THE RELIABILITY AND USEFULNESS OF BIOMECHANICAL MEASURES OF COUNTERMOVEMENT JUMP PERFORMANCE IN ELITE ROWERS

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Countermovement jump performance and associated biomechanical variables are commonly used to monitor athletes' neuromuscular function. The purpose of this study was to quantify the reliability and usefulness of these variables in a cohort of fourteen elite male rowers, and to apply these findings in individual athlete monitoring. Seven of the nine variables demonstrated acceptable reliability (CV < 5%). Peak power was classified as OK for usefulness (CV ≈ SWC; signal-to-noise ratio ≈ 1) while all others were classified as poor. Within the athlete monitoring program, many of the observed changes in countermovement jump variables exceeded the threshold for interpretation of a clear change based on the signal-to-noise ratio. This study demonstrates the importance of understanding the reliability and usefulness measurements for accurate interpretation of monitoring data.

KEYWORDS: athlete monitoring, ground reactions forces, jumping, rowing

INTRODUCTION: Monitoring of athletes' physical state is routine in elite sport. The countermovement jump is one of the most common monitoring tools, used as an assessment of neuromuscular fatigue. This test has been shown to be sensitive to changes in performance immediately following, and up to 72 hours after an acute high-intensity load (such as a match or fatiguing running protocol) (Gathercole, Sporer, Stellingwerff & Sleivert 2015). Gathercole and colleagues demonstrated that, even after performance (jump height and power output) has returned to pre-fatigue levels, athletes may display an altered movement strategy that could indicate persistent neuromuscular fatigue. Therefore, analysis of countermovement jump variables related to the performance outcome and movement strategy is recommended in athlete monitoring practice.
When interpreting athlete monitoring results, practitioners need to know (i) whether changes observed are due to measurement noise or real performance change, and (ii) whether a change in the test result is practically meaningful (Hopkins, 2004). Measurement noise is caused by performance variability and/or methodological error, and can be quantified by calculating the typical error (TE) and coefficient of variation (CV) across multiple trials. The signal that the test is attempting to detect is represented by a practically meaningful performance improvement or decrement, known as the smallest worthwhile change (SWC). A test is considered reliable if the CV is less than 5%, and useful if the CV is less than the SWC and the signal-to-noise ratio is greater than 1 (Roe, et al., 2016). If the signal is larger than the noise, results can be interpreted as a clear change. However, if the noise is larger than the signal, results may only be interpreted as clear when the change is greater than the noise (Hopkins, 2004).
This study aimed to assess the reliability and usefulness of biomechanical variables derived from force-time analysis of a countermovement jump, and to demonstrate the practical application of this information in the monitoring of elite rowers.

METHODS: Fourteen elite male rowers (mean ± standard deviation [SD]: age = 23 ± 3 years; stature = 1.92 ± 0.05 m; mass = 88.7 ± 4.7 kg) participated in the study. Testing procedures were part of a regular monitoring programme and athletes were therefore familiar with the instructions and tasks prior to collecting the data for this study.

Following a standardised dynamic warm-up that included submaximal countermovement jumps, athletes performed three maximal effort countermovement jumps separated by approximately 10 s of rest. Jumps were performed on a single-axis force plate (6090-06, Bertec, USA) that recorded vertical force at a sampling rate of 1000 Hz. Athletes were instructed to stand perfectly still with their hands on their hips prior to each jump, until instructed to “jump as fast and high as possible”, while keeping the hands on the hips.

Force-time data were acquired using myoResearch 3.12 software (Noraxon, USA) and exported to a CSV file which was processed using a custom-built Matlab program for batch processing. Body weight was obtained during a portion of quiet standing in each recording by taking the mean vertical force measured within the 1s window with the lowest variance. Jump events were derived using standard thresholds (initiation and take-off) and impulse-momentum calculations. The acceleration of the centre of mass (COM) was derived from the vertical force measurement and integrated from jump initiation to track COM velocity and displacement. Jump height was calculated using take-off velocity derived from the net impulse.

The variables of interest were selected based on current recommendations for athlete monitoring practice (Gathercole, et al., 2015). These variables were: flight time (FT), peak velocity (PV), peak negative velocity (PnegV), net impulse (NI), jump height (JH), peak power (PP), peak force (PF), force at zero velocity (F0V), reactive strength index modified (RSImod) (Suchomel, et al., 2015). Force, impulse and power were expressed relative to body mass.

The intraday TE was calculated as the SD of the between-trial difference scores divided by $\sqrt{2}$, and reported ± 90% confidence intervals (CI). The CV across the three trials was calculated as the between-trial SD divided by the mean, and expressed as a percentage ± 90% CI. For each athlete, the mean of the three trials was used as their performance measure, and the group mean and SD calculated from these. The SWC was calculated as 0.2x the group SD and expressed in the relevant units for each variable and as a percentage of the mean. The signal-to-noise ratio was calculated as SWC divided by TE. The usefulness of the measure was classified as good (CV < SWC; signal-to-noise ratio > 1), OK (CV ≈ SWC; signal-to-noise ratio ≈ 1), or poor (CV > SWC; signal-to-noise ratio < 1) (Hopkins, 2004; Roe, et al., 2016). Individual athlete differences between two testing sessions separated by four weeks were calculated and reported as a multiple of the SWC.

RESULTS: The smallest worthwhile change in countermovement jump variables ranged from 1.1% to 4.1% (Table 1). Reliability and usefulness results are presented in Table 2. All variables, except PnegV and RSImod, were found to be reliable. Signal-to-noise ratios ranged from 0.49 to 0.82. Only PP was classified as OK for usefulness, while all other measures were classified as poor.

Table 1: Group mean values and smallest worthwhile change

	Mean	SD	SWC	SWC (%)
FT (s)	0.51	0.03	0.01	1.2
PV (m/s)	2.51	0.13	0.03	1.1
PnegV (m/s)	1.09	0.22	0.04	4.1
NI (Ns/kg)	2.48	0.13	0.03	1.1
JH (cm)	32.32	3.41	0.68	2.1
PP (W/kg)	47.28	3.56	0.71	1.5
PF (N/kg)	22.12	2.01	0.40	1.8
F0V (N/kg)	19.95	2.91	0.58	2.9
RSImod	0.35	0.07	0.01	4.1

Table 2: Reliability and usefulness of countermovement jump variables

	TE	90% CI	CV (%)	(90% CI)	Signal:Noise	Usefulness
FT (s)	0.01	(0.01 - 0.02)	1.6	(1.0 - 2.2)	0.54	Poor
PV (m/s)	0.06	(0.05 - 0.08)	1.7	(1.1 - 2.2)	0.49	Poor
PnegV (m/s)	0.06	(0.02 - 0.03)	5.6	(4.0 - 7.2)	0.78	Poor
NI (Ns/kg)	0.06	(0.04 - 0.08)	1.7	(1.2 - 2.2)	0.48	Poor
JH (cm)	1.39	(1.12 - 1.91)	3.3	(2.3 - 4.3)	0.49	Poor
PP (W/kg)	0.87	(0.70 - 1.19)	1.8	(1.4 - 2.1)	0.82	OK
PF (N/kg)	0.68	(0.54 - 0.93)	2.7	(1.8 - 3.6)	0.59	Poor
F0V (N/kg)	1.11	(0.89 - 1.51)	4.6	(3.3 - 5.8)	0.53	Poor
RSImod	0.03	(0.02 - 0.03)	5.5	(3.1 - 7.8)	0.59	Poor

The changes in countermovement jump performance and associated biomechanical measures, expressed as a percentage of SWC, are presented for individual athletes in Table 3. Ten of the fourteen athletes demonstrated a change in jump height of at least 1x SWC, with six of these athletes changing by ≥ 2x SWC. Ten athletes were found to have two or more variables that changed by ≥ 2x SWC.

Table 3: Individual differences between sessions expressed as a multiple of the smallest worthwhile change (xSWC ≥ 2 in bold)

Subject	FT	PV	PnegV	NI	JH	PP	PF	F0V	RSImod
1	-1.1	**-4.3**	-0.1	**-4.3**	**-4.3**	**-4.4**	-1.2	-1.5	-1.5
2	**2.8**	**4.0**	**-2.4**	**4.0**	**4.0**	**3.3**	-0.2	-0.9	-0.2
3	**-2.2**	0.0	**2.8**	0.1	0.0	-1.1	-1.1	-0.2	1.1
4	-0.6	0.2	-0.6	0.3	0.2	-0.3	-0.4	-0.4	-1.0
5	**5.1**	**7.0**	0.4	**7.0**	**7.1**	**8.1**	1.1	0.6	**8.3**
6	0.0	-1.0	**3.0**	-1.1	-1.0	-1.6	**-3.6**	1.3	**-2.1**
7	**-2.2**	-1.3	0.2	-1.3	-1.4	1.3	-1.9	-0.9	-1.4
8	1.1	1.3	0.4	1.3	1.3	**3.1**	0.9	0.1	1.3
9	**-2.2**	-0.5	**-2.6**	-0.8	-0.6	-0.1	-0.9	**-3.2**	-0.8
10	1.7	1.8	0.3	1.5	1.9	**2.1**	1.8	1.2	**4.6**
11	**3.4**	**5.0**	-0.2	**5.0**	**4.2**	**4.8**	**2.1**	1.6	**4.3**
12	**-5.6**	**-5.5**	-1.8	**-5.3**	**-5.7**	**-4.8**	-0.4	**-3.5**	-1.4
13	**-2.2**	**3.8**	**-2.1**	**3.9**	**4.1**	1.7	-1.6	-1.4	0.8
14	-1.1	-1.8	-0.4	**-2.0**	-1.8	**-2.6**	-0.6	-0.1	**-2.6**

DISCUSSION: The first aim of this study was to assess the reliability and usefulness of the selected countermovement jump variables. All variables with the exception of PnegV and RSImod demonstrated acceptable intraday reliability (CV < 5%). Only PP could be described as OK for usefulness, with a CV ≈ SWC and signal-to-noise ratio ≈ 1. All other variables demonstrated a CV larger than the SWC and a signal-to-noise ratio < 1 and were therefore classified as poor for usefulness.

The second aim was to apply the reliability and usefulness findings to an example of individual athlete monitoring. Given the signal-to-noise ratio of ≈ 0.5 for seven of the nine variables assessed (FT, PV, NI, JH, PF, F0V, RSImod), only changes greater than 2x SWC could be interpreted as clear. In a pragmatic and conservative approach, this threshold was applied to all variables to determine a clear meaningful change. Of the nine variables assessed across fourteen athletes, 38% differed by at least 2x SWC between the assessments four weeks apart.

Analysis of the test results in this way permits more detailed interpretation of individual changes. For example, athlete 8 demonstrated an unclear improvement in JH and several other variables, but a clear improvement in PP and may therefore be considered to be in an improved neuromuscular state compared to the previous assessment. Athlete 9 demonstrated no change in JH but a clear decrease in PnegV and F0V indicating an alteration in the eccentric phase of the countermovement jump, which could suggest neuromuscular fatigue despite an equivalent jump performance outcome.
The determination of the SWC has a fundamental influence on the signal-to-noise ratio and usefulness of a test. In this study, 0.2x the between-athlete SD was used to determine the SWC. In a homogenous group such as this one, this results in a small SWC that requires extremely good reliability and very low measurement noise in order for the test to be classified as useful. Despite most of the measures in this study being classified as poor for usefulness, many of the observed changes exceeded 2x SWC (the threshold for a clear change), making them sufficiently sensitive to still be of practical use in this athlete monitoring program.
Existing literature on countermovement jump monitoring in athletes is heavily weighted toward field- or court-based team sports, with half of the studies included in a recent meta-analysis involving football (soccer) alone (Claudino, et al., 2017). No previous study has examined the use of countermovement jump monitoring in rowers. Future studies in this population are needed to investigate the value of this test in a sport that involves less lower-body impact and stretch-shortening cycle emphasis than running-based sports.

CONCLUSION: It is essential for practitioners to understand the reliability and usefulness of biomechanical variables associated with athlete monitoring tests in order to accurately interpret the results. This study demonstrated acceptable reliability but poor usefulness for most countermovement jump variables, and showed how to apply these findings to interpret the results of countermovement jump monitoring in individual athletes.

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