations on the foot plantar pressure mechanism.

AVAILABILITY OF DATA AND MATERIALS

Data are available for research purposes upon reasonable request to the corresponding author.

AUTHOR CONTRIBUTIONS

MK, AB, ABT and UDB—designed the research study. MK, AB, ABT and YY—wrote the manuscript. MK, AB, ABT, EA, MT and UDB—performed the research. MK, AB and ABT—analyzed the data. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Participants were given detailed information about the purpose, content, importance, application and possible risks of the study before starting the measurements and tests according to the procedures of the Declaration of Helsinki, and an informed consent form was signed. Istanbul Nisantasi University Ethical Committee approval (Reference number: 2021/13) was obtained for the study.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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