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Competition Volume and Changes in Countermovement Jump Biomechanics and Motor Signatures in Female Collegiate Volleyball Players

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Abstract

Kipp, K, Kiely, M, and Geiser, C. Competition volume and changes in countermovement jump biomechanics and motor signatures in female collegiate volleyball players. *J Strength Cond Res* 35(4): 970–975, 2021—The purpose of this study was to investigate the relationship between competition volume and preseason to postseason changes in countermovement jump (CMJ) biomechanics and motor signatures in female collegiate volleyball players. Ten National Collegiate Athletic Association Division I female volleyball players performed CMJs on force plates before (PRE) and after (POST) their season. Countermovement jump height was calculated, and 4 discrete biomechanical variables (peak body-mass normalized force [PeakF], peak body-mass normalized rate of force development [PeakRFD], movement time [TIME], and the ratio between eccentric and total movement time [EccT:TIME]) were calculated. A factor analysis of the 4 biomechanical variables was used to identify CMJ motor signatures. The total number of sets played by each player was used to define total competition volume for the season. Correlation coefficients were used to investigate the associations between competition volume and changes in CMJ height, discrete biomechanical variables, and the components of the CMJ motor signature. The statistical analysis indicated that team-average jump height did not change over the course of the season. However, competition volume was negatively associated with changes in CMJ height, such that decreases in CMJ height over the course of the season occurred in players who played large numbers of sets. Although CMJ during POST testing was characterized by longer TIME and greater PeakRFD, CMJ motor signatures did not change and suggest that the female volleyball players in this study retained their preferred jumping strategy across the season. Given that decreases in CMJ height were most pronounced in players who played the most sets, and scored the most points during the season, future research may need to focus on player- or position-specific interventions that help players retain CMJ performance in the face of the competitive demands of a collegiate volleyball season.

Introduction

Maximal dynamic performance of the lower extremities during athletic movements, such as jumping, is an essential part of success in a broad variety of team sports, such as volleyball ([13,22]). Because lower extremity performance is important for sports performance, it becomes imperative to quantify performance characteristics (e.g., biomechanical and neuromuscular characteristics) of the lower extremity, so that training can be appropriately monitored and directed in an optimal manner ([10–12]). To assess biomechanical and neuromuscular performance characteristics, and help monitor longitudinal changes of these characteristics, researchers and practitioners often analyze data obtained from countermovement jump (CMJ) force-time records ([4,19]).

To investigate CMJ force-time records, researchers generally extract and analyze a large number of discrete variables, such as peak ground reaction forces (GRFs), peak rates of GRF development, or peak mechanical power output ([1,9]). Previous studies have used up to 20 different biomechanical variables, which were derived from the CMJ force-time record, within their statistical design and analysis ([2,10,11]). Given that the analysis of a large number of variables can pose statistical problems (e.g., multicollinearity among dependent variables or increase risk of type II errors) when disseminated in a scientific forum or lead to interpretation problems (e.g., communication with coaches) in an applied setting, some researchers have resorted to factor analyses in an effort to better characterize and study CMJ performance and the associated biomechanical and neuromuscular characteristics ([15–18]). A factor analysis of discrete data reduces the dimensionality of the data set and helps researchers interpret the underlying structure and relationship between the input variables. Researchers who have used factor analyses to study discrete biomechanical data derived from CMJ force-time records have generally identified 2 factors: a “speed” and a “force” factor ([15,17,18]). Furthermore, other researchers have used components derived from factor analyses to characterize “motor signatures” to analyze neuromuscular responses to fatigue during activities such as repeated sprints ([5]). Other researchers have used factor analyses to illustrate cross-sectional differences in CMJ motor signatures between athletes from different sport-specific backgrounds and between male and female athletes ([18,21]). Collectively, these studies highlight that the analysis of motor signatures provides a better theoretical and more holistic method to analyze sport-specific movement patterns than the analysis of individual discrete variables ([5,18]).

Although longitudinal changes in discrete biomechanical variables associated with CMJ performance have been studied ([4,10,19]), no such data exist about CMJ motor signatures. Given that traditional discrete biomechanical variables may not always provide an accurate reflection of physiological changes (e.g., neuromuscular fatigue) ([10]), it could be surmised that motor signatures may provide important additional information that could be used to track CMJ performance over the course of a competition season or guide training in that specific neuromuscular aspects (i.e., force or speed factor) could be targeted. Furthermore, because the physiological demands associated with playing competitive volleyball can lead to overtraining ([23]), quantifying the effects of competition volume on CMJ performance and biomechanics seems warranted. Especially when combined with analysis of CMJ motor signatures, such information would provide valuable insight for coaches as well as strength and conditioning practitioners. The purpose of this study was to investigate the effects of competition volume on preseason to postseason changes in CMJ biomechanics and motor signatures of female collegiate volleyball players. We hypothesized that the total number of sets played during the season would negatively correlate with changes in CMJ biomechanics and motor signatures.

Methods

Experimental Approach to the Problem

CMJ biomechanics of female collegiate volleyball players were collected during preseason and postseason testing sessions. Standard biomechanical variables were extracted from the GRF during the CMJ and used to compute motor signatures through a factor analysis. Competition volume was quantified based on the number of sets played and then correlated against changes in CMJ variables to determine the effects of competition volume on preseason to postseason changes in CMJ biomechanics.

Subjects

Thirteen female National Collegiate Athletic Association (NCAA) Division I volleyball players were recruited for this study (mean ± *SD*; age: 20 ± 1 years; height: 1.81 ± 0.10 m; body mass: 71.6 ± 7.6 kg). Parental consent was not necessary as all players were older than 18. Before the start of testing, all players were briefed on the scope of the study and read and signed a written informed consent document that was approved by Marquette University's Institutional Review Board for Human Subjects Testing.

Procedures

All players were asked to report for 2 testing sessions: one at the beginning and at the end of the collegiate volleyball season. The preseason (PRE) testing occurred in the middle of August before the onset of the competitive season, and the postseason (POST) testing occurred in the beginning of December after completion of the Big East conference tournament and the first round of the NCAA championship tournament. Because of reasons not related to the current study, POST testing data were not available for 3 players. At each testing time point, players were tested in the morning before any skill or conditioning work. All players were asked not participate in heavy resistance training for 48 hours before testing. During each testing session, subjects performed a brief dynamic warm-up that included a variety of submaximal and maximal jumps. Each player then performed several submaximal CMJ trials, after which they performed 3 maximal-effort CMJs without arm swing (i.e., hands on hips in an akimbo position) so as to isolate the contribution of the lower extremity muscles to CMJ performance. Approximately 30 seconds of rest was allowed between each maximal-effort CMJ. All subjects were familiar with the CMJ through their regular strength and conditioning practices and were therefore provided with only minimal familiarization, which was primarily allocated, so that each subject could get used to the layout of the force plates.

Subjects performed all CMJs while standing on 2 force plates (Advanced Mechanical Technologies, Inc., Watertown, MA) that were mounted flush with the floor. Subjects were positioned such that each foot was positioned fully on 1 force plate. Kinetic data from the force plates were recorded at 1,000 Hz and smoothed with a fourth-order low-pass Butterworth filter at 15 Hz. The filtered vertical GRF data from both force plates were then summed into a single vertical GRF vector and normalized to each subjects' body mass. This body-mass normalized vector was then differentiated with the central difference method to calculate the rate of force development ([22]). The vertical GRF-time records were also used to calculate the acceleration of the center of mass (COM). After calculating the net vertical acceleration of the COM and accounting for the acceleration due to gravity, the net acceleration data were numerically integrated once to calculate COM velocity, which in turn was integrated again to calculate the COM position ([14]). The COM velocity was multiplied with vertical GRF data to produce COM power, which in turn was then used to identify eccentric (negative power) and concentric (positive power) movement phases ([14]). The total movement time was calculated as the difference between the point of take-off, which was denoted at the point when the GRFs reached zero, and the onset of movement, which was identified as the point when the GRF fell below 95% of body mass. The following dependent variables were extracted and used for statistical analysis: peak body-mass normalized GRF (PeakF [$N \cdot kg^{-1}$]), peak body-mass normalized rate of force development (PeakRFD [$N \cdot kg^{-1} \cdot s^{-1}$]), movement time (TIME [s]), and eccentric-to-total time ratio (EccT:TIME [$s \cdot s^{-1}$]) (Figure 1). The data from all 3 CMJ efforts were averaged for each subject, and the three-trial average was then used for subsequent analyses. All processing occurred with custom-written MATLAB routines (The Mathworks, Inc., Natick, MA) programs.

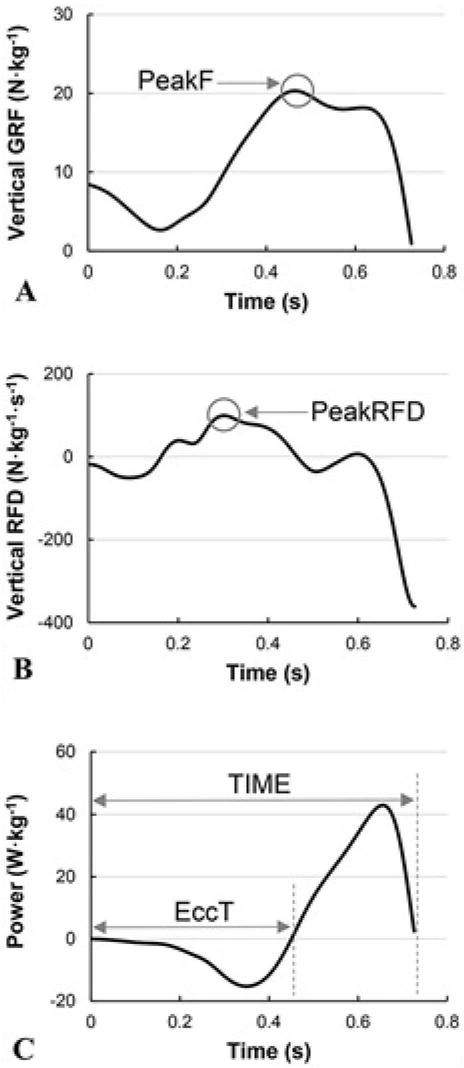

Figure 1.: Representative A) body-mass normalized vertical ground reaction force (GRF), (B) body-mass normalized vertical rate of force development (RFD), and (C) center-of-mass power during a countermovement jump. PeakF = peak body-mass normalized ground reaction force (N·kg^{-1}); PeakRFD = peak body-mass normalized rate of force development (N·kg^{-1}·s^{-1}); TIME = movement time (s); EccT:TIME = eccentric-to-total time ratio (s·s^{-1}).

Statistical Analyses

Intraclass correlation coefficients (ICCs) based on the absolute agreement of average measures were calculated from the data of the 3 CMJ trials during PRE testing to establish reliability for the 4 biomechanical variables, CMJ height, and the extracted factors scores. The ICC data were used to calculate *SEM* and minimal difference (MD) values.

Preliminary analysis of the biomechanical variables yielded a Kaiser-Meyer-Olkin criterion value of 0.649 and a significant Bartlett's Test of Sphericity ($p = 0.001$); a factor analysis was therefore deemed appropriate. All discrete biomechanical data from PRE and POST testing were entered into a single factor analysis. The analysis used a principal component method to extract factors from the correlation matrix of the input data ([16]). The correlation matrix was used rather than the covariance matrix because of the magnitude differences in the measurement scales of the input variables. The decision on how many factors to retain from among the extracted factors was based on visual inspection of the scree plot and the magnitude of the eigenvalues associated with each factor. To facilitate the interpretation of the retained factors, a VARIMAX rotation procedure was used to optimize the loading of each variable onto the minimum number of factors. Given that factor analyses typically require large data sets, small (<0.70) factor loadings were suppressed to provide a more conservative interpretation of the respective factors ([8]). Factor scores were then calculated with the regression method and subsequently used for further statistical analyses.

Paired *t*-tests were used to compare the means of all dependent variables (i.e., CMJ height, discrete biomechanical data, and extracted factor scores) between PRE and POST testing sessions. In addition, effect sizes (ES) (Cohen's *d*) were calculated to help with the practical interpretation of all *p* values. The magnitude of the ES were interpreted as small (∼0.2), moderate (∼0.5), and large (∼0.8) ([6]). Associations between competition volume and dependent variables were assessed with Pearson correlation coefficients (*r*). The a priori alpha level for statistical significance was set at 0.05. All statistical analyses were performed in SPSS 22 (IBM Analytics, New York, NY).

Results

The ICC, *SEM*, and MD values for all dependent biomechanical variables are presented in Table 1.

Table 1 - Intraclass correlation coefficient (ICC), *SEM*, and minimal difference (MD) for countermovement jump (CMJ) height, discrete biomechanical variables, and factor scores in female college volleyball players.*

	ICC	***SEM***	**MD**
CMJ height (m)	0.983	0.01	0.02
Biomechanical Variables			
PeakF ($N \cdot kg^{-1}$)	0.931	0.5	1.5
PeakRFD ($N \cdot kg^{-1} \cdot s^{-1}$)	0.950	13.1	36.4
TIME (s)	0.753	0.072	0.201
EccT:TIME ($s \cdot s^{-1}$)	0.689	0.02	0.06
Factor Scores			
Factor 1 (AU)	0.906	0.30	0.83
Factor 2 (AU)	0.669	0.59	1.62

*PeakF = peak body-mass normalized ground reaction force; PeakRFD = peak body-mass normalized rate of force development; TIME = movement time; EccT:TIME = eccentric-to-total time ratio; AU = arbitrary units.

The competitive season lasted 95 days, during which the team played in 33 matches; the average number of sets played by each athlete was 94.5 ± 29.7.

The factor analysis of the 4 discrete biomechanical variables produced 2 factors that characterized each player's motor signature. The first factor accounted for 56.1% of the variance in the input data and the second factor accounted for 25.2%. PeakF and PeakRFD loaded onto the first factor, whereas TIME and EccT:TIME loaded onto the second factor (Table 2).

Table 2 - Factor loadings of the 2 extracted factors from the analysis of discrete biomechanical variables derived from the countermovement jump of female, NCAA DI volleyball players (*n* = 10).*

	Factor 1	**Factor 2**
PeakF ($N \cdot kg^{-1}$)	0.87	
PeakRFD ($N \cdot kg^{-1} \cdot s^{-1}$)	0.86	
TIME (s)		0.71
EccT:TIME ($s \cdot s^{-1}$)		−0.70

*PeakF = peak body-mass normalized ground reaction force; PeakRFD = peak body-mass normalized rate of force development; TIME = movement time; EccT:TIME = eccentric-to-total time ratio.

The PRE and POST comparisons of CMJ height, discrete biomechanical variables, and the 2 factors scores revealed significant statistical, and moderate practical, increases in TIME (change = 0.065 ± 0.075 seconds; p = 0.026; ES = 0.57) and PeakRFD (change = 27.7 ± 38.8 $N \cdot kg^{-1} \cdot s^{-1}$; p = 0.040; ES = 0.55) (Table 3). Individual data are presented in Table 4.

Table 3 - Mean ± *SD* countermovement jump (CMJ) height, discrete biomechanical variables, and factor scores of female college volleyball players (n = 10) before (PRE) and after (POST) the season.*

	PRE	**POST**	***p***	**Effect size**
CMJ height (m)	0.279 ± 0.047	0.290 ± 0.048	0.136	0.23
Biomechanical variables				
PeakF ($N \cdot kg^{-1}$)	22.3 ± 1.9	22.7 ± 2.4	0.366	0.18
PeakRFD ($N \cdot kg^{-1} \cdot s^{-1}$)	128.9 ± 57.8	156.5 ± 50.4†	**0.040**	0.55
TIME (s)	0.965 ± 0.121	1.030 ± 0.114†	**0.026**	0.57
EccT:TIME ($s \cdot s^{-1}$)	0.36 ± 0.03	0.36 ± 0.03	0.800	0.07
Factor scores				
Factor 1 (AU)	−0.08 ± 0.92	0.08 ± 1.01	0.428	0.01
Factor 2 (AU)	−0.20 ± 0.80	0.20 ± 0.91	0.101	0.15

*PeakF = peak body-mass normalized ground reaction force; PeakRFD = peak body-mass normalized rate of force development; TIME = movement time; EccT:TIME = eccentric-to-total time ratio; AU = arbitrary units.

†$p < 0.05$ vs. Pre (significant p values noted in bold).

Table 4 - Countermovement jump (CMJ) height, discrete biomechanical, and factor score data for each individual volleyball players before (PRE) and after (POST) the season.*

Position	**Sets played**	**CMJ height**		**PeakF**		**PeakRFD**		**TIME**		**EccT:TIME**		**Factor 1 score**		**Factor 2 score**	
		PRE	**POST**	**PRE**	**POST**	**PRE**	**POST**	**PRE**	**POST**	**PRE**	**POST**	**PRE**	**POST**	**PRE**	**POST**
DS	56	0.308	0.317	25.6	26.2	201.7	174.1	0.865	0.803	0.35	0.34	1.31	1.39	−0.46	−0.72
DS	81	0.295	0.323	23.1	23.7	150.5	152.5	1.015	0.942	0.37	0.37	0.09	0.32	0.01	−0.51
DS	120	0.255	0.258	21.0	21.0	93.7	103.1	1.137	0.919	0.41	0.42	−1.22	−0.80	−0.19	−1.48
Hitter	120	0.403	0.392	25.4	25.7	162.7	154.9	1.028	0.861	0.32	0.35	0.91	0.99	0.89	−0.62
Hitter	34	0.242	0.288	22.1	21.9	221.8	167.0	0.981	0.923	0.34	0.34	0.69	0.41	0.56	0.18
Hitter	120	0.280	0.263	22.1	24.2	250.8	228.5	0.955	1.006	0.37	0.32	0.68	1.21	−0.16	0.99
Hitter	114	0.279	0.299	21.5	20.0	78.4	78.3	1.197	1.084	0.41	0.39	−1.37	−1.28	0.08	−0.13
Hitter	91	0.237	0.242	20.8	19.5	140.0	88.7	1.181	1.205	0.33	0.35	−0.42	−1.21	1.69	1.34
Setter	111	0.233	0.210	20.3	19.3	101.8	65.4	0.989	0.954	0.35	0.40	−0.59	−1.29	0.17	−0.91
Setter	98	0.271	0.293	25.3	21.7	209.1	86.6	0.841	0.872	0.39	0.38	1.05	−0.43	−1.31	−1.08

*DS = defensive specialist; PeakF = peak body-mass normalized ground reaction force ($N \cdot kg^{-1}$); PeakRFD = peak body-mass normalized rate of force development ($N \cdot kg^{-1} \cdot s^{-1}$); TIME = movement time (s); EccT:TIME = eccentric-to-total time ratio ($s \cdot s^{-1}$).

The correlation analysis between competition volume and changes in CMJ height, discrete biomechanical variables, and the 2 factors scores revealed that greater competition volume was negatively ($r = -0.715$; $p = 0.020$) associated with increases in CMJ height (Figure 2). No other correlations between competition volume and changes in biomechanical variables or the 2 factors scores were significant.

Figure 2.: Individual preseason to postseason percent change in countermovement jump (CMJ) height for all players in relation to the total number of sets they played during the season. Data points are labeled by each players' position (DS = defensive specialist).

Discussion

The purpose of this study was to investigate the effects of competition volume on preseason to postseason changes in CMJ biomechanics and motor signatures of female collegiate volleyball players. We hypothesized that the total number of sets played during the season would negatively correlate with changes in CMJ biomechanics and motor signatures. The results partially supported our hypothesis in that greater competition volume was correlated with a decrease in CMJ height. The results also showed that CMJ during postseason testing was characterized by longer TIME and greater PeakRFD. Interestingly, however, the overall CMJ height and motor signatures did not change, which may reflect athlete-specific attempts to retain a stable and preferred CMJ strategy regardless of competition volume and changes in selected, single discrete variables. Future research may need to focus on player- and position-specific interventions to help players retain CMJ performance in the face of the competitive demands of a collegiate volleyball season.

The female volleyball players who participated in this study played in 33 matches and in an average 94 sets. The results indicate that the total number of sets played was negatively correlated with changes in CMJ height over the course of the season. Although this correlation may initially suggest that greater competition volumes (i.e., total number of sets played) were associated with greater decreases in CMJ height from preseason to postseason testing, a quick examination of the scatterplot for this correlation indicates that only 3 players exhibited a decrease in CMJ height. Incidentally, the players who exhibited decrements in CMJ height collectively scored 64% of the points for the entire team during whole season and may also suggest that positional differences (e.g., front row vs. back row) and greater physiological demand (e.g., more spike jumps) precipitate detrimental changes in CMJ performance that may not be apparent at the team or group-average level. This notion is further supported by the fact that all 3 of the defensive specialists (i.e., back row players) exhibited increases (1–10%) in CMJ height despite exhibiting a wide range of competition volume (56–120 sets). In addition, the ability to retain high CMJ performance may not be as crucial for back row players as for front row hitters, which further underscores that position-specific. Given that decreases in CMJ height were most pronounced in players who played the most sets and scored the most points during the season, player and position-specific interventions to retain CMJ performance and deal with the physical demands of a collegiate volleyball season seem warranted.

Comparisons of team-average data between PRE and POST testing sessions showed that CMJ height remained relatively stable across the season. In fact, the only CMJ variables that differed between PRE and POST testing sessions were TIME and PeakRFD. The results indicate that CMJs during POST season testing were characterized by greater rates of force development and a longer movement times. Because the ratio between eccentric and concentric movement times (i.e., EccT:TIME) did not change between PRE and POST testing sessions, subjects spent more total time in the eccentric phase. Given that longer total and eccentric phase durations are associated with worse CMJ performance and height ([7,11,17]), the increase in TIME during POST season CMJs may reflect a negative adaptation. On the other hand, greater relative eccentric rates of force development have been associated with higher CMJ height ([18,20]). One could speculate that the increase in PeakRFD "offset" the negative consequence of a longer eccentric phase duration, which could help explain the stability in CMJ height between PRE and POST testing. Given this trade-off, it may be informative to examine the motor signatures to determine whether changes in discrete variables affected the basic CMJ structure.

Consistent with previous research, the factor analysis procedure used in the current study extracted 2 factors associated with a CMJ motor signature that consisted of a "speed" and "force" factor ([17]). The pattern in which the CMJ force-time variables loaded onto these factors indicated that the first factor of the motor signature captured force-dependent characteristics (i.e., PeakF and PeakRFD) and that the other captured temporal- or speed-dependent characteristics (i.e., TIME and EccT:TIME). The directionality of the factor loadings indicated that increases in both PeakF and PeakRFD positively contribute to the greater force factor scores. Similarily, studies on other motor tasks (e.g., isometric midthigh pull) have demonstrated significant correlations between peak force output and peak rate of force development ([3]). The directionality of the factor loadings for the second factor indicated that a longer TIME and smaller EccT:TIME ratio positively contribute to greater speed factor scores. In combination, the 2 variables captured by the speed factor specify that larger speed factor scores are the result of greater concentric phase duration, which would serve to increase the net vertical impulse and CMJ height. The lack of changes in team-average factor scores supports the aforementioned idea of a trade-off between the discrete variables TIME and PeakRFD because these 2 variables loaded onto the speed and force factor, respectively. As such, one can conclude that the overall team-average motor signature and CMJ did not change and surmise that this lack of change likely factored into the results obtained from the analysis of the discrete variables.

This study is not without limitations, and the results should be interpreted under their consideration. First, all the players who participated in this study were recruited from an NCAA DI women's volleyball team, which may therefore limit the generalizability of the results to that specific population and sport, and may not necessarily translate to others. A second limitation is presented by the small sample size. To partially address this limitation, the factor analysis was conservatively adjusted so as to reduce the risk of incorrectly assigning variables to the extracted factors and interpret motor signatures based on accordingly large factor loading coefficients ([8]). It should also be kept in mind that the factor scores themselves represent a multifactorial combination of several variables and that a decrease in, e.g., the speed factor therefore represents not only a longer total movement time but perhaps also a longer eccentric phase. Given the variance in the changes in some of the biomechanical variables and CMJ height, it is also likely that the player-specific changes may reflect position-specific differences. Unfortunately, the small number of players in the current study does not allow for investigation of position-specific changes. Another point to consider is that the current study did not include data on other neuromuscular variables (e.g., maximal strength), which could have been used to make inferences about the physiological mechanisms that underlie the individual variations in motor signature changes.

Practical Applications

The current study investigated the effects of competition volume on preseason to postseason changes in CMJ biomechanics and motor signatures of female collegiate volleyball players. The results indicated that greater competition volume was correlated with a decrease in CMJ height and that CMJ during postseason testing was characterized by longer CMJ movement times and greater relative rates of force development. Yet, despite these changes, the team-average CMJ height and motor signatures did not change. It could therefore be speculated that individual players make subject-specific changes in their CMJ motor signatures to cope with physiological responses (e.g., accumulated fatigue) that accompany the position-specific demands of a competitive volleyball season. In addition, it should be noted that in fact CMJ height only decreased in 3 players; however, given that the offensive production by these players accounted for 64% of the total points scored by the entire team, focus on player-specific, and perhaps even position-specific, interventions to help players retain CMJ performance in the face of the competitive demands of a collegiate volleyball season may be warranted.

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