CHANGES IN PRINCIPAL COMPONENT STRUCTURE OF COUNTERMOVEMENT JUMPS AFTER A VOLLEYBALL SEASON

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The purpose of this study was to investigate changes in the principal component structure of countermovement jumps (CMJ) in female volleyball players over the course of a competitive season. Eleven NCAA Division I female volleyball players performed CMJs on a force plate before and after a competitive season. Discrete biomechanical variables were extracted from the force-time records of all CMJs and entered into a factor analysis. The analysis yielded two factors that could account for the biomechanical structure of the CMJs: a temporal and a force factor. Although no differences in factor scores were identified between pre- and post-season testing sessions, sub-group analysis highlighted large individual changes in temporal and force factor scores.

KEY WORDS: volleyball, biomechanics, principal components analysis.

INTRODUCTION: The force-time record of the countermovement jump (CMJ) is often used to assess biomechanical and neuromuscular characteristics related to maximal dynamic performance of the lower extremities. Given the large number of variables that are typically extracted from force-time records, researchers have resorted to factor analysis to better understand CMJ performance (Kollias, Hatzitaki, Papaiakovou, & Giatsis, 2001). Factor analyses of CMJ force-time records generally identify a principal component structure that captures ‘temporal’ and ‘force’ factors (Laffaye, Bardy, & Durey, 2007). The data from these analyses have been used to successfully illustrate cross-sectional differences in these factors between male and female athletes, and between athletes from different sport-specific backgrounds (Laffaye, Wagner, & Tombleson, 2014; Panoutsakopoulos, Papachatzis, & Kollias, 2014). It is currently not known, however, how stable the temporal and force structure is when athletes are tested at different time points (i.e., pre-season vs. post-season). Knowledge about whether the principal component structure of CMJ force-time records changes over time would provide important information to practitioners and scientists, because this information could potentially be used to track performance parameters and guide conditioning processes because specific physiological aspects could be targeted (e.g., force factors). The added benefit of investigating the principal component structure over individual discrete variables is that it provides a more holistic way to characterize sport-specific movement signatures (Choukou, Laffaye, & Heugas-De Panafieu, 2012; Laffaye, Wagner, & Tombleson, 2014).
The objective of this study was to use a factor analysis framework and investigate longitudinal changes in the principal component structure of CMJs in female volleyball players over the course of a competitive season. Our hypothesis was that this analysis would identify changes in temporal and force factors between pre- and post-season testing sessions.

METHODS: Participants for this study were recruited from an NCAA Division I volleyball team. Prior to the start of testing, all players were briefed on the scope of the study, and read and signed an informed consent document that was approved by the local institutions Institutional Review Board for Human Subjects Testing. All players reported for two testing sessions: one before and one after their collegiate season.
During each testing session, data from three CMJs were collected with two AMTI force plates. Kinetic data were recorded at 1000 Hz and smoothed with a 4^{th} order low-pass Butterworth filter at 15 Hz. The filtered data from both force plates were summed into a single ground reaction force vector and were differentiated with the central difference method to calculate the rate of force development. Eccentric and concentric movement phases were identified from the velocity- and position-time records, which were derived through numerical

integration of the force-time record. Data extracted for analysis included the movement time (TIME: [s]), eccentric time (EccT: [s]), eccentric-to-total time ratio (EccT:T: [AU – Arbitrary Units]), peak body-mass normalized ground reaction force (PeakF: [N/kg]), peak body-mass normalized rate of force development (PeakRFD: [N/kg/s]).
All biomechanical data from pre- and post-season testing were entered into a factor analysis that used a principal component method and varimax rotation to extract factors and factor scores (Kollias, Hatzitaki, Papaiakovou, & Giatsis, 2001). Paired *t*-tests were used to compare factor scores. In addition, the extracted factor scores were used as inputs to two multiple linear regression models (i.e., One for pre- and one for post-season testing sessions) in order to predict actual jump height. The standardized regression beta-weights for the factor scores were then used to help interpret the effects of these scores on the movement signatures and help determine changes any such over the course of the season (Choukou, Laffaye, & Heugas-De Panafieu, 2012). The *a priori* alpha-level for statistical significance was set at 0.05 for all analyses. All statistical analyses were performed in SPSS 22 (IBM, New York, NY, USA).

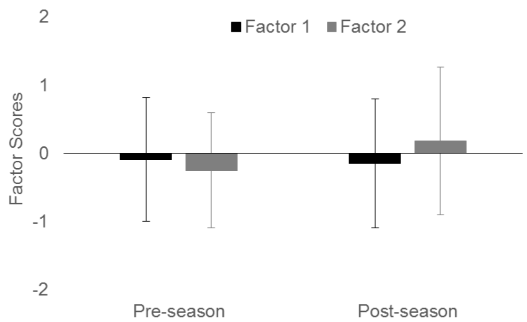
RESULTS: The analysis revealed significant pre- to post-season group changes in Time (p = 0.026) and Peak nRFD (p = 0.04) (Table 1).

Table 1
Pre- and post-season countermovement jump data

	Jump Height (m)	Time (s)	PeakF (N/kg)	Peak nRFD (N/kg/s)	EccT (s)	EccT:T (AU)
Pre	0.29	1.03	22.74	156.53	0.18	0.36
Post	0.28	0.97*	22.35	131.16*	0.19	0.36

* $p < 0.05$ vs. Pre

The factor analysis extracted two factors. The pattern in which the force-time variables loaded onto these factors indicated that one factor captured temporal characteristics (e.g., EccT and EccT:T) and that the other captured force characteristics (e.g., PeakF) of the CMJs. Comparison of factor scores for the group as a whole did not reveal any differences between testing sessions (Figure 1A), while sub-group comparison of factor scores showed large individual differences in factor score changes (Figure 1B).



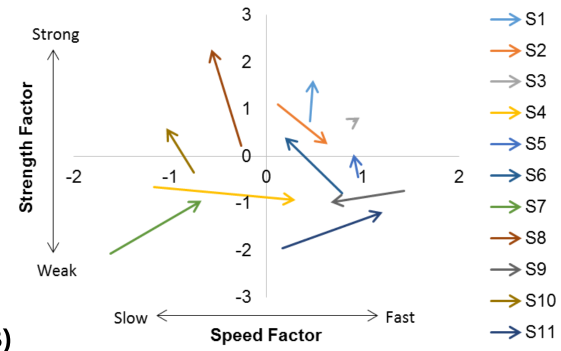


Figure 1: A) Pre- to post-season changes in average factor scores (Factor 1 = Temporal factor, Factor 2 = Force factor). B) Pre- to post-season changes in individual factor scores for all eleven participants (S1-S11). Note: Arrow points in direction of change from pre- to post-season.

The analysis of the regression-based beta-weights showed that at the time of post-season testing the group relied equally on both extracted factors (Factor 1: 0.346; Factor 2: 0.305), whereas at the time of pre-season testing the group relied primarily on one extracted factor (Factor 1: 0.253; Factor 2: 0.592). However, neither of the regression models significantly predicted jump height.

DISCUSSION: The purpose of this study was to investigate changes in the principal component structure of CMJs in female volleyball players over the course of a competitive season. Consistent with previous research, the analysis extracted two factors that could be described as a 'temporal' and a 'force' factor (Laffaye, Bardy, & Durey, 2007). Pre- and post-season comparisons for the temporal and force factor scores indicated that, as a group, the team did not exhibit changes in the principal component structure of CMJs. While group analysis did not reveal any changes in the principal component structure of CMJs, sub-group analysis showed large individual differences between factors scores from pre- and post-season testing sessions.

Individual changes in the principal component structure of CMJs from pre- to post-season testing showed interesting individual changes such as 1) S8 jumped with much greater force factor, but also a smaller (i.e., slower) temporal factor, 2) S4 jumped with a smaller force factor, but greater temporal factor, 3) S1, S6, and S7 jumped with greater force and temporal factors, and 4) S9 had the worst combined change (smaller force & temporal factor). The variety in factor score changes in both direction and magnitude underscore the individual responses of athletes to the demands of a competitive volleyball season. When interpreting the individual changes one needs to keep in mind that they are based on the factor scores, which themselves represent a multi-factorial combination of several variables. A decrease in the temporal factor may therefore represent not only a longer total movement time but also a longer eccentric time, which is known to decrease jump performance (Laffaye, Wagner, & Tombleson, 2014).

Pre- and post-season group comparisons of the discrete countermovement jump variables showed that jump height remained relatively stable. In fact the only variable that changed between pre- and post-season testing sessions was peak body-mass normalized rate of force development, which decreased signficantly. This change may also be responsible for the change in regression-based beta-weights. During pre-season testing, the volleyball players as a group displayed movement signatures that were skewed towards the force factor (i.e., Factor 2), whereas the post-season movement signatures were characterized by more uniform combinations of force and temporal factors. Given that jump height did not change between testing sessions it seems likely that the change in movement signature reflects a compensatory strategy in response to some other physiological modification (e.g., accumulated fatigue).

CONCLUSION: Changes in the principal component structure of CMJs in female volleyball players over the course of the competitive season appeared to be highly individualized. Future research should address individual changes in the principal component structure of CMJs as well changes in the movement signature and try to determine the physiological causes of these changes.

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