SHORT COMMUNICATION

Assessing jump strategy changes in collegiate women's soccer players

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Objectives: This study aimed to assess jump strategy changes and determine which variables were sensitive to change over three days in collegiate women's soccer players.

Methods: This study assessed 16 soccer players using a countermovement jump from pre- to post-practice for three consecutive days. A paired t-test was conducted for each day of testing to determine the differences in performance pre- to post-practice. A single-subject analysis was conducted to determine whether the individuals experienced a true potential change.

Results: Significant changes were observed on each day for propulsive impulse. Jump height and RSImod were significant on Days 2 and 3. At the individual level, not every participant saw improvements pre- to post-practice for each day.

Conclusions: This study shows that when assessed for three days, collegiate women's soccer players see similar changes in jump performance pre- to post-practice. The intensity of the session is important for understanding how CMJ performance will be impacted post-practice. Coaches and staff should consider session intensity when looking at how individuals respond post-practice.

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Key words: ■ countermovement jump ■ single-subject analysis ■ acute monitoring ■ female athletes

INTRODUCTION

Soccer athletes typically encounter high physical demands during their training sessions.[1] These athletes can cover distances ranging from 2,500 to 3,000 meters during a standard collegiate soccer practice[1]. Athletes can be susceptible to acute fatigue from a single practice. If not addressed early, acute fatigue may progress to chronic fatigue, a consequence of inadequate recovery, which increases the likelihood of injury among athletes.[2] Impaired neuromuscular control can reduce coordination and reaction times, leading to inadequate responses. Most sports actions take 200-500 milliseconds, and delayed reactions could cause injury.[3] This highlights the need for close athlete monitoring to assess how practice impacts them, allowing proper recovery to prevent further fatigue.

One of the most commonly used physical performance tests is the countermovement jump due to its sensitivity to neuromuscular changes, particularly in force production.[4] The test itself is quick and easy to implement, making it useful when testing under time constraints, a common limitation in high-performance populations.[5] One of the issues with the CMJ literature is that jump height is typically the only metric reported.[6] The issue with jump height is that it is not as sensitive to neuromuscular fatigue as other metrics.[7] This highlights the need for additional metrics when monitoring our athletes. One potential option is to monitor how athletes change their jump strategy, which is characterized by the technique and mechanics that individuals use to optimize performance.[8]

Current studies often assess athletes acutely, usually within a single day, assuming these responses represent typical practice.[9] However, this approach overlooks individual differences and day-to-day variability, especially without tracking the rate of perceived exertion (RPE). Group testing further complicates understanding fatigue because it varies individually.[10] Combining multiple monitoring methods could improve insights into acute performance changes. These studies emphasize that robust methodologies are needed to provide a more definitive conclusion on the impact of acute performance. The primary goal of this investigation was to examine which metrics changed from pre- to post-practice in collegiate women's soccer each day across three consecutive training sessions. Additionally, this investigation sought to examine how jump strategy changed from pre- to post-practice. We hypothesized that jump strategy would change from pre- to

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post-practice on each of the three consecutive training days.

METHODS

An observational approach was used to investigate changes in vertical jump performance metrics over three days. Testing occurred pre- and post-practice over three consecutive days (Day 1, Day 2, & Day 3). Each day followed the same protocol in the following order: a self-determined warm-up, pre-testing (PRE), sport-specific training, post-testing (POST), and a cool-down. Participants performed three maximal-effort CMJ trials, both pre-and post-training. The session's internal training load was taken approximately five minutes post-practice using the CR10 Borg Scale.[11] Each participant engaged in all team activities for three days. Each practice's breakdown is listed in Table 1.

Participants

Sixteen NCAA Division I (DI) women soccer players (19.2 ± 1.26 yrs., 1.67 ± 0.11 m, 65.33 ± 8.73 kg) participated in this study. All participants were cleared for sports participation by the university's sports medicine staff and were free of injury at the time of each testing session. Athletes were included in the study if they were free of any lower-body musculoskeletal and neuromuscular injuries. Athletes were excluded if they had undergone any lower-body surgery within the past six months. This study was approved by the Institutional Review Board at the university. Each participant provided written informed consent before any testing was conducted.

Procedures

CMJ

Each jump test session followed the same procedures. Each participant completed a self-determined warmup that consisted of dynamic lower-body movements as well as submaximal vertical jumps. They performed three CMJ trials on a portable force platform (AMTI, AccuPower, Watertown, MA, USA). Each trial involved placing a 1.83 m PVC pipe on their upper back, like in a back squat. Participants used self-selected foot width and countermovement depth[12]. Before jumping, they stood still for at least one second to allow body mass calculation. Instructions: "jump as high as possible in 3, 2, 1, go," with 20 seconds rest between trials. A trial was acceptable if they landed back on the plate and kept the dowel in place.

RPE

Each participant's RPE was collected approximately five minutes after the training session using the modified CR10 Borg Scale.[11] The RPE test was conducted by asking each participant, "How difficult was your session?" with one being very easy with minimal effort and 10 being maximal effort with no ability to continue the exercise.[11] Participants were told to answer based on the entire session and not just the most recent intensity. All participants were familiarized with the scale to assess the rate of perceived exertion before the study was conducted. Session rate of perceived exertion (sRPE) was calculated by taking each individual's RPE and multiplying it by the session duration.

Data Analysis

For each trial, all force-time data were collected at 1000 Hz. Raw force-time data were exported into a custom MATLAB script (2024a MATLAB, MathWorks, Natick, Massachusetts, USA) for analysis. Each trial was divided into different phases based on the definitions of McMahon et al.[13]. The phases of interest in this study are the braking and propulsive phases. Movement onset was calculated by taking body mass minus five standard deviations (5SD).[13] The braking phase is defined as the point at which the vertical ground reaction force surpasses the body mass calculated during the second of quiet standing.[13] This phase ends when velocity is equal to zero[13]. The propulsive phase was defined as the end of the braking phase to when the ground reaction force was less than 10N.[13] Jump height (JH) was calculated based on takeoff velocity. RSImodified (RSImod) is calculated by dividing JH by time-to-takeoff (TTT). This metric reflects an individual's ability to generate maximum force quickly.[14] System weight refers to the combined weight of the individual and the dowel, measured in Newtons during the weighing phase. This value is used to normalize force outputs for accurate inter-individual comparisons.[13]

Statistical Analyses

All variables were assessed for normality using the Shapiro–Wilk test. Variability was assessed using intraclass correlation coefficients (ICC) and coefficients of variation (CV). A two-way random ICC was used to determine the amount of random error between the subject and the assessment, and the absolute agreement. Absolute agreement was used to determine whether all trials agreed with each other. Variability was deemed acceptable when ICC values were above 0.80 and CV values were below 10%.[12] This study used a single-subject analysis. A biological window of variation was created by adding and subtracting each individual's CV from their mean, which consisted of three trials. If post-testing means fell outside this window, then it can be deemed that

Table 1. Main Training Program and RPE and sRPE for Each Day

Length of Practice		RPE	sRPE	Sport-Specific Training	Emphasis
Day 1	75	3.87 ± 1.03	290.63 ± 76.85	Constraints-Based Skill	Passing Drills
Day 2	75	3.38 ± 1.41	253.13 ± 105.62	Small-Sided Game	Tactical Drills
Day 3	90	3.75 ± 1.29	337.50 ± 116.19	Simulated Game	Tactical Drills

RPE: rate of perceived exertion; sRPE: session rate of perceived exertion a change may have occurred. A CV was calculated for each day using the participant's PRE values. Individual CVs were calculated in a customized Excel spreadsheet (Microsoft Corp., Redmond, WA, USA). Paired t-tests assessed performance differences between pre- and post-tests. A Bonferroni correction was applied to reduce the Type I error, which resulted in an a priori alpha level of < 0.001. Effect sizes, calculated as Hedges' g, were interpreted as trivial (< 0.20), small (0.2-0.49), moderate (0.5-0.79), and large (> 0.80). One-way ANOVA evaluated RPE differences across three days and pre-value consistency. Significance was set at $p < 0.05$. All analyses were conducted in SPSS 24 (SPSS Inc., IBM, Chicago, IL, USA).

RESULTS

Reliability data is displayed in Table 2. Almost all metrics achieved an acceptable level of reliability. However, mean braking force, force at zero velocity, and countermovement depth were slightly below this threshold. This study examined that propulsive impulse consistently changed across the three days. RSImod and JH were statistically significant on Days 2 and 3. Although not statistically significant, several metrics displayed a large effect, including mean braking force (Day 2), braking impulse (Day 3), mean propulsive force (Days 2 and 3), JH (Day 1), and RSImod (Day 1)(Table 3). RPE and sRPE values are listed in Table 1. RPE values were not significantly different across the three days ($p = 0.62$); however, sRPE values were significantly different across the three days ($p = 0.07$). This is likely due to the increased session duration on the third day. The pre-practice values across the three days were not significantly different from each other. This indicates that the athletes returned to baseline for each day (*p*-value between 0.431 and 0.986).

The individual changes for the metrics that were statistically significant are displayed in Figure 1A-C. The solid line represents when the individual's post-test value falls outside their biological window of variation. The dashed line is when individuals fell within their biological window of variation. These figures indicate that the majority of individuals across the three days fell outside their biological window of variation. Figure 1D displays changes from pre-testing (gray) on Day 3 to post-testing (black) on Day 3. The force-time curve shows increased force output overall from pre- to post-testing on Day 3. This enhancement was most evident during the propulsive phase, with post-testing values being consistently higher than pre-testing values during the latter portion of the jump. Although the propulsive force was not significant across the three days, the force-time curve shows that force output did increase pre- to post-testing.

Table 2. Intraclass Correlation (ICC) and Coefficient of Correlation (CV)

	Day 1		Day 2		Day 3	
	ICC (95%CI)	CV (95%CI)	ICC (95%CI)	CV (95%CI)	ICC (95%CI)	CV% (95%CI)
System Weight (N)	0.99 (0.99-1.00)	0.49 (0.66-0.32)	0.99 (0.99-1.00)	0.51 (0.30-0.71)	0.99 (0.99-1.00)	0.42 (0.19-0.65)
Mean Braking Force (N)	0.86 (0.65-0.94)	14.38 (11.61-17.16)	0.88 (0.76-0.95)	15.33 (10.39-20.28)	0.93 (0.86-0.97)	13.52 (9.96-17.08)
Braking Duration (ms)	0.85 (0.68-0.94)	8.64 (6.27-11.02)	0.79 (0.57-0.90)	9.33 (5.74-12.92)	0.90 (0.80-0.95)	8.71 (5.28-12.14)
Braking Impulse (N·s)	0.94 (0.85-0.98)	8.36 (6.48-10.23)	0.94 (0.89-0.98)	7.42 (4.85-10.00)	0.96 (0.93-0.98)	7.01 (5.01-9.00)
Force at Zero Velocity (N)	0.87 (0.73-0.95)	8.07 (5.57-10.56)	0.92 (0.84-0.96)	9.70 (6.09-13.31)	0.89 (0.79-0.95)	10.51 (6.48-14.54)
Mean Propulsive Force (N)	0.94 (0.89-0.98)	5.16 (2.45-7.87)	0.97 (0.94-0.99)	5.07 (3.63-6.51)	0.97 (0.95-0.99)	5.12 (3.91-6.33)
Propulsive Duration (ms)	0.96 (0.91-0.98)	3.42 (2.35-4.50)	0.95 (0.89-0.98)	3.78 (2.34-5.22)	0.96 (0.93-0.98)	4.26 (2.87-5.66)
Propulsive Impulse (N·s)	0.99 (0.98-0.99)	1.70 (1.12-2.28)	0.98 (0.97-0.99)	2.73 (1.68-3.79)	0.99 (0.98-0.99)	1.85 (1.28-2.43)
Jump Height (m)	0.98 (0.96-0.99)	3.29 (1.88-4.69)	0.96 (0.91-0.98)	5.18 (3.20-7.16)	0.98 (0.96-0.99)	4.09 (2.97-5.20)
Time-To-Takeoff (s)	0.89 (0.79-0.95)	7.46 (2.83-12.08)	0.88 (0.76-0.95)	6.55 (6.67-8.43)	0.93 (0.86-0.97)	5.92 (4.76-7.08)
RSImod	0.93 (0.86-0.97)	8.67 (4.82-12.51)	0.94 (0.88-0.97)	9.13 (6.84-11.42)	0.96 (0.91-0.98)	8.36 (6.62-10.09)
Countermovement Depth (m)	0.94 (0.88-0.98)	11.75 (2.10-25.61)	0.94 (0.88-0.97)	6.76 (4.64-8.89)	0.96 (0.93-0.98)	5.78 (3.76-7.80)

CI: Confidence Interval

RSImod = Reactive Strength Index Modified

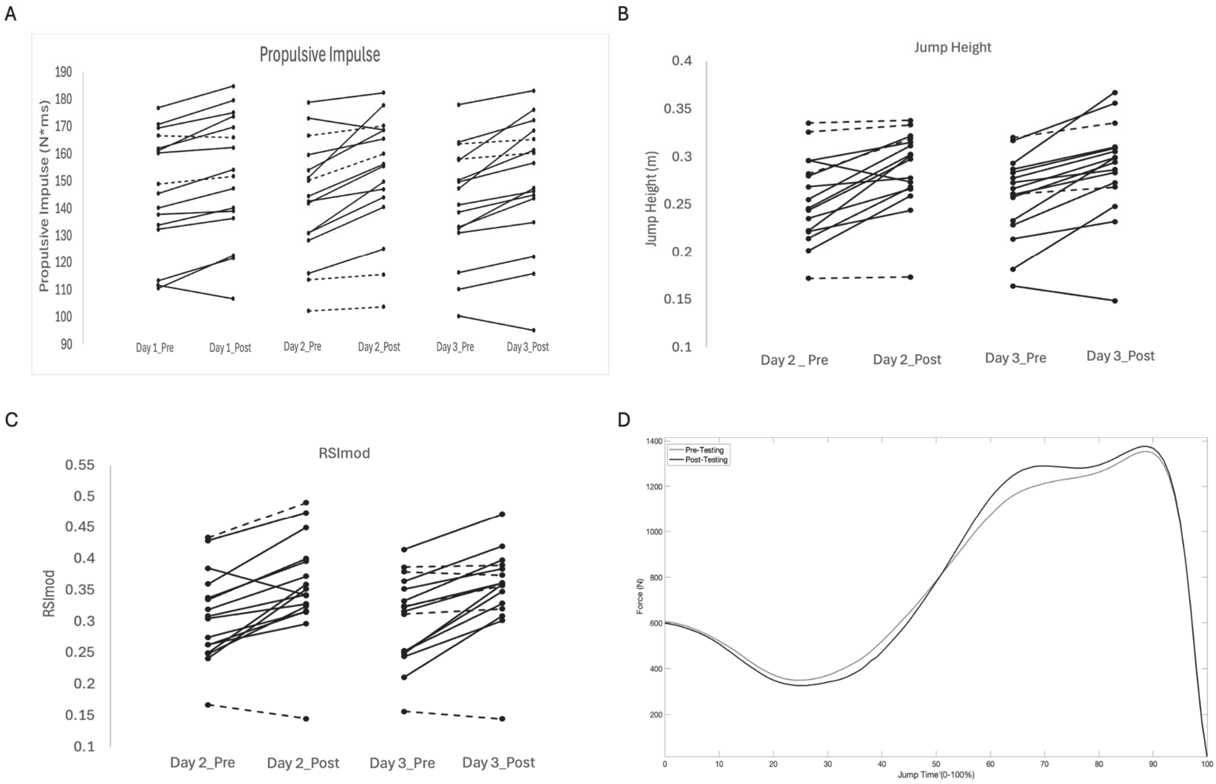

Figure 1. F The individual responses for propulsive impulse for days 1, 2, and 3 and jump height and RSImod for days 2 and 3, measuring pre- and post-practice. Solid lines represent individuals who fell outside their biological window, and the dashed lines represent individuals who fell within their biological window (**A, B, and C**). Represents the force-time curve from Day 3, comparing pre- (gray) and post-practice (black) CMJ performance (**D**).

DISCUSSION

This study aimed to assess changes in jump strategy and identify metrics that may be sensitive to acute changes in a DI women's soccer team. This study observed that propulsive impulse significantly increased across the three consecutive practice days. Additionally, RSImod and JH significantly increased pre- to post-practice on Day 2 and Day 3. When looking at these results from an individual perspective, we observed that a majority of the participants improved in these subsequent metrics across the associated days. These results support our hypothesis that participants would alter their jump strategy across consecutive practices.

A factor that likely contributed to performance improvement was post-activation performance enhancement (PAPE). PAPE occurs when an individual undergoes a high-intensity voluntary conditioning that leads to the improvement of voluntary muscular performance but lacks the qualities of classical post-activation potentiation.[15] Although research is conflicting about how PAPE is impacted by fatigue, the low intensity of practice likely allowed PAPE to occur, resulting in improved performance post-practice.[16] Previous research conflicts with this study, which found CMJ performance typically decreases acutely.[17,18] The key difference is session intensity. Studies reporting higher RPE[17,18] had athletes in greater fatigue, explaining performance declines. This study's lower RPE suggests less fatigue, allowing PAPE to manifest, unlike in highly fatigued athletes, where fatigue masks performance gains. Coaches should consider session intensity when monitoring athletes, as it affects performance.

Our results suggest PAPE might cause performance changes during training, but other factors, like a dynamic warm-up before the pretest, also impacted results. Pagaduan et al. showed that a general plus dynamic warm-up significantly increases jump height, possibly affecting PRE values daily.[19] However, since performance improved after practice, the warm-up didn't negatively influence findings. Coaches using CMJ to measure performance should note that warm-ups can inflate pre-test results and plan accordingly.

This study shows that there are several metrics that can be reliable for monitoring performance in this associated population. They can also help coaches to better understand how session intensity can impact performance pre- to post-practice. A decline in post-practice CMJ performance that is inconsistent with the associated training load may indicate underlying performance issues. In these instances, individualized monitoring and targeted training may be warranted to mitigate any potential decrements to performance.

The main limitation of this study is the session intensity across the three days. Participants in this study rated their RPE relatively low, which is inconsistent with the previous lit-

Table 3. Countermovement Jump Changes Across Three Days

	Day	PRE	POST	p	g
System Weight (N)	1	635.27 ± 85.55	634.30 ± 82.86	0.70	0.10
	2	627.11 ± 75.54	629.21 ± 84.08	0.53	-0.15
	3	624.21 ± 81.84	621.01 ± 82.08	0.01	0.70
Mean Braking Force (N)	1	361.46 ± 86.72	413.31 ± 109.06	0.006	-0.76
	2	340.36 ± 86.58	400.71 ± 120.30	0.004	-0.80
	3	335.69 ± 103.40	387.12 ± 110.93	0.005	-0.78
Braking Duration (ms)	1	188.40 ± 26.70	173.92 ± 28.04	0.02	0.62
	2	190.75 ± 35.37	185.21 ± 57.19	0.60	0.13
	3	190.13 ± 48.05	176.42 ± 31.23	0.05	0.52
Braking Impulse (N·s)	1	66.22 ± 13.37	69.60 ± 15.78	0.02	-0.61
	2	62.31 ± 15.68	67.63 ± 15.68	0.02	-0.65
	3	60.09 ± 14.06	65.68 ± 16.22	0.004	-0.80
Mean Propulsive Force (N)	1	541.01 ± 97.74	585.56 ± 141.04	0.007	-0.74
	2	528.26 ± 106.90	566.76 ± 137.74	0.001	-0.96
	3	532.92 ± 120.62	573.95 ± 125.92	0.004	-0.82
Propulsive Duration (ms)	1	275.33 ± 29.95	265.42 ± 35.48	0.04	0.55
	2	273.67 ± 33.26	274.06 ± 43.93	0.95	-0.01
	3	271.96 ± 39.39	265.75 ± 35.41	0.15	0.36
Propulsive Impulse (N·s)	1*	146.30 ± 21.87	151.88 ± 22.92	< 0.001	-1.14
	2*	142.75 ± 21.63	148.35 ± 25.71	< 0.001	-1.14
	3*	142.03 ± 21.01	149.60 ± 23.66	< 0.001	-1.10
Force at Zero Velocity (N)	1	685.42 ± 120.70	739.64 ± 191.09	0.03	-0.56
	2	636.97 ± 132.53	725.93 ± 185.20	0.01	-0.68
	3	634.27 ± 151.73	712.23 ± 176.86	0.01	-0.66
Countermovement Depth (m)	1	0.26 ± 0.08	0.26 ± 0.07	0.08	0.45
	2	0.27 ± 0.05	0.28 ± 0.05	0.17	-0.34
	3	0.26 ± 0.05	0.27 ± 0.05	0.04	-0.54
Time-to-Takeoff (s)	1	0.88 ± 0.11	0.84 ± 0.18	0.37	0.17
	2	0.85 ± 0.11	0.84 ± 0.14	0.59	0.22
	3	0.87 ± 0.12	0.84 ± 0.10	0.07	0.47
Jump Height (m)	1	0.26 ± 0.04	0.29 ± 0.05	0.004	-0.82
	2*	0.26 ± 0.05	0.28 ± 0.05	< 0.001	-1.01
	3*	0.26 ± 0.04	0.29 ± 0.05	< 0.001	-1.26
RSImod	1	0.31 ± 0.07	0.36 ± 0.09	0.002	-0.90
	2*	0.31 ± 0.07	0.35 ± 0.09	< 0.001	-1.14
	3*	0.30 ± 0.07	0.35 ± 0.07	< 0.001	-1.21

* p < 0.001.
RSImod: reactive strength index modified
g = Hedge's effect size

erature. While this is a typical intensity for this specific sample size, future studies should see how more intense soccer practices alter CMJ performance pre- to post-practice.

This study is one of the first to monitor athletes across multiple days while recording the RPE and individual changes. This study found that bidirectional changes occurred in athletes across all three days, with some individuals performing negatively across days. However, the RPE remained relatively consistent and low across the three days. This study found that collegiate women's soccer players were able to manipulate their jump strategy pre- to post-practice by switching which phase they emphasized throughout the jump. The inclusion of these factors can provide a more in-depth analysis, allowing practitioners to make better data-driven decisions regarding potential influences on performance changes.

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CONFLICTS OF INTEREST

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