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Comparison of Force-Time Metrics Between Countermovement Vertical Jump With and Without an Arm Swing in Professional Male Basketball Players

Dimitrije Cabarkapa[1], Nicolas M. Philipp[1], Damjana V. Cabarkapa[1], Drake A. Eserhaut[1] & Andrew C. Fry[1]

[1]Jayhawk Athletic Performance Laboratory – Wu Tsai Human Performance Alliance, Department of Health, Sport and Exercise Sciences, University of Kansas, Lawrence, KS, USA

Corresponding Author: dcabarkapa@ku.edu

ABSTRACT

With technological developments over the last decade, a wide range of countermovement vertical jump (CMJ) force-time metrics can be derived from commercially available portable force plate systems. However, it should be noted that how the test is performed can have a substantial impact on the outcome of the assessment. Thus, the purpose of the present study was to determine differences in biomechanical variables between CMJ with and without an arm swing in a cohort of elite athletes. Ten professional male basketball players volunteered to participate in the present study. Following a standardized warm-up procedure, athletes stepped on a uni-axial force plate sampling at 1000 Hz and performed three CMJ without arm swing (i.e., hands on the hips) followed by three CMJ with an arm swing (i.e., arms positioned slightly in the front of the body with elbows flexed at a 90-degree angle). To minimize the possible influence of fatigue, each jump was separated by a 15-30 s rest interval. The findings of the present study indicate phase-specific differences in multiple force-time metrics between the two CMJ testing modalities. While having greater eccentric duration, CMJ with an arm swing had lower eccentric braking and deceleration rate of force development and lower eccentric peak force when compared to CMJ without an arm swing. During the concentric phase of the jump, concentric duration, impulse, peak velocity, and peak power were significantly greater in favor of CMJ with an arm swing. Also, despite longer contraction time, incorporating an arm swing resulted in greater vertical jump heights. Overall, these data describe the CMJ performance of professional male basketball players and provide helpful information for practitioners when designing assessment protocols to monitor athletes' neuromuscular performance.

Keywords: sport; performance; testing; monitoring; kinetics; kinematics; concentric; eccentric

INTRODUCTION

While many physical performance parameters influence success in basketball, an athlete's ability to efficiently use their stretch-shortening cycle may be one of the most important. As a major contributor to sport-specific tasks such as running, sprinting, or jumping, the stretch-shortening cycle has been previously defined as a natural muscle function in which the preactivated muscle-tendon complex is lengthened in the eccentric phase followed by a muscle-tendon shortening in the concentric phase [1].

A considerable amount of scientific literature has been focused on quantifying the efficient use of the stretch-shortening cycle [2-4]. One commonly identified way to non-invasively measure and analyze this neuromuscular phenomenon is by a countermovement vertical jump (CMJ) performed on force plates. This performance assessment modality requires athletes to rapidly perform an eccentric phase (i.e., lengthening of the muscle-tendon unit), followed by a quick concentric phase (i.e., shortening of the muscle-tendon unit). When performed on a force plate, different insights may be observed pertaining to how the athlete interacts with the ground while performing this task.

Previous research has documented various phase-specific CMJ force-time metrics that may be analyzed to gain detailed insight into the athletes' neuromuscular performance [5]. This task is especially common amongst basketball players, given the nature of the game, which is in part dependent on the athletes' ability to rapidly produce force in a vertical manner. Moreover, alongside neuromuscular performance assessment, CMJ analysis has been used to identify fatigue and athletes' readiness status [6].

From an execution standpoint, CMJ is most commonly instructed to be performed with either the arms "akimbo" (i.e., hands on the hips during the entire movement) or by allowing the athlete to use an arm swing. Although both testing modalities have been shown to provide a reliable means of assessing vertical force production ability [7], previous research has documented that the type of execution (i.e., arm vs. no arm swing) and instructions provided to the athlete may influence CMJ performance [8-10]. However, it should be noted that the findings of a recently published study suggest that the hands-on-hips version of the assessment may be more beneficial for detecting acute changes in neuromuscular fatigue and athlete readiness status, while the CMJ with an arms swing version may lend itself to be more appropriate for sport-specific assessment of longitudinal changes in physical performance [7].

With the wide range of force-time performance metrics derived from commercially available portable force plate systems, the purpose of the present study was to determine differences in biomechanical parameters between CMJ with and without an arm swing. This information may benefit practitioners in the assessment selection process when attempting to monitor athletes' neuromuscular performance. It is hypothesized that notable differences exist between the aforementioned testing modalities.

METHODS

Participants

Ten professional male basketball players (age=25.7±2.5 years, height=191.8±11.5 cm, body mass=88.7±12.1 kg) volunteered to participate in the present study. All participants previously competed at the collegiate level of basketball competition in the United States (e.g., NCAA Division-I) and were under or between a professional contract at the time point of the data collection (e.g., Germany and France ProA Leagues). The testing procedures performed in this investigation were previously approved by the University's Institutional Review Board and all participants signed an informed consent document.

Procedures

Upon arrival at the basketball gym, participants performed a standardized warm-up protocol led by a certified strength and conditioning professional. The warm-up procedure consisted of a set of dynamic stretching exercises (e.g., high knees, butt-kicks, lunge-and-twist, A-skips, karaoke, pogo jumps) and 15 min of partner free-throw, two-point, and three-point shooting drills (e.g., one player rebounds the ball while the other one shoots, alternating roles every 10 shooting attempts) [11,12]. After the completion of the warm-up protocol, each participant stepped on a portable uni-axial dual force plate system (ForceDecks Max, VALD Performance, Brisbane, Australia) that based on previously published research reports demonstrated solid levels of measurement sensitivity and accuracy [13-16] and performed three CMJ without arm swing followed by three CMJ with an arm swing. The force plate system sampling at 1000 Hz was calibrated/zeroed between each participant. When performing CMJ with an arm swing, participants were instructed to keep their hands on the hips during the entire movement. On the other hand, when performing CMJ with an arm swing, participants were instructed to start with arms positioned slightly in the front of the body with elbows flexed at a 90-degree angle and reach the highest possible vane with a dominant hand on the Vertec device (Sports Imports, Hilliard, OH, USA).

Each participant was verbally encouraged to give maximal effort and focus on pushing away from the ground as explosively as possible [9]. To minimize the possible influence of fatigue, each jump was separated by a 15-30 s rest interval.

Variables

The following variables were obtained during the eccentric phase of the CMJ: duration of braking and deceleration phase, braking impulse, total eccentric duration, braking rate of force development (RFD), deceleration impulse and RFD, peak velocity, mean and peak power, and mean and peak force. The following variables were obtained during the concentric phase of the CMJ: total concentric duration, impulse, peak velocity, mean and peak force, mean and peak power, and RFD. In addition, contraction time, jump height, and modified reactive strength index (RSI-modified = jump height / contraction time) between concentric and eccentric phases were obtained (Figure 1). A detailed description of the previously mentioned CMJ metrics is presented in the VALD force plates user manual (https://valdperformance.com/forcedecks/) and previous research reports that demonstrated [7,17].

Statistical Analysis

Descriptive statistics, means and standard deviations ($\bar{x}$±SD), were calculated for each dependent variable. An average of three jump trials was used for the analysis. Shapiro-Wilk test indicated that the assumption of normality was not violated. Paired-samples t-tests were used to examine statistically significant differences in dependent variables examined in the present study between CMJ with and without arm swing. Cohen's *d* was used to calculate the measure of effect size (i.e., d=0.2 is a small effect, d=0.5 is a moderate effect, and d=0.8 is a large effect) [18]. Statistical significance was set a priori to p<0.05. All statistical analyses were completed with SPSS (Version 26.0; IBM Corp., Armonk, NY, USA).

RESULTS

Descriptive statistics for each force-time metric examined in this study are presented in Table 1. Statistically significant differences in biomechanical characteristics between CMJ with and without arm swing were observed in eccentric duration ($t_{[9]}$=-2.850, p=0.019, d=0.697), jump height ($t_{[9]}$=-3.982, p=0.003, d=1.160), concentric duration ($t_{[9]}$=-2.397, p=0.040, d=0.833), concentric peak velocity ($t_{[9]}$=-3.910, p=0.004, d=1.155), eccentric braking RFD ($t_{[9]}$=3.418, p=0.008, d=0.387), eccentric deceleration RFD ($t_{[9]}$=2.802, p=0.021, d=0.463), eccentric peak force ($t_{[9]}$=3.357, p=0.008, d=0.434), contraction time ($t_{[9]}$=-3.599, p=0.006, d=0.968), concentric peak power ($t_{[9]}$=-3.924, p=0.003, d=0.841), and concentric impulse ($t_{[9]}$=-3.856, p=0.004, d=0.564).

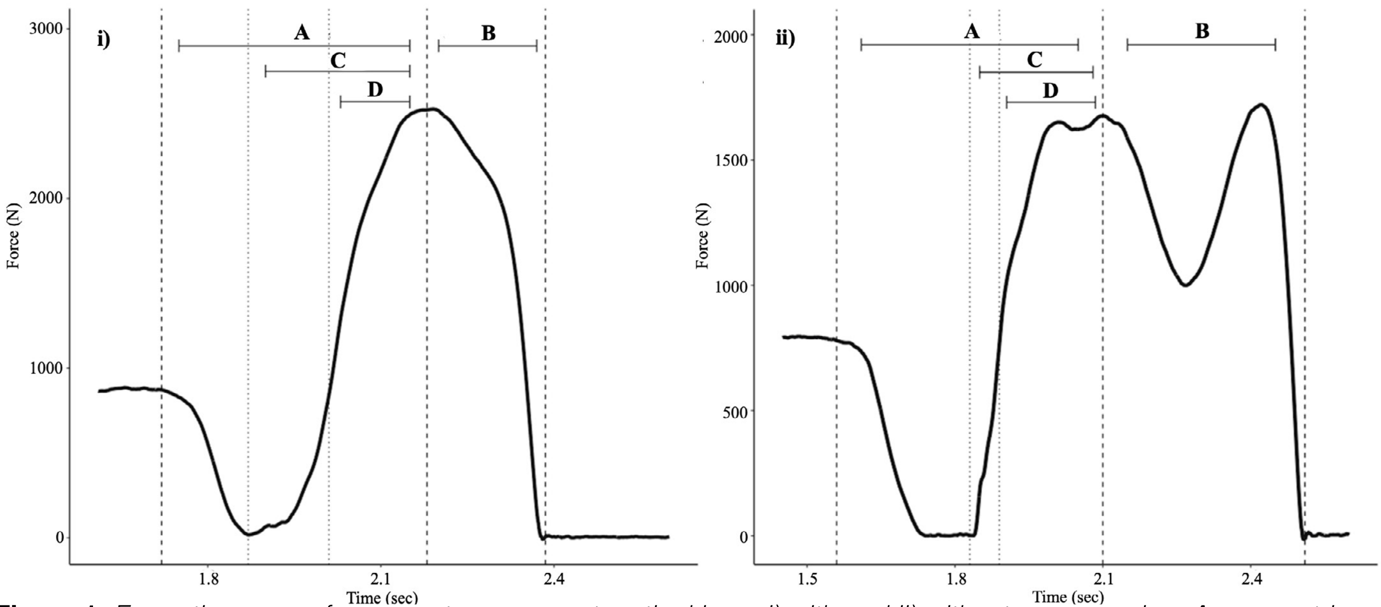

Figure 1. *Force-time curve for a countermovement vertical jump i) with and ii) without an arm swing.* ***A*** *– eccentric phase;* ***B*** *– concentric phase;* ***C*** *– braking phase;* ***D*** *– deceleration phase.*

Table 1. Descriptive statistics, mean and standard deviation (x̄±SD), for each dependent variable examined in the present study.

Variable [unit]	CMJ without arm swing	CMJ with arm swing
Eccentric phase		
Braking phase duration [s]	0.30±0.06	0.30±0.05
Eccentric braking impulse [N·s]	55.2±15.4	56.6±16.3
Eccentric duration [s]	0.483±0.054	0.519±0.050*
Eccentric braking RFD [N·s^{-1}]	7109.7±2959.6	6037.3±2566.1*
Deceleration phase duration [s]	0.16±0.04	0.16±0.03
Eccentric deceleration impulse [N·s]	114.1±26.3	109.7±23.7
Eccentric deceleration RFD [N·s^{-1}]	9829.1±5178.1	7757.8±3627.3*
Eccentric peak velocity [m·s^{-1}]	-1.29±0.24	-1.24±0.23
Eccentric peak power [W]	1781.1±680.1	1636.2±572.2
Eccentric mean power [W]	553.6±110.0	516.5±92.7
Eccentric peak force [N]	2229.3±491.8	2036.1±394.1*
Eccentric mean force [N]	871.0±114.6	870.9±114.4
Concentric phase		
Concentric duration [s]	0.244±0.021	0.264±0.028*
Concentric impulse [N·s]	256.0±32.6	275.8±37.4*
Concentric mean force [N]	1933.9±307.7	1929.8±302.7
Concentric peak force [N]	2435.2±421.7	2454.2±373.8
Concentric peak velocity [m·s^{-1}]	3.02±0.14	3.24±0.23*
Concentric peak power [W]	5521.1±870.3	6294.1±964.8*
Concentric mean power [W]	3071.8±569.5	3195.9±610.4
Concentric RFD [N·s^{-1}]	2873.7±1578.7	3649.3±2222.2
Other		
Contraction time [s]	0.726±0.066	0.782±0.049*
Jump height [cm]	42.7±4.6	49.8±7.4*
RSI-modified [m·s^{-1}]	0.61±0.10	0.63±0.11

*Note: CMJ=countermovement vertical jump; RSI-modified=reactive strength index-modified; RFD=rate of force development; *significantly different when compared to CMJ with no arm swing (p<0.05).*

No statistically significant differences between the two CMJ testing modalities were observed in braking phase duration ($t_{[9]}$=-0.587, *p*=0.572, *d*=0.001), eccentric mean force ($t_{[9]}$=0.207, *p*=0.840, *d*=0.009), eccentric braking impulse ($t_{[9]}$=-0.422, *p*=0.683, *d*=0.088), eccentric deceleration impulse ($t_{[9]}$=1.246, *p*=0.244, *d*=0.176), deceleration phase duration ($t_{[9]}$=-0.500, *p*=0.629, *d*=0.001), eccentric peak velocity ($t_{[9]}$=-1.229, *p*=0.250, *d*=0.213), RSI-modified ($t_{[9]}$=-0.959, *p*=0.362, *d*=0.190), concentric mean force ($t_{[9]}$=0.171, *p*=0.868, *d*=0.013), concentric mean power ($t_{[9]}$=-2.111, *p*=0.064, *d*=0.210), concentric peak force ($t_{[9]}$=-0.351, *p*= 0.734, *d*=0.048), concentric RFD ($t_{[9]}$=-1.412, *p*=0.192, *d*=0.402), eccentric mean power ($t_{[9]}$=2.022, *p*=0.074, *d*=0.365), and eccentric peak power ($t_{[9]}$=1.562, *p*=0.153, *d*=0.231).

DISCUSSION

The purpose of the present study was to compare force-time characteristics between CMJ with and without an arm swing in professional male basketball players. It was hypothesized that several dissimilarities were likely to be observed between the two testing modalities. In line with the aforementioned hypothesis, the findings of the present study reveal statistically significant differences between multiple force-time metrics (e.g., concentric impulse and peak power, eccentric peak force, jump height). However, it is interesting to note that the observed differences seem to be phase-specific. This trend became apparent when analyzing metrics within each of their respective subgroups (e.g., eccentric and concentric phase).

Previous research has found that using an arm swing tends to slow down the rate of descent (i.e., slower rate of the hip, knee, and ankle flexion) while producing greater ground reaction forces during the eccentric phase of CMJ [8,19,20]. These findings seem to be in the agreement with the results obtained in the present investigation where CMJ without an arm swing was depicted by notably faster eccentric duration times. This allowed athletes to generate significantly higher eccentric braking and deceleration RFD. However, CMJ without an arm swing demonstrated superior eccentric peak force when compared to CMJ with an arm swing, which is contradictory to the previously mentioned research reports [8,19,20]. While further research is warranted on this topic, this disagreement may be specific to the cohort of participants examined in the present study. For example, when performing rebounding tasks, basketball players are less focused on attaining a peak jump performance, but rather on securing an optimal position to get a rebound within a limited amount of time [21]. Thus, due to on-court playing demands, they might be more accustomed to performing CMJ without incorporating a full arm swing motion. In addition, similar findings pertaining to braking phase duration (0.30±0.03 s), deceleration phase duration (0.17±0.02 s), eccentric duration (0.473±0.04 s), and deceleration RFD (9509±1856 $N·s^{-1}$) for CMJ without an arm swing were observed by Merrigan et al. [22] when examining a cohort of NCAA Division-I American football players (i.e., hybrid position – running backs, tight end/fullback, linebackers). Interestingly, the same group of authors reported slightly higher values for peak force (2519±267 N), mean force (967±85 N), and peak power (2402±444 W) when compared to the findings of the present study [22]. This discrepancy may be attributed to the position- and sport-specific requirements (e.g., basketball vs. American football) as well as differences in participants' anthropometric characteristics (e.g., body mass – 88.7±12.1 vs. 98.5±8.68 kg).

A considerable amount of scientific literature has documented a positive impact of arm swing on CMJ performance [7,8,21,22,24]. Rather than being attributed to a single biomechanical alteration, this performance enhancement involves a complex series of events that allow for the build-up of energy in the early phases of the jump that is later on transferred to the rest of the body [23,25]. When examining force-time metrics within the concentric phase subgroup, the findings of the present study reveal that the addition of an arm swing resulted in a significant increase in CMJ concentric duration, impulse, peak velocity, and peak power. Similar observations pertaining to an increase in concentric phase duration (0.29±0.05s) and impulse (283.2±46.7 N·s) were made by Vaverka et al. [24] when investigating the effect of an arm swing on CMJ performance in professional male volleyball players. Also, previous research focused on studying the CMJ performance of NCAA Division-I male and female basketball players have reported similar magnitudes for the concentric duration (0.289 s), impulse (265.6 N·s), peak velocity (3.0 $m·s^{-1}$), and RFD (3637.6 $N·s^{-1}$), such as the ones observed in the present investigation [7]. Yet, when incorporating an arm swing movement, it should be noted that 78% of an improvement in CMJ performance can be attributed to an increase in the velocity of the movement [23]. This comes from energy built up in the shoulders and elbow joints as well as extra work done by the hip [23]. With that being said, considering that no difference in concentric peak force has been observed in the present study between CMJ with and without an arm swing, we can conclude that the aforementioned increase in velocity is one of the key factors driving an increase in concentric peak power (i.e., power = force x velocity) [26]. In addition, concentric peak force and peak power values for CMJ with an arm swing are similar to basketball dunking motions [27,28], and greater than the values observed for jump-shooting motions [29,30], which is expected considering the differences in the intensity of these basketball-specific skills.

Lastly, the benefit of an arm swing for attaining greater CMJ heights has been well-documented in the scientific literature [7,8,21,24,31]. A recently published study reported a 13.6% increase in CMJ height when using an arm swing [8]. However, it should be noted that incorporating an arm swing to attain greater jump height may increase contraction time [21], which has been observed in the present study. In certain instances, gaining 3-4 cm by performing a CMJ with an arm swing may jeopardize an athlete's ability to properly respond to on-court playing demands. Thus, this decision may be situation-dependent and rests on the athlete's expertise as well as the competitive environment. In addition, vertical jump height, RSI-modified, and contraction time values observed in the present study are similar or slightly greater than previously reported in NCAA Division-I athletes, which is understandable considering differences in competitive levels (i.e., collegiate vs. professional) [7,22,32].

To the best of our knowledge, this is the first study that examined phase-specific differences in force-time metrics within a cohort of professional male basketball players. While offering additional insight into the biomechanical characteristics of the two most commonly implemented CMJ testing modalities, this study is not without limitations. The sample of athletes that volunteered to participate in the present investigation could have been larger in size. Also, due to the uniformity of the sample of participants, caution is advised when trying to generalize the study findings to other populations, as results may look different. Likewise, further research should focus on examining differences in force-time metrics between CMJ with and without arm swing in female basketball players as well as other competitive levels.

In conclusion, the findings of the present study reveal significant differences in multiple force-time metrics between the CMJ with and without and arm swing. While having greater eccentric duration, CMJ with an arm swing had lower eccentric braking and deceleration RFD and lower eccentric peak force, when compared to CMJ without an arm swing. During the concentric phase of the jumping motion, concentric duration, impulse, peak velocity, and peak power were significantly greater in favor of CMJ with an arm swing. Moreover, despite longer contraction time, incorporating an arm swing resulted in greater vertical jump heights. Overall, these data provide additional insight into CMJ performance parameters of professional male basketball players that may benefit practitioners with the assessment selection process when attempting to monitor athletes' neuromuscular performance. Also, due to the observed differences in multiple force-time metrics (e.g., concentric impulse and peak power, eccentric peak force, jump height), the findings of the present study suggest that CMJ with and without an arm swing should not be used interchangeably. The selection of the specific testing modality needs to be determined in advance and needs to remain unchanged throughout the testing timeline (e.g., practice session, season-long analysis) in order to obtain adequate and comparable results.

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