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Assessing Jump Performance: Intra and Interday reliability and sensitivity of Countermovement Jump and Drop Jump Measurements Using Force Platforms

Jaime González-García [1,2,*], Manuel Conejero [1] and Jorge Gutiérrez-Hellín [1]

[1] xercise and Sport Sciences, Faculty of Health Science, Universidad Francisco de Vitoria, 28223 Pozuelo, Spain
[2] Camilo José Cela University. Faculty of Health Science Madrid, Spain
* Correspondence: jaime.gonzalez@ufv.es

Abstract: Understanding the reliability and sensitivity of jump testing is essential to determine the neuromuscular progress of athletes and make informed decisions. This study aimed to assess the reliability and sensitivity of countermovement jump (CMJ) and drop jump (DJ) tests metrics in female volleyball players. Sixteen semi-professional female volleyball players participated in the study. Intrasession and intersession reliability of CMJ and DJ metrics were evaluated using a randomized cross-over design. Dual force platform was used to collect data, and several dependent variables were calculated using forward dynamics. Intraclass correlation coefficients (ICC), coefficients of variation (CV) and minimum difference (MD) were calculated. The third attempt presented the highest values for both test, and changes in jump strategy in DJ. CMJ is consistent across sessions, while DJ also shows intersession differences ($p<0.05$) in 11 out of 15 variables. Most CMJ variables exhibit excellent reliability while DJ variables have lower reliability and higher variability. Concentric and eccentric impulses for DJ showed excellent reliability. Most CMJ variables showed excellent reliability and variability, DJ had lower reliability, higher variability, and lower sensitivity. These findings provide valuable information when assessing athletes' performance and highlight the reliability, sensitivity, and variability in jump performance for CMJ and DJ tests.

Keywords: reliability; force platform; countermovement jump; drop jump; volleyball; CV; ICC; women; sport; jump

1. Introduction

In high-performance sports settings, monitoring athlete's readiness, fatigue, and subsequent recovery in response to training loads is critical to optimize performance outcomes [1,2]. Effective athlete monitoring strategies should be minimally invasive, reliable, and time-efficient to avoid stress or fatigue on the athlete [2,3]. The countermovement jump (CMJ) and drop jump (DJ) tests widely used for evaluating lower-limb power and neuromuscular function in athletes due to their simplicity, non-fatiguing nature, and time efficiency [4–9]. Therefore, the assessment of vertical jump performance can be used as a valuable tool for coaches and trainers to monitor athletes' physical progress.

These tests have been studied in various populations, especially the CMJ [4,6], but research is limited regarding the sensitivity and reliability of these tests in female athletes specialized in jumping. Most studies that have examined the reliability of vertical jump tests have been predominantly conducted in non-specialized sports populations for jumping (i.e., vertical jumping is not the primary movement pattern during competition and/or training). The characteristics of the specific sports activity can lead to adaptations over time in contraction time and force production, both in CMJ and DJ, providing different jump patterns as previously explained through principal

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component analysis [10]. On the other hand, when the reliability of these tests has been analyzed in volleyball populations, the research has primarily focused on men. However, none of these studies have reported on the sensitivity of jumping metrics of both tests in female volleyball players, despite possible differences that may arise due to athletes' sport background and gender [11].

Furthermore, force plate jump testing is becoming more accessible to training coaches due to advances in technology and reductions in cost [12]. In this sense, utilizing force platform technology for analyzing vertical jump kinetics, kinematics and jump strategy offers several advantages as it allows for a more comprehensive neuromuscular evaluation beyond just outcome measures such as jump height or contact time [13]. By including those force-time and strategy metrics, practitioners can gain valuable insights into an athlete's neuromuscular function as seems to be more sensitive to change compared to jump height measures, particularly in scenarios such as after intense exercise, returning from injury, during long-term athlete development, and when assessing neuromuscular function across different age groups [7,14]. While the advantages of force platform technology are clear, there are several factors that need careful consideration. Numerous studies have recognized the limitations of relying solely on outcome measures and emphasized the importance of concurrently monitoring kinetics, kinematics and jump strategy as well [7,13]. However, several factors may affect the reliability of volitional tests, such as fatigue, learning effects, motivation and/or hormonal status that may be considered as a source of measurement error during testing [15]. Despite the valuable information that CMJ and DJ metrics obtained with forces platforms can provide in the assessment of female jumping players' performance [16–18] and the probably differences in jumping force time metrics in comparison to other modalities athletes [10,11], the intrasession (consistency of observations within a session) and interday (consistency between different days/weeks) reliability and sensitivity of the CMJ and DJ force-time metrics remain under-researched. Therefore, it seems crucial to evaluate the reliability and sensitivity of these tests with the aim of providing accurate information and minimum cut-off sensitivity values on metrics associated to athletes' performance and neuromuscular status.

The hypothesis for this study is that the CMJ and DJ tests using force platforms will exhibit high reliability and sensitivity, both within a single testing session (intrasession reliability) and across different testing days (interday reliability), in measuring lower-limb neuromuscular function and jump strategy in semi-professional female volleyball players. In summary, this study aims to contribute to the existing literature by providing valuable information on the reliability and sensitivity of the CMJ and DJ outcomes, kinetics, kinematics and jump strategy using force platforms in semi-professional female volleyball players. This information can allow volleyball coaches and strength and conditioning professionals to understand the variability of the monitored metrics of the vertical jump. This will lead them to rely on and have confidence when making training decisions based on objective data.

2. Materials and Methods

To identify the intra and interday reliability of the CMJ an DJ metrics, a randomized cross-over within subject design was used. Participants performed 3 CMJs and 3 DJs trials on a force platform, in a randomized order, separated by one week. Each attempt was separated by at least 3 mins of passive recovery. Each jump for both tests were performed on a Force-Decks FD4000 Dual Force platform (ForceDecks London, United Kingdom) with a sampling rate of 1,000 Hz. The vertical ground reaction force data obtained from each jump was inputted into the ForceDecks software (ForceDecks, London, United Kingdom) for analysis. A fourth-order Butterworth low-pass filter with a cut-off frequency of 50 Hz was used to generate all the dependent variables for each jump. All dependent variables were calculates using forward dynamics [12]. One week prior to the first testing session, participants performed a familiarization session to ensure an appropriate CMJ and DJ technique. For participants' description, body composition was analyzed through bioelectrical impedance [19]. All assessments were conducted in a room adjacent to a multi-sport indoor court within the same sports facility.

Sixteen volunteers of the same semi-professional female volleyball team were recruited for this study (Mean±SD: age=20.3±2.47; weight=61.36±8.42; height=1.67±0.04; body mass index=21.96±2.62; fat percentage=24.70±4.91; fat mass=15.69±4.39: fat free mass=15.69±4.08; basal metabolic rate=1453.78±108.29). Prior to testing, all participants underwent a thorough medical screening as per their team's medical protocols to ensure they were free from any lower-body injuries that could potentially impact their jumping performance. Players with a lower body injury in the 3 months prior to the first testing session were excluded from the study. Additionally, all participants had at least two years of experience in strength and power training and provided written consent to participate in the university research ethics committee-approved project.

During the in-season training period, all testing was conducted within a 3-week time frame. Each subject participated in 3 different sessions of jump assessments. One familiarization session and two evaluation sessions. Participants´ performed 3 Countermovement Jump (CMJ) and 3 Drop Jumps (DJ) exercises in each session. The order of the jump type was randomized, and during the second evaluation session, subjects performed the jumps in the same order. A rest period of at least 3 minutes was given between each jump trial. To ensure consistency, both testing sessions were conducted within the same hour in the afternoon, between 19:00 and 20:00, as previous literature has indicated the influence of time of day on jump performance [20,21]. To maintain standardization, testing was performed during the same training day of their typical weekly microcycle structure. Training loads were matched 72 hours before both testing sessions, with sport-specific practice duration matched in the days leading up to both trial sessions. Additionally, subjects were instructed not to engage in any physical exertion before arriving for testing. For ecological validity, subjects wore their standard practice gear, including their chosen shoes, and they were required to wear the same pair of shoes during both testing sessions. All testing was conducted at the participants´ volleyball training facility. No dietary restrictions were implemented; however, athletes were advised to maintain their normal dietary intake. For testing days, participants were asked to refrain from alcohol and caffeine for 24 hours prior to the session to minimize their impact on jump performance [22,23]. To minimize the effect of instructions on jumping performance, the instructions provided to participants were standardized. A 3-2-1 countdown followed by a verbal stimulus was performed to support maximal effort during jump execution. A standardized warm-up was performed before each testing session using the RAMP (Rise – Activate and mobilize – Potentiate)[24] method, consisting of 5 minutes of jogging, 5 minutes of dynamic stretching, mobility, and core activation, ending with 1x5 CMJ and 1x5 rebound CMJ. 2 minutes of passive rest was provided between each warmup block. The warm-up gradually increased in intensity to prepare participants for maximal performance during jump testing.

To ensure proper weighing of the subjects (and thus a proper forward dynamic process) the force platforms were zeroed. Immediately after, the subjects were placed on the force platforms and held as still as possible for at least 1 second to ensure proper weighing [14]. The center-of-mass (COM) velocity was calculated by dividing the vertical ground reaction force (minus body weight) by body mass and then integrating the product using the trapezoid rule [25]. Instantaneous power was calculated by multiplying the vertical force by the COM velocity. COM displacement was determined by double integrating the vertical force data. To consider a jump successful, participants had to perform it with their arms akimbo and remain completely still for at least one second during the weighing phase. The onset of movement was determined when a drop of 20 N from the baseline force (recorded during the weighing phase) was observed. Several variables derived of the force-time data were included in the reliability analysis (Tables 1 and 2) because they may be of interest to strength and conditioning coaches for different reasons [7,26]. For intersession reliability the mean of the 3 jumps was used for analysis while intersession reliability was calculated with the 3 jumps of the first testing day.

Table 1. Repeatability of CMJ F-T derived variables.

	Trial 1		Trial 2		Trial 3		p value	ICC (95%CI)			SEM	SEM (%)	MD 95%CI	MD95% CI(%)	MD 90%CI	MD90% CI(%)	CV (%)
	Mean	SD	Mean	SD	Mean	SD		ICC	UL	LL							
Jump outcomes																	
Jump Height (Imp-Mom) [cm]	27,74	4,85	28,26	5,08	29,00	4,79	**0,012**	0,97	0,93	0,99	1,25	4,39	3,45	12,18	2,90	10,22	4,06
Jump Height (Flight Time) [cm]	29,29	5,58	30,12	5,81	31,11	5,30	**0,003**	0,96	0,92	0,98	1,60	5,29	4,43	14,67	3,72	12,31	4,71
RSI-modified [m/s]	0,42	0,08	0,44	0,08	0,44	0,07	**0,028**	0,91	0,79	0,96	0,03	6,51	0,08	18,04	0,07	15,14	5,85
Kinetics																	
Concentric Mean Force [N]	1205,6	156,3	1218,6	181,7	1211,4	154,0	0,418	0,99	0,96	1,00	27,26	2,25	75,56	6,24	63,42	5,23	1,89
Concentric Mean Force / BM [N/kg]	18,70	1,01	18,88	1,26	18,81	1,26	0,476	0,91	0,76	0,97	0,41	2,20	1,15	6,11	0,96	5,13	1,94
Concentric Peak Force [N]	1548,8	204,7	1565,1	243,7	1568,9	213,0	0,495	0,97	0,91	0,99	49,87	3,19	138,2	8,86	116,0	7,43	2,67
Concentric Peak Force / BM [N/kg]	24,07	2,15	24,26	2,18	24,34	1,92	0,259	0,90	0,74	0,98	0,75	3,08	2,07	8,54	1,74	7,17	2,72
Concentric Impulse [N s]	149,5	17,52	151,0	19,22	152,9	18,19	**0,011**	0,98	0,96	0,99	3,36	2,22	9,32	6,17	7,82	5,18	2,01
Concentric Impulse-50ms [N s]	42,31	7,27	43,76	8,47	43,96	6,55	0,169	0,92	0,78	0,97	2,70	6,23	7,48	17,26	6,28	14,48	5,35
Concentric Impulse-100ms [N s]	78,23	13,06	80,88	16,25	80,29	12,28	0,247	0,92	0,79	0,97	4,66	5,84	12,93	16,20	10,85	13,59	5,02
Eccentric Mean Force [N]	635,0	90,15	634,9	89,98	635,3	90,02	0,689	1,00	1,00	1,00	1,44	0,23	3,98	0,63	3,34	0,53	0,21
Eccentric Peak Force [N]	1533,2	236,1	1578,6	278,4	1575,0	216,4	0,205	0,91	0,77	0,97	79,71	5,10	220,9	14,14	185,4	11,87	3,83
Eccentric Peak Force / BM [N/kg]	23,83	2,88	24,43	2,73	24,43	1,95	0,237	0,79	0,50	0,92	1,14	4,70	3,16	13,03	2,65	10,94	3,86
Force at Zero Velocity [N]	1518,6	231,2	1555,3	244,5	1566,8	214,4	0,073	0,96	0,89	0,90	62,86	4,06	174,2	11,26	146,2	9,45	3,30
Eccentric Braking Impulse [N s]	41,25	12,90	45,95	13,89	47,76	15,73	**0,046**	0,81	0,55	0,93	7,79	17,32	21,59	48,00	18,12	40,29	16,23
Eccentric Braking RFD [N/s]	5220,1	2104,3	5855,6	2640,1	5443,2	1661,1	0,113	0,89	0,71	0,96	876,8	15,92	2430,2	44,14	2039,7	37,04	12,38
Kinematics																	
Concentric Mean Power [W]	1574,0	179,8	1609,4	222,0	1621,3	182,6	**0,039**	0,95	0,87	0,98	55,72	3,48	154,5	9,64	129,6	8,09	3,15
Concentric Mean Power / BM [W/kg]	24,53	2,61	25,0	2,79	25,29	2,87	**0,034**	0,94	0,84	0,98	0,86	3,44	2,38	9,54	2,00	8,01	3,20

Peak Power [W]	2810,5	370,2	2830,00	401,9	2841,7	347,7	0,560	0,97	0,91	0,99	80,96	2,86	224,4	7,94	188,3	6,66	2,64
Peak Power / BM [W/kg]	43,75	5,04	43,98	4,88	44,24	4,86	0,561	0,95	0,87	0,98	1,25	2,85	3,48	7,91	2,92	6,64	2,67
Concentric Peak Velocity [m/s]	2,46	0,19	2,47	0,18	2,50	0,18	**0,006**	0,97	0,92	0,99	0,04	1,79	0,12	4,96	0,10	4,16	1,72
Velocity at Peak Power [m/s]	2,22	0,18	2,24	0,18	2,27	0,17	**0,023**	0,95	0,87	0,98	0,05	2,20	0,14	6,09	0,11	5,11	2,01
Eccentric Mean Power [W]	413,8	83,01	433,6	83,63	435,8	90,68	0,093	0,95	0,85	0,98	31,74	7,42	87,97	20,57	73,83	17,26	6,49
Eccentric Mean Power / BM [W/kg]	6,46	1,29	6,75	1,17	6,74	1,10	0,139	0,93	0,80	0,97	0,47	7,08	1,31	19,63	1,10	16,47	6,48
Eccentric Peak Power [W]	1263,9	435,0	1393,6	509,58	1313,9	331,7	0,144	0,88	0,70	0,96	187,9	14,19	520,8	39,34	437,1	33,02	10,40
Eccentric Peak Power / BM [W/kg]	19,76	6,78	21,49	6,72	20,32	4,32	0,175	0,87	0,67	0,95	2,67	13,01	7,40	36,05	6,21	30,26	10,41
Eccentric Peak Velocity [m/s]	-1,29	0,28	-1,35	0,23	-1,35	0,22	0,105	0,97	0,93	0,99	0,09	-6,57	0,24	-18,22	0,20	-15,29	5,86
Jump strategy																	
Contraction Time [ms]	714,0	116,0	691,4	99,68	716,8	89,20	0,198	0,94	0,85	0,98	43,39	6,13	120,3	17,00	100,9	14,27	4,86
Concentric Duration [ms]	263,4	32,84	262,3	38,90	267,5	37,51	0,430	0,94	0,84	0,98	11,82	4,47	32,76	12,39	27,49	10,40	3,70
Eccentric Duration [ms]	450,6	90,44	429,2	68,90	449,3	60,92	0,164	0,94	0,84	0,98	35,61	8,04	98,71	22,28	82,84	18,70	6,28
Countermovement Depth [cm]	29,30	6,13	29,52	6,65	30,96	6,70	**0,034**	0,95	0,86	0,98	2,01	6,73	5,58	18,65	4,69	15,66	5,71

Table 2. Within week reliability of CMJ F-T derived variables.

	Day 1		Day 2		p value	ICC (95%CI)			SEM	SEM (%)	MD 95%CI	MD95% CI(%)	MD 90%CI	MD90% CI(%)	CV (%)
	Mean	SD	Mean	SD		ICC	UL	LL							
Jump outcomes															
Jump Height (Imp-Mom) [cm]	28,32	4,80	28,51	4,32	0,341	0,93	0,81	0,97	1,28	4,49	3,54	12,46	2,97	10,45	3,75
Jump Height (Flight Time) [cm]	30,18	5,44	30,09	4,91	0,438	0,92	0,79	0,97	1,52	5,05	4,22	14,00	3,54	11,75	4,30
RSI-modified [m/s]	0,43	0,07	0,42	0,07	0,128	0,92	0,80	0,97	0,02	4,97	0,06	13,79	0,05	11,57	4,25
Kinetics															
Concentric Mean Force [N]	1211,8	162,9	1217,8	164,9	0,292	0,97	0,92	0,99	29,65	2,44	82,18	6,76	68,97	5,68	2,00
Concentric Mean Force / BM [N/kg]	18,78	1,15	18,82	1,19	0,409	0,87	0,66	0,95	0,44	2,35	1,22	6,50	1,03	5,46	2,01
Concentric Peak Force [N]	1560,9	217,3	1552,9	241,4	0,376	0,92	0,79	0,97	67,57	4,34	187,3	12,03	157,2	10,10	2,85
Concentric Peak Force / BM [N/kg]	24,22	2,01	23,99	2,47	0,278	0,80	0,53	0,93	1,03	4,29	2,87	11,89	2,41	9,98	3,05

Concentric Impulse [N s]	151,1	18,16	152,4	18,63	0,117	0,98	0,94	0,99	2,98	1,97	8,27	5,45	6,94	4,58	1,66
Concentric Impulse-50ms [N s]	43,34	7,15	43,29	8,26	0,480	0,88	0,70	0,96	2,74	6,33	7,60	17,54	6,37	14,72	4,28
Concentric Impulse-100ms [N s]	79,79	13,45	79,99	14,63	0,452	0,91	0,76	0,97	4,44	5,56	12,32	15,42	10,34	12,94	4,35
Eccentric Mean Force [N]	635,1	89,89	637,6	86,69	0,098	1,00	0,99	1,00	5,50	0,86	15,24	2,39	12,79	2,01	0,78
Eccentric Peak Force [N]	1562,3	236,5	1553,4	244,8	0,381	0,90	0,74	0,96	79,32	5,09	219,9	14,11	184,5	11,85	3,55
Eccentric Peak Force / BM [N/kg]	24,22	2,39	24,00	2,60	0,312	0,78	0,48	0,92	1,21	5,01	3,35	13,88	2,81	11,65	3,79
Force at Zero Velocity [N]	1546,9	225,2	1546,1	242,6	0,489	0,91	0,76	0,97	73,36	4,74	203,3	13,15	170,7	11,04	3,22
Eccentric Braking Impulse [N s]	44,99	12,93	45,36	11,60	0,423	0,83	0,58	0,94	5,21	11,54	14,45	31,99	12,13	26,85	9,85
Eccentric Braking RFD [N/s]	5506,3	2060,6	5327,3	1633,5	0,251	0,86	0,65	0,95	722,7	13,34	2003,3	36,98	1681,3	31,04	11,60
Kinematics															
Concentric Mean Power [W]	1601,6	191,2	1618,5	212,6	0,172	0,95	0,86	0,98	48,79	3,03	135,3	8,40	113,5	7,05	2,53
Concentric Mean Power / BM [W/kg]	24,94	2,67	25,08	2,74	0,322	0,93	0,80	0,97	0,77	3,08	2,13	8,53	1,79	7,16	2,71
Peak Power [W]	2827,4	367,9	2858,6	372,4	0,139	0,96	0,89	0,99	78,94	2,78	218,8	7,70	183,7	6,46	2,40
Peak Power / BM [W/kg]	43,97	4,80	44,24	4,29	0,291	0,92	0,79	0,97	1,35	3,07	3,75	8,50	3,15	7,14	2,67
Concentric Peak Velocity [m/s]	2,48	0,18	2,49	0,16	0,229	0,93	0,81	0,98	0,05	1,94	0,13	5,38	0,11	4,52	1,61
Velocity at Peak Power [m/s]	2,24	0,18	2,26	0,16	0,221	0,92	0,80	0,97	0,05	2,18	0,14	6,04	0,11	5,07	1,80
Eccentric Mean Power [W]	427,8	82,25	412,6	76,03	0,099	0,86	0,64	0,95	32,73	7,79	90,73	21,59	76,15	18,12	6,30
Eccentric Mean Power / BM [W/kg]	6,65	1,13	6,38	0,95	0,073	0,80	0,52	0,92	0,52	7,93	1,43	21,97	1,20	18,44	6,50
Eccentric Peak Power [W]	1323,8	405,3	1234,4	333,5	0,061	0,85	0,62	0,94	161,9	12,66	448,7	35,08	376,6	29,44	9,70
Eccentric Peak Power / BM [W/kg]	20,53	5,67	19,08	4,52	0,055	0,80	0,52	0,93	2,56	12,91	7,09	35,80	5,95	30,04	9,64
Eccentric Peak Velocity [m/s]	-1,33	0,23	-1,28	0,19	0,083	0,84	0,59	0,94	0,09	-7,25	0,26	-20,10	0,22	-16,87	5,22
Jump strategy															
Contraction Time [ms]	707,3	96,15	723,1	95,79	0,159	0,82	0,56	0,93	43,31	6,06	120,1	16,79	100,8	14,09	4,56
Concentric Duration [ms]	264,3	35,18	265,0	32,94	0,447	0,82	0,56	0,93	15,05	5,69	41,70	15,76	35,00	13,23	4,08
Eccentric Duration [ms]	443,0	68,85	458,0	71,53	0,111	0,80	0,52	0,92	33,91	7,53	93,98	20,86	78,88	17,51	5,84
Countermovement Depth [cm]	29,93	6,33	29,53	5,23	0,314	0,86	0,65	0,95	2,23	7,51	6,19	20,83	5,20	17,48	5,05

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The drop jump test was performed by dropping from a 30 cm box, which has proven to be one of the optimal heights for this test [27] following previously guidelines using just one force platform [5]. Before stepping onto the 30 cm box, the participants weighed themselves on the strength platforms. The weight recorded during the weighing phase was used throughout the drop jump test. For this purpose, the mean force during at least 5 seconds were recorded until the body weight fluctuates by no more than +/- 0.1 kg. At this moment the Forcedecks® software accept this weight as the weight of the subject.

After weighing, participants remain one second on top of the box and then drop onto the force platforms after a 3-2-1 countdown. The moment when the force plates recorded the landing was determined by detecting the initial force that exceeded a threshold 20N. The landing velocity was estimated from the height of the box using the conservation of mechanical energy principle, as the square root of 2 × 9.81 × box height (in m). Similar to Countermovement Jump (CMJ), various kinetics, kinematics, and strategy variables of different phases of the jump were incorporated into the reliability analysis (Tables 3 and 4).

Inferential statistical tests were carried out using IBM SPSS Statistics v26.0 (IBM Corp., Armonk, NY, U.S.A.) while reliability tests were carried out with previously published Excel® spreadsheets [28]. Intrasession reliability (repeatability) was computed using the three CMJ´s and DJ´s recorded during the first experimental session while intersession reliability was calculated using the mean of three trials of each experimental days (day 2 and 3). Between trial mean differences and repeated measures ANOVA were used to identify intrasession bias. Bonferroni's post-hoc test was used to check pairwise comparisons. Similarly, between days mean differences and paired T-Test were carried out to identify between sessions bias [29]. Intraclass correlation coefficients (ICC) were calculated as a measure of relative reliability [30]. Intraclass correlation coefficients (ICC) with 95% confidence intervals (95%CI) were analyzed as follows: poor reliability, <0.5; moderate reliability, 0.5-0.75; good reliability, 0.75- 0.90; and excellent reliability, >0.90 [31]. Absolute reliability was analyzed using the coefficient of variation (CV) [32], while sensitivity was measured as the standard error of measurement (SEM) and minimum difference (MD) to be considered "real". The CV was calculated as between trials SD/mean × 100. Acceptable CV was set at <10% [32]. The SEM was calculated as follows: $SD(pooled) \times \sqrt{1 - ICC}$. MD was calculated constructing a 90 and 95% confidence interval (CI) for the SEM using the z-score associated at each CI percentage [30]. Group data is presented as means ± SD, and the level of significance was set at p<0.05.

3. Results

Repeatability of the CMJ variables were displayed in Table 1. Several variables presented differences between trials (p<0.05). For all jump outcomes, kinetics and kinematics, the highest score was obtained in the trial 3, being the highest differences between trials 3 and 1 (Table 1). Relative to jumping strategy, the deepest countermovement was also observed during the last trial (p=0.034). Jump outcomes and concentric kinetics and kinematics displayed excellent absolute reliability (ICC ranging 0.91 to 0.98) while some eccentric variables displayed lower absolute reliability than concentric metrics (Table 1). Relative reliability and sensitivity of the dependent variables was also shown in Table 1.

Similarly, Table 2 displays the repeatability and sensitivity of the DJ metrics. Seven of the 15 variables analyzed in the DJ test displayed a main effect of the trial (Table 2), being the third trial the one who presented the highest values. Absolute reliability was excellent (ICC>0.91) for Jump Height (Imp-Mom), Jump Height (Flight Time), Concentric Impulse and Concentric Velocity. Acceptable relative reliability (CV<10%) was observed in all variables except for RSI (Flight Time/Contact Time), RSI (JH/Contact Time) and Contact Time.

Table 3. Repeatеability of DJ F-T derived variables.

	Trial 1		Trial 2		Trial 3		p	ICC (95%CI)			SEM	SEM	MD	MD95%	MD	MD90%	CV (%)
	Mean	SD	Mean	SD	Mean	SD	value	ICC	UL	LL		(%)	95%CI	CI(%)	90%CI	CI(%)	
Jump outcomes																	
Jump Height (Imp-Mom) [cm]	25,46	5,49	27,27	4,78	27,51	5,08	**0,007**	0,91	0,77	0,97	2,16	8,09	6,00	22,44	5,04	18,83	6,72
Jump Height (Flight Time) [cm]	25,40	5,50	27,25	4,77	27,46	5,09	**0,021**	0,91	0,76	0,97	2,19	8,22	6,08	22,78	5,10	19,12	6,78
RSImod [m/s]	0,98	0,24	1,11	0,21	1,13	0,26	**0,011**	0,79	0,48	0,93	0,17	15,64	0,47	43,34	0,39	36,37	11,70
Kinetics																	
Concentric Mean Force [N]	1630,9	223,1	1718,6	196,9	1715,6	230,7	0,062	0,78	0,44	0,92	141,8	8,40	393,1	23,28	329,9	19,54	6,66
Concentric Impulse [N s]	142,5	16,95	147,9	18,24	146,2	15,02	**0,008**	0,94	0,82	0,98	6,28	4,31	17,40	11,95	14,60	10,03	3,35
Eccentric Mean Force [N]	2017,6	363,1	2106,6	347,2	2094,2	391,5	0,164	0,88	0,87	0,96	210,2	10,14	582,5	28,10	488,9	23,59	8,14
Eccentric Impulse [N s]	160,2	22,96	162,2	22,79	159,2	23,94	0,512	0,94	0,82	0,98	6,21	3,87	17,21	10,72	14,45	9,00	3,35
Kinematics																	
Concentric Mean Power [W]	6167,1	870,1	6604,4	726,8	6570,6	788,9	**0,012**	0,78	0,4	0,91	570,2	8,84	1580,6	24,52	1326,6	20,58	7,00
Concentric Mean Power / BM [W/kg]	96,36	13,28	103,3	11,60	104,1	13,04	**0,015**	0,81	0,5	0,93	9,24	9,12	25,60	25,28	21,48	21,22	6,99
Peak Power [W]	8556,3	1496,4	9193,5	1189,1	9183,4	1317,8	0,069	0,73	0,34	0,9	1059,7	11,80	2937,3	32,72	2465,2	27,46	9,28
Peak Power / BM [W/kg]	133,6	22,78	143,8	19,42	145,2	19,72	0,110	0,75	0,39	0,91	17,36	12,33	48,12	34,16	40,39	28,67	9,28
Concentric Peak Velocity [m/s]	2,36	0,21	2,43	0,18	2,44	0,18	**0,016**	0,91	0,76	0,97	0,09	3,54	0,24	9,81	0,20	8,23	2,74
Jump strategy																	
Contact Time [s]	0,26	0,04	0,25	0,04	0,25	0,04	0,296	0,68	0,25	0,88	0,04	13,94	0,10	38,64	0,08	32,43	10,63
Countermovement Depth [cm]	18,31	2,72	17,49	2,06	17,68	3,44	0,392	0,7	0,29	0,89	2,18	12,24	6,05	33,93	5,08	28,48	9,59

Table 4. Within week reliability of DJ F-T derived variables.

	Day 1		Day 2		p	ICC (95%CI)			SEM	SEM	MD	MD95%	MD	MD90%	CV (%)
	Mean	SD	Mean	SD	value	ICC	UL	LL		(%)	95%CI	CI(%)	90%CI	CI(%)	
Jump outcomes															

Jump Height (Imp-Mom) [cm]	26,81	4,86	27,11	3,44	0,332	0,81	0,55	0,93	1,87	6,94	5,19	19,24	4,35	16,14	6,05
Jump Height (Flight Time) [cm]	26,77	4,88	27,08	3,42	0,332	0,81	0,53	0,93	1,91	7,08	5,28	19,62	4,43	16,46	6,18
RSImod[m/s]	1,08	0,20	0,97	0,15	**0,003**	0,73	0,38	0,90	0,12	11,67	0,33	32,36	0,28	27,16	10,64
Kinetics															
Concentric Mean Force [N]	1694,69	183,82	1601,25	220,45	**0,010**	0,78	0,47	0,92	117,79	7,15	326,51	19,81	274,04	16,63	5,81
Concentric Impulse [N s]	146,39	16,39	148,83	16,50	0,107	0,91	0,76	0,97	5,42	3,67	15,01	10,17	12,60	8,54	3,05
Eccentric Mean Force [N]	2087,38	324,15	1912,81	339,53	**0,001**	0,89	0,70	0,96	169,62	8,48	470,16	23,51	394,60	19,73	6,76
Eccentric Impulse [N s]	161,44	22,54	158,94	21,45	**0,014**	0,99	0,96	0,99	3,32	2,07	9,21	5,75	7,73	4,82	1,69
Kinematics															
Concentric Mean Power [W]	6482,94	684,19	6063,63	758,27	**0,004**	0,74	0,40	0,90	478,80	7,63	1327,17	21,16	1113,87	17,76	6,57
Concentric Mean Power / BM [W/kg]	101,37	10,69	93,84	8,10	**0,001**	0,70	0,33	0,88	7,49	7,68	20,77	21,28	17,43	17,86	7,05
Peak Power [W]	9019,06	1039,39	8210,44	1201,37	**0,001**	0,70	0,34	0,89	842,92	9,78	2336,44	27,12	1960,94	22,76	8,02
Peak Power / BM [W/kg]	140,89	15,21	127,09	14,21	**0,001**	0,65	0,24	0,86	13,16	9,82	36,48	27,23	30,62	22,85	8,37
Concentric Peak Velocity [m/s]	2,42	0,18	2,44	0,13	0,211	0,81	0,54	0,93	0,07	2,96	0,20	8,21	0,17	6,89	2,50
Jump strategy															
Contact Time [s]	0,25	0,03	0,29	0,04	**0,002**	0,49	0,02	0,79	0,04	13,03	0,10	36,12	0,08	30,31	9,13
Countermovement Depth [cm]	17,76	2,05	19,73	3,08	**0,004**	0,56	0,11	0,82	2,22	11,83	6,15	32,79	5,16	27,52	8,10

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Intersession reliability and sensitivity of the CMJ was displayed in Table 3. No intersession significant bias was identified for any metric (p>0.05). However, CMJ eccentric kinematics tend to be lower during the Day 2 presenting good absolute reliability (ICC range: 0.80 to 0.85). On the contrary, DJ presented a systematic bias in the weekly reliability of most of the variables analyzed, both in jump outcomes, kinetics, kinematics and jumping strategy (Table 4). Acceptable CVs were observed for all DJ except for RSI (JH/Contact Time) (CV=10.64%).

4. Discussion

The objective of this study is to present valuable findings regarding the reliability and sensitivity of the CMJ and DJ outcomes, as well as the kinetics, kinematics, and jump strategy employed by female volleyball players using force platforms. The initial hypothesis has been partially fulfilled. There is a significant increase in the main outcomes of the Countermovement Jump (CMJ) and Drop Jump (DJ) within the same session, with the third attempt showing the highest performance values (i.e increases in jump height, force and power) accompanied by changes in the strategy of the jump, showing greater countermovement depths. Moreover, CMJ did not shown intersession differences, whereas this occurred in 11 out of the 15 variables analyzed in the DJ. According to the criteria of relative reliability, most of the analyzed variables in the CMJ, both within and between sessions, showed excellent reliability (ICC > 0.9; CV < 5%). However, some eccentric variables exhibited lower and questionable (ICC>0.78; CV <11.6%) intersession reliability compared to concentric metrics, indicating potential variability in the eccentric phase of the jump (Table 2). Intrasession absolute reliability in the DJ variables was excellent for jump height (imp-mom), concentric impulse, concentric velocity, and jump height though flight time method. However, some variables, such as RSI (Flight Time/Contact Time), RSI (JH/Contact Time), and Contact Time, showed lower ICC´s (Range: 0.68 to 0.79) and higher variability (CV > 10%), indicating potential limitations in their use due to its higher variability. Only concentric and eccentric impulses meet the excellent reliability criteria after intersession analysis (Table 4), demonstrating their validity as potential metrics in the longitudinal assessment of the DJ.

CMJ

Vertical jump height and, more recently, RSImod are common CMJ reported metrics in the reviewed literature due to their association with various performance markers and their sensitivity to detect fatigue [7,16]. In this study, significant differences were observed in these metrics between trials, indicating an improvement in jump capacity with shortened contraction time, probably attributed to a learning and/or a warm-up effect, which enables maximizing jump height. Both the impulse-momentum method and flight time estimation, along with the modified RSI, exhibited excellent intraclass correlation coefficients and coefficients of variation (Table 1). Comparing our findings with previous research [4], a similar pattern emerged. They also reported a percentage difference of 4.0 ± 3.3% between trial 1 and trial 2 in NCAA D-1 volleyball players and excellent reliability (ICC >0.93), which aligns with our investigation (Table 1). Despite the excellent reliability observed and the highly familiarization of the participants with vertical performance tasks, these results suggest that it may be necessary to discard the first attempt in order to minimize sources of error from a possible learning effect or completion of warm-up. The majority of the kinetic, kinematic, and jump strategy variables of the present study demonstrated excellent reliability and variability, except for certain eccentric phase variables such as peak force/BM, braking impulse, braking RFD, peak power, and peak power/BM (Table 1). Heishman et al.[33] also reported excellent intrasession reliability for no arm swing CMJ "typical variables", including performance metrics (ICC range= 0.873 to 0.967; CV range=,8.3 to 1.9%) concentric mean force (ICC=0.965; CV=2.8%) and power (ICC=0.968: CV=4.3%), concentric impulse (ICC=0.987; CV=2.2%), and concentric peak velocity (ICC=0.958; CV=1.9%). However, the reliability of kinetic, kinematic, and strategy variables during the eccentric phase of the jump generally exhibited lower values compared to the concentric phase (ICC range=0.319 to 0.999; CV range=23.5% to 0.4%). Considering the presented findings, it is important to note that variables with an ICC > 0.9 and a CV < 5% exhibit excellent reliability and can

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be confidently utilized. The decision to incorporate these variables into practice or research should be based on their internal logic and sensitivity to changes induced by intense exercise, as they have the potential to effectively detect fatigue [7]. Ultimately, coaches and sports scientists should carefully evaluate and select the most appropriate variables based on these considerations. No differences ($p>0.05$) were detected between the measured variables across the testing days when using the mean of three jumps. Intersession analysis showed that 52% (16/31) of the variables examined in the Countermovement Jump (CMJ) demonstrated excellent relative reliability. Furthermore, 71% (22/31) of the variables exhibited a coefficient of variation (CV) below 5%. Except for Eccentric Braking RFD, all variables displayed an ICC above 0.7 and a CV below 10%, indicating satisfactory reliability across all analyzed variables. Notably, the variables that exhibited the highest reliability and lowest variability were eccentric force/BM (ICC=1.00; CV=0.78%), concentric impulse (ICC=0.98; CV=1.66%), and concentric peak velocity (ICC=0.93; CV=1.61%). Similarly, Anicic et al.,[9] showed that jump height, regardless of the calculation method, as well as RSImod, exhibited excellent intersession reliability criteria. Jump height previously reported variability showed a CV<5%, a slightly higher variability than observed in the present study (CV=3.75%). Likely due to the greater familiarity of our population compared to active individuals who are not specialized in jump sport [9]s. Accordingly again with previous research [9,33], variables related to force production and impulse were the most reliable, particularly in the concentric phase of the jump (CV<4.35%), as also occurred in intrasession analysis. On the other hand, propulsive RFD has shown to have high variability and low reliability [9]. In this sense, to detect longitudinal changes in force production rate within early time windows (50-100ms), concentric impulse at both 50ms and 100ms has proven to be a highly reliable and less variable alternative (ICC>0.88; CV<4.35%) with a sensitivity of 6.37 and 10.34 Ns. CMJ (imp-mom) and RSImod demonstrated intrasession MD90CI values of 10.22 (2.9 cm) and 15.14% (0.07 m/s), respectively. Moreover, among the intrasession variables examined, the most sensitive ones were mean concentric force/BM, mean eccentric force, peak concentric velocity, and concentric impulse, all of which exhibited a sensitivity of less than 5.18% (Table 1). On the other hand, the most sensitive intersession variables were mean eccentric force, concentric impulse, and peak concentric velocity, with reliable cutoff thresholds at the 90%CI of 12.79N, 12.79Ns, and 0.11 m/s, respectively. Our cutoff thresholds are larger than previously observed due to differences in the statistical technique used for sensitivity [9,33] (MD vs Typical Error [28]). These results indicate that these cutoff thresholds are of practical significance to assess acute sensitivity in female jumping dominant sports.

DJ

Neuromuscular function could be assessed through drop jump (DJ) tests involving 1 dual force plate to directly measure force-time data. This procedure has been shown to be valid in recent studies [5,8]. However, the reliability of the metrics derived from forward dynamics procedures are not stablished yet. Limited research has examined the between session reliability of certain variables, including GCT [34,35], RSI, and JH [34]. However, none of these studies have comprehensively investigated the intraday reliability of various kinetic, kinematic, and jump strategy variables. Consequently, the comparability of our findings is hindered. A noteworthy finding was the significant increase in performance metrics such as force and power observed in jumps 2 and 3 compared to jump 1 (Table 3). This suggests that the first jump may not accurately represent an individual's true performance. As a result, and like for CMJ testing, it is recommended to exclude the initial jump when conducting the DJ test to enhance the reliability of the data. Moreover, relative reliability was excellent for 5/15 metrics (jump height, concentric impulse, eccentric impulse and concentric peak velocity) while just 3 presented lower than 5% CV (concentric impulse, eccentric impulse and concentric peak velocity). Jump height meet acceptable criteria (CV <6.78%). In addition, these four variables were also the most sensitive, exhibiting a MD90CI of 8-18%. In contrast, the reliability observed in our study for RSI and contact time did not meet acceptable cutoff reliability thresholds (Table 3). Eleven of 15 variables in the DJ demonstrated significant differences between day 1 and day 2 (Table 4). Only 2 variables exhibited excellent reliability and variability (concentric and eccentric impulse). Moreover, acceptable between days reliabilities were also observed for jump

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heights with similar drops (30cm) in adults with resistance training experience [34] despite the differences in the time window between sessions (2 vs 7 days). Nevertheless, it is important to note that contact time and countermovement depth did not meet the established reliability thresholds, indicating that the DJ test may involve a non-reproducible jumping strategy. This finding directly affects the duration athletes spend applying vertical force to the ground, thereby impacting the reliability of force production and RSI [36]. However, it does not seem to have an impact on the reliability of concentric impulse and concentric peak velocity, as participants adapted the jumping strategy to compensate for the lower force production giving similar impulse and change in center of mass velocity [37]. According to the discussed results, the variability and reliability of DJ metrics suggest that the concentric and eccentric impulse should be prioritized in the assessment and monitoring of DJ performance over time. Practitioners are advised to carefully consider the jump strategy when assessing the drop jump to ensure consistent contact times and countermovement depths. This is crucial to minimize any potential influence on other metrics [36].

While the present study provides valuable insights into the reliability and sensitivity of various performance metrics it is important to acknowledge certain limitations that should be considered when interpreting the findings. The study included a relatively small sample of 16 female volleyball players. This limited sample size has direct implications for the interpretation of intersession reproducibility, as statistical power will be severely limited. In this sense, low statistical power increases the probability of committing type II errors, restricting the ability of the statistical test to detect true changes. Variations in body composition, neuromuscular characteristics, and skill levels across different populations could influence the reliability and sensitivity of the measured variables. Although attempts were made to standardize the testing conditions variations in environmental conditions, participant readiness, or instructions given may introduce additional sources of variability. In conclusion, the first repetition does not accurately represent the jumping ability, for both the CMJ and DJ, in the analyzed cohort. Most of the outcomes, kinetic, kinematic, and jumping strategy variables examined in the CMJ exhibited excellent reliability and variability within and between sessions. However, certain eccentric phase variables showed lower reliability. Conversely, DJ demonstrated lower reliability, higher variability, and lower sensitivity compared to the CMJ in both intra- and intersession. Nevertheless, the performance, kinetic, and kinematic metrics of the DJ generally meet the minimum acceptable threshold, whereas jump strategy do not. This information can assist coaches and fitness trainers in developing assessment methodologies that enhance the reliability of their evaluations. It also enables them to make informed decisions regarding the utilization of metrics from both tests for assessing athletes' performance in accordance with reliability results. These results highlight the reliability, sensitivity and variability in jump performance when monitoring CMJ and DJ tests.

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References

1. Borresen, J.; Ian Lambert, M. The Quantification of Training Load, the Training Response and the Effect on Performance. *Sports Medicine* **2009**, *39*, 779–795, doi:10.2165/11317780-000000000-00000/METRICS.
2. Halson, S.L. Monitoring Training Load to Understand Fatigue in Athletes. *Sports Medicine* **2014**, *44*, 139–147, doi:10.1007/S40279-014-0253-Z/TABLES/2.
3. Sattler, T.; Sekulic, D.; Hadzic, V.; Uljevic, O.; Dervisevic, E. Vertical Jumping Tests in Volleyball: Reliability, Validity, and Playing-Position Specifics. *J Strength Cond Res* **2012**, *26*, 1532–1538, doi:10.1519/JSC.0B013E318234E838.
4. Carroll, K.M.; Wagle, J.P.; Sole, C.J.; Stone, M.H. Intrasession and Intersession Reliability of Countermovement Jump Testing in Division-I Volleyball Athletes. *J Strength Cond Res* **2019**, *33*, 2932–2935, doi:10.1519/JSC.0000000000003353.
5. McMahon, J.J.; Lake, J.P.; Stratford, C.; Comfort, P. A Proposed Method for Evaluating Drop Jump Performance with One Force Platform. *Biomechanics* **2021**, *1*, doi:10.3390/biomechanics1020015.
6. Mercer, R.A.J.; Russell, J.L.; McGuigan, L.C.; Coutts, A.J.; Strack, D.S.; McLean, B.D. Finding the Signal in the Noise - Interday Reliability and Seasonal Sensitivity of 84 Countermovement Jump Variables in Professional Basketball Players. *J Strength Cond Res* **2023**, *37*, 394–402, doi:10.1519/JSC.0000000000004182.
7. Bishop, C.; Jordan, M.; Torres-Ronda, L.; Loturco, I.; Harry, J.; Virgile, A.; Mundy, P.; Turner, A.; Comfort, P. Selecting Metrics That Matter: Comparing the Use of the Countermovement Jump for Performance Profiling, Neuromuscular Fatigue Monitoring, and Injury Rehabilitation Testing. *Strength Cond J* **2023**, *Vol Ahead of Print*, doi:10.1519/SSC.0000000000000772.
8. Badby, A.J.; Mundy, P.D.; Comfort, P.; Lake, J.P.; Mcmahon, J.J.; Badby, A.J.; Mundy, P.D.; Comfort, P.; Lake, J.P.; Mcmahon, J.J. The Validity of Hawkin Dynamics Wireless Dual Force Plates for Measuring Countermovement Jump and Drop Jump Variables. *Sensors 2023, Vol. 23, Page 4820* **2023**, *23*, 4820, doi:10.3390/S23104820.
9. Anicic, Z.; Janicijevic, D.; Knezevic, O.M.; Garcia-Ramos, A.; Petrovic, M.R.; Cabarkapa, D.; Mirkov, D.M. Assessment of Countermovement Jump: What Should We Report? *Life (Basel)* **2023**, *13*, doi:10.3390/LIFE13010190.
10. Kollias, I.; Panoutsakopoulos, V.; Papaiakovou, G. Comparing Jumping Ability among Athletes of Various Sports: Vertical Drop Jumping from 60 Centimeters. *J Strength Cond Res* **2004**, *18*, doi:10.1519/1533-4287(2004)18<546:CJAAAO>2.0.CO;2.
11. Laffaye, G.; Wagner, P.P.; Tombleson, T.I.L. Countermovement Jump Height: Gender and Sport-Specific Differences in the Force-Time Variables. *J Strength Cond Res* **2014**, *28*, 1096–1105, doi:10.1519/JSC.0b013e3182a1db03.
12. Comfort, P.; Jones, P.A.; McMahon, J.J. *Performance Assessment in Strength and Conditioning*; Comfort, P., Jones, P.A., McMahon, J.J., Eds.; 1st ed.; Routledge: London, 2019;
13. Attia, A.; Dhahbi, W.; Chaouachi, A.; Padulo, J.; Wong, D.P.; Chamari, K. Measurement Errors When Estimating the Vertical Jump Height with Flight Time Using Photocell Devices: The Example of Optojump. *Biol Sport* **2017**, *34*, 63, doi:10.5114/BIOLSPORT.2017.63735.
14. McMahon, J.J.; Suchomel, T.J.; Lake, J.P.; Comfort, P. Understanding the Key Phases of the Countermovement Jump Force-Time Curve. *Strength Cond J* **2018**, *40*, 96–106, doi:10.1519/SSC.0000000000000375.
15. Payne, R.W. Reliability Theory and Clinical Psychology. *J Clin Psychol* **1989**, *45*, doi:10.1002/1097-4679(198903)45:2<351::AID-JCLP2270450228>3.0.CO;2-W.
16. Bishop, C.; Turner, A.; Jordan, M.; Harry, J.; Loturco, I.; Lake, J.; Comfort, P. A Framework to Guide Practitioners for Selecting Metrics during the Countermovement and Drop Jump Tests. *Strength Cond J* **2022**, *44*, 95–103, doi:10.1519/SSC.0000000000000677.
17. Cormie, P.; McBride, J.M.; McCaulley, G.O. Power-Time, Force-Time, and Velocity-Time Curve Analysis of the Countermovement Jump: Impact of Training. *J Strength Cond Res* **2009**, *23*, 177–186, doi:10.1519/JSC.0b013e3181889324.
18. Marques, M.C.; Izquierdo, M.; Marinho, D.A.; Barbosa, T.M.; Ferraz, R.; González-Badillo, J.J. Association Between Force-Time Curve Characteristics and Vertical Jump Performance in Trained Athletes. *J Strength Cond Res* **2015**, *29*, 2045–2049, doi:10.1519/JSC.0000000000000739.
19. McLester, C.N.; Nickerson, B.S.; Kliszczewicz, B.M.; McLester, J.R. Reliability and Agreement of Various InBody Body Composition Analyzers as Compared to Dual-Energy X-Ray Absorptiometry in Healthy Men and Women. *Journal of Clinical Densitometry* **2020**, *23*, 443–450, doi:10.1016/J.JOCD.2018.10.008.
20. Teo, W.; McGuigan, M.R.; Newton, M.J. The Effects of Circadian Rhythmicity of Salivary Cortisol and Testosterone on Maximal Isometric Force, Maximal Dynamic Force, and Power Output. *J Strength Cond Res* **2011**, *25*, 1538–1545, doi:10.1519/JSC.0b013e3181da77b0.
21. Rae, D.E.; Stephenson, K.J.; Roden, L.C. Factors to Consider When Assessing Diurnal Variation in Sports Performance: The Influence of Chronotype and Habitual Training Time-of-Day. *Eur J Appl Physiol* **2015**, *115*, 1339–1349, doi:10.1007/S00421-015-3109-9.

22. Shaw, A.G.; Chae, S.; Levitt, D.E.; Nicholson, J.L.; Vingren, J.L.; Hill, D.W. Effect of Previous-Day Alcohol Ingestion on Muscle Function and Performance of Severe-Intensity Exercise. *Int J Sports Physiol Perform* **2021**, *17*, 44–49, doi:10.1123/IJSPP.2020-0790.
23. Del Coso, J.; Pérez-López, A.; Abian-Vicen, J.; Salinero, J.J.; Lara, B.; Valadés, D. Enhancing Physical Performance in Male Volleyball Players with a Caffeine-Containing Energy Drink. *Int J Sports Physiol Perform* **2014**, *9*, 1013–1018, doi:10.1123/ijspp.2013-0448.
24. Jeffreys, I. The Warm-up : Maximize Performance and Improve Long-Term Athletic Development; Human Kinetics, 2018; ISBN 9781492571278.
25. Moir, G.L. Three Different Methods of Calculating Vertical Jump Height from Force Platform Data in Men and Women. *Meas Phys Educ Exerc Sci* **2008**, *12*, 207–218, doi:10.1080/10913670802349766.
26. González-García, J.; Latella, C.; Aguilar-Navarro, M.; Romero-Moraleda, B. Effects of Resistance Priming Exercise on Within-Day Jumping Performance and Its Relationship with Strength Level. *Int J Sports Med* **2023**, *44*, 38–47, doi:10.1055/A-1898-4888.
27. Byrne, P.J.; Moran, K.; Rankin, P.; Kinsella, S. A Comparison of Methods Used to Identify Optimal Drop Height for Early Phase Adaptations in Depth Jump Training. *J Strength Cond Res* **2010**, *24*, doi:10.1519/JSC.0b013e3181d8eb03.
28. Hopkins, WG. Spreadsheets for Analysis of Validity and Reliability. *Sportscience* **2015**, *19*, 36–42.
29. Baumgartner, T.A. Norm-Referenced Measurement: Reliability. *Measurement concepts in physical education and exercise science* **1989**, *20*, 45–47.
30. Weir, J.P. Quantifying Test-Retest Reliability Using the Intraclass Correlation Coefficient and the SEM. *J Strength Cond Res* **2005**, *19*, 231–240, doi:10.1519/15184.1.
31. Portney, L.G.; Watkins, M.P. Foundations of Clinical Research: Applications to Practice, 3rd Edition | Pearson; New Jersey, 2008;
32. Atkinson, G.; Nevill, A.M. Statistical Methods for Assessing Measurement Error (Reliability) in Variables Relevant to Sports Medicine. *Sports Med* **1998**, *26*, 217–238, doi:10.2165/00007256-199826040-00002.
33. Heishman, A.D.; Daub, B.D.; Miller, R.M.; Freitas, E.D.S.; Frantz, B.A.; Bemben, M.G. Countermovement Jump Reliability Performed With and Without an Arm Swing in NCAA Division 1 Intercollegiate Basketball Players. *J Strength Cond Res* **2018**, *34*, 546–558, doi:10.1519/JSC.0000000000002812.
34. Feldmann, C.R.; Weiss, L.W.; Schilling, B.K.; Whitehead, P.N. Association of Drop Vertical Jump Displacement with Select Performance Variables. *J Strength Cond Res* **2012**, *26*, 1215–1225, doi:10.1519/JSC.0B013E318242A311.
35. Tenelsen, F.; Brueckner, D.; Muehlbauer, T.; Hagen, M. Validity and Reliability of an Electronic Contact Mat for Drop Jump Assessment in Physically Active Adults. *Sports (Basel)* **2019**, *7*, doi:10.3390/SPORTS7050114.
36. Pérez-Castilla, A.; Weakley, J.; García-Pinillos, F.; Rojas, F.J.; García-Ramos, A. Influence of Countermovement Depth on the Countermovement Jump-Derived Reactive Strength Index Modified. *Eur J Sport Sci* **2021**, *21*, 1606–1616, doi:10.1080/17461391.2020.1845815.
37. Ruddock, A.D.; Winter, E.M. Jumping Depends on Impulse Not Power. *J Sports Sci* **2016**, *34*, 584–585, doi:10.1080/02640414.2015.1064157.