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Influence of technique on upper body force and power production during medicine ball throws

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ABSTRACT

This project examined the interrelationships between power production and upper body kinematics during a series of medicine ball push-press (MBP-P) throws. Twenty-five regular weight trainers (body mass = 86 ± 10 kg) performed a series of ballistic vertical MBP-P throws at loads representing 5% and 10% of their assessed 5RM bench press. Throws were performed lying supine on a force platform (1 kHz) with upper body kinematics assessed using standard infra-red motion capture techniques (0.5 kHz). Gross measures of performance and power production such as peak vertical ball velocity (Vel_{peak}), peak force (F_{peak}) and power (P_{peak}) were recorded during the propulsive phase of the movement. Comparative analyses indicated that despite significant reductions in Vel_{peak} from the 5% to 10% loads ($P < 0.001$), F_{peak} remained largely unchanged ($P = 0.167$). Analysis of inter-trial variability showed that the gross measures of performance and power were relatively stable (Coefficient of Variation [CV%] <13%), while most upper limb segmental kinematics varied considerably between trials (CV% up to 70%). This project highlights the complexity of the relationships between power production and upper body kinematics during light load ballistic MBP-P throwing. Additionally, it shows how trained athletes can achieve similar outcomes during ballistic movements using a variety of movement strategies.

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KEYWORDS
Power testing; dynamic strength; ballistic strength

Introduction

The load that elicits maximum upper body power has been subject to considerable investigation throughout the scientific literature (Baker, 2001; Alemany et al., 2005; Argus, Gill, Keogh, & Hopkins, 2014; Baker, 2002; Baker, Nance, & Moore, 2001; Baker & Newton, 2007; Bevan et al., 2010; Brandenburg, 2005; Cronin, McNair, & Marshall, 2001, 2003; Cronin & Owen, 2004; Cronin & Sleivert, 2005; Jandacka & Vaverka, 2008; Newton, Kraemer, Hakkinen, Humphries, & Murphy, 1996; Newton et al., 1997). Typically, researchers in this domain assess upper body power via a bench press throw (BP-T) performed on a modified Smith Machine. Results from these studies indicate that peak BP-T power is generated between 30% (Argus et al., 2014; Bevan et al., 2010) and 70% (Baker et al., 2001; Cronin et al., 2001) of the participant's bench press single repetition maximum (1RM). However, the quantification of upper body power using BP-T may also oversimplify the role that technique (Cormie, McBride, & McCaulley, 2009; Cronin et al., 2003; Newton et al., 1997) has in the development of power in high velocity sporting movements. Accordingly, several researchers suggest that maximum force and maximum movement velocity data need to be reported in studies investigating ballistic power (Cormie et al., 2009; Cronin et al., 2003; Hori et al., 2009; Newton et al., 1997; Samozino, Morin, Hintzy, & Belli, 2008). The importance of reporting the latter is likely to be particularly pertinent in upper body sporting movements where the objects involved are often proportionally light (e.g. the mass of a regulation basketball is only 0.57 to 0.62 kg).

To address issues such as these some researchers assess upper body using medicine ball throws, suggesting that this may provide a more functional measure of performance in these high velocity movements (Debanne & Laffaye, 2011; Ignjatovic, Markovic, & Radovanovic, 2012; Mayhew et al., 2005; Salonia, Chu, Cheifetz, & Freidhoff, 2004; Sreckovic et al., 2015; Stockbrugger & Haennel, 2001; Vossen, Kramer, Burke, & Vossen, 2000). Additionally, the use of medicine balls also allows for loads < 10 kg to be assessed (Ignjatovic et al., 2012; van den Tillaar & Marques, 2011, 2013), an issue that can be problematic during standard BP-T testing (i.e. an unloaded bar in a Smith Machine is typically >20 kg). However, the use of medicine ball throwing to assess upper body power can also be problematic, as most of these studies rely on gross measures such as throw distance to estimate upper body power. Throw distance is obviously influenced by both the angles and velocities at the instance of ball release, with the absence of standardised angles of release throughout these studies limiting the reliability of findings (Falvo, Schilling, & Weiss, 2006; van den Tillaar & Marques, 2013). Importantly, many of the highlighted issues with medicine ball push-press (MBP-P) testing can be addressed if the medicine ball is projected vertically whilst lying supine, with the vertical throw allowing the standardisation of release angle (Sayers & Bishop, 2017). Our testing has shown that the incorporation of a force platform during vertical MBP-P tests also enables the reliable quantification of power related variables such as peak force (F_{peak}) and power (P_{peak}) and (Sayers & Bishop, 2017). Additionally, this protocol

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also allows the collection of time series force data, facilitating the calculations of peak rate of force development (RFD_{peak}) and other variables during the acceleration phase of the movement.

While outcome variables such as jump/throw height or F_{peak} and P_{peak} are used frequently throughout the literature to assess power in ballistic activities, researchers in this domain acknowledge that measures such as these occur as a function of the complex integration of multiple neuromuscular and mechanical systems (Cross, Brughelli, Samozino, & Morin, 2017; Jaric, 2015). The complexity of these systems is such that in skilled movement, the same outcome can be achieved through numerous movement strategies (Seifert, Araujo, Komar, & Davids, 2017; Seifert, Button, & Davids, 2013; Seifert, Komar, Araujo, & Davids, 2016; Seifert et al., 2014). From a practical perspective this can make the results from ballistic tests such as the vertical MBP-P difficult for strength and conditioning coaches to interpret, with improvements in performance based potentially on an increase in muscular power, an increase in the application of power due to improved technique, or various combinations of both.

Accordingly, the purpose of this study was to assess the interactions between upper body kinematics and power production during vertical MBP-P throws using medicine ball loads typical of those used in medicine ball training (5% and 10% of 5RM). We were particularly interested in examining whether these variables, and the interactions between them, differed for these two loads.

Methods

Participants

Volunteer participants for this study (n = 25) were all regular weight trainers who had been weight training at least twice a week for a minimum of 1 year (body mass (BM) = 86 ± 10 kg). They had all participated in several orientation sessions and were proficient in the MBP-P throw task. Participants were informed of the risks and experimental procedures and all provided their informed consent prior to attending several familiarisation sessions. This research was approved by the institutional Human Research Ethics Committees.

Data collection

Data collection occurred on two separate days, with at least 4 days separating each testing session. In order to calculate the relative medicine ball loads, bench press 5RM data were collected on Day 1, using a free weight bench press bench (Calgym Pty Ltd, Caloundra, QLD), a standard 20 kg Olympic bar and Olympic size weights. At the completion of a 10 min self-structured warm-up, which included standard upper body locomotor activities and 2 sets of light-moderate load bench presses, standard protocols were followed to determine the participant's 5RM bench press (Kraemer, Ratamess, Fry, & French, 2006). These data were recorded to the nearest 1 kg (mean = 88 ± 7kg).

The MBP-P tests were performed on Day 2. Prior to this testing 14 mm retro-reflective markers were attached to the skin bilaterally adjacent to the anterior and posterior superior iliac spines, iliac crests, acromion processes, deltoid tuberosities, medial and lateral humeral epicondyles, the ulna and radial styloid processes and the distal ends of the 2^{nd} and 5^{th} metacarpals. Single markers were attached adjacent to the manubrium, xiphoid process and the spinous processes of the 7^{th} and 12 thoracic vertebra. Three marker clusters were attached to the mid-point of both upper arms and forearms, with three additional markers attached to each medicine ball. A standing static capture was then performed with the participant standing, after which the posterior iliac spine and thoracic vertebrae markers were removed.

Participants were then given approximately 10 min to complete a self-structured warm-up, which included 2 sets of 8 repetitions bench presses at approximately 50% of their individual 5RM and several MBP-P. Testing was performed with the participants lying supine on a custom-made 9 mm thick steel platform that was attached to a force platform sampling at 1kHz (Bertec Corporation, Columbus, Ohio, USA), with their hips and knees flexed 90 deg. Each MBP-P starting with the medicine ball pressed against the participant's chest (no counter movement) and the upper arms horizontally extended, flexed and slightly abducted and the elbows flexed. On a verbal signal participants threw the medicine ball explosively upwards with as much force as possible in a chest passing action (Sayers & Bishop, 2017). The MBP-P loads were set at 5% and 10% (Ignjatovic et al., 2012; van den Tillaar & Marques, 2013) of the participant's 5RM bench press (3 repetitions per load), with trial order randomised between participants. There was approximately 2 mins rest between repetitions.

A 10 camera 0.5 kHz infrared motion capture system (Qualisys AB, Gothenburg, Sweden) was used to track the marker trajectories, with these data synchronised with the force platform outputs via an AD converter (BNC/USB/19 Rack, Qualisys AB, Gothenburg, Sweden). At the completion of testing, biomechanical modelling software (Visual3D, C-Motion Inc., Germantown, USA) was used to smooth these marker trajectories and force platform outputs using second order low pass digital filters (kinematic data at 12 Hz and force data at 25 Hz). This software was then used to develop an eight segment rigid body model of the upper limbs, torso and pelvis. A global reference system was defined relative to the static capture positions so that the positive Y-axis was directed anteriorly, the X-axis laterally (positive direction to the right) and the positive Z-axis pointing vertically. During modelling, pelvic orientation was calculated relative to the global reference system with segment coordinate systems for upper limb segment constructed according to standard biomechanics principles (Wu et al., 2005). Three dimensional movements about the shoulder, elbow and wrist joints were then defined by angular movements of the distal segment in relation to its proximal one. Accordingly, flexion (and shoulder horizontal flexion), adduction and internal rotation were defined as positive rotations about each segment's X, Y and Z-axes respectively. All segment orientations were normalised as 0 deg using mean angles from the static trial.(Kawamoto, Miyagi, Ohashi, & Fukashiro, 2007).

Variables

The propulsive phase of the MBP-P movement was defined as occurring from the point where the vertical ground reaction force during the acceleration phase was 20 N greater than baseline (i.e. the weight of the participant and ball), with ball release defined as the instant where vertical ball acceleration became negative. The first and second differentials of the medicine ball vertical displacement data were used to calculate the peak vertical ball velocity (Vel_{peak}) and peak vertical ball acceleration ($Accel_{peak}$) during the propulsive phase. F_{peak} and time to F_{max} were calculated from the vertical GRF data, with P_{peak} and mean power (P_{mean}) calculated from the product of the vertical GRF and vertical ball velocity data. RFD_{peak} was recorded as the maximum value from the first differential of the vertical GRF data. In order to quantify the involvement of the upper body action in the MBP-P throws, maximal shoulder flexion and horizontal flexion velocities, together with elbow extension and wrist flexion velocities were derived from the first order differentials of the respective segmental angular displacement data.

Statistical analyses

The influence of medicine ball load on the various kinematic and power related variables were determined via a series of paired t-tests. The relative magnitude of differences between medicine ball loads were quantified using standard Effect Size (*ES*) analyses (Cohen, 1988) (*negligible* = < 0.2, *small* = 0.2 to 0.5, *medium/moderate* = 0.5 to 0.8 and *large* > 0.8). The relationships between force and velocity for each medicine ball load were determined using Pearson's Product Moment correlation coefficients (and 95% confidence limits), with values of 0.09, 0.10–0.29, 0.30–0.49, 0.50–0.69, 0.70–0.89, 0.90–0.99, and 1.00 interpreted as *trivial, small, moderate, large, very large, nearly perfect*, and *perfect*, respectively (Hopkins, Marshall, Batterham, & Hanin, 2009). The relative magnitude of the coefficient of variation (CV%) data across the three trials were used as an indication of inter-trial consistency (Hopkins, 2000). Statistical analysis were performed using the statistics package SPSS for Windows (version 22), with the alpha level set to $P < 0.05$. All data are presented at means ±1 standard deviation (SD) unless stated otherwise.

Results

Analyses indicated that all values for medicine ball kinematic data decreased significantly (with *large* ES) from the lighter to the heavier medicine ball load (Table 1). However, peak elbow extension velocity was the only upper body kinematic variable that either differed significantly, or achieved greater than a *moderate* difference between the two medicine ball loads. Time to F_{max}, P_{mean} and P_{max} were the only force related variables that differed significantly between medicine ball loads, although there was only a *small* reduction in the latter for the heavier medicine ball load (Table 2). Analysis of inter-trial consistency for the force and power data shows that, with the exception of maximal elbow extension data, there was considerable variance in the upper body maximal angular velocity data. Correlation analyses indicated *small* to *moderate* non-significant relationships between Vel_{peak} and both F_{max} and P_{max} at the 5% of 5RM load (*r* = 0.25, *P* = 0.219, *r* = 0.35, *P* = 0.086), with these relationships becoming stronger and significant for the heavier medicine ball load (*r* = 0.42, *P* = 0.035, *r* = 0.63, *P* = 0.001). Similarly, 5RM bench press load recorded non-significant correlations with Vel_{peak} at both the 5% of 5RM (*r* = 0.04, *P* = 0.868) and 10% of 5RM loads (*r* = 0.39, *P* = 0.051). All other variables achieved *trivial* to *small*, non-significant correlations with Vel_{peak}.

Analysis of time series data for vertical medicine ball velocity and acceleration, coupled with vertical force and rate of force development data (Figure 1) highlights the relatively large differences in medicine ball velocity and acceleration (Figure 1(a,b)) that are occurring in the absence of noticeable differences in ground reaction force data (Figure 1(c,d)). The time series upper body angular velocity data show a tendency for participants to extend their wrists early in the propulsive phase for both medicine ball loads (Figure 2(a,b) respectively). Although some variations existed in the magnitude and timing of this movement, there were only three throws (of the 150 assessed) in which this action did not occur. These data also indicate the peak wrist flexion velocities occur after the peak elbow extension and shoulder horizontal flexion velocities, with the latter working largely synchronously. As was the case for the discrete angular velocity data, it is important to note that considerable intra and inter-individual differences existed in upper body kinematics.

Table 1. Mean (±1SD) ball and upper body kinematic data for each ball load during ballistic medicine ball push press throws. Analysis includes coefficient of variation (*CV%*) data for each variable at each load and the results from paired t-tests and effect size (*ES*) analyses for each variable between loads.

Variable	Load	Mean (±1SD)	*CV* %	*P* *ES*
Peak ball velocity (m/s)	5% of 5RM	5.27 (0.31)	3.2	< 0.001
	10% of 5RM	4.09 (0.31)	3.3	1.76
Peak ball acceleration (m/s^2)	5% of 5RM	40.12 (5.23)	6.7	< 0.001
	10% of 5RM	25.33 (4.19)	5.3	1.68
Peak shoulder horizontal flexion velocity (deg/s)	5% of 5RM	355 (88)	44.6	0.071
	10% of 5RM	322 (90)	39.9	0.38
Peak shoulder flexion velocity (deg/s)	5% of 5RM	263 (98)	27.3	0.301
	10% of 5RM	251 (91)	36.1	0.13
Peak elbow extension velocity (deg/s)	5% of 5RM	818 (78)	7.2	< 0.001
	10% of 5RM	705 (86)	8.3	1.14
Peak wrist flexion velocity (deg/s)	5% of 5RM	795 (295)	44.0	0.226
	10% of 5RM	729 (285)	70.0	0.23

Table 2. Mean (±1SD) force and power related data for each ball load during explosive medicine ball push press throws. Analysis includes coefficient of variation (*CV%)* data for each variable at each load and the results from paired t-tests and effect size (*ES*) analyses for each variable between loads.

Variable	Load	Mean (±1SD)	*CV* %	*P* *ES*
Peak vertical force (N)	5% of 5RM	368 (64)	7.6	0.167
	10% of 5RM	381 (88)	7.0	0.17
Peak rate of force development (N/s)	5% of 5RM	5892 (1399)	15.0	0.995
	10% of 5RM	5894 (1692)	16.9	0.00
Time to peak force (ms)	5% of 5RM	155 (29)	20.7	< 0.001
	10% of 5RM	182 (34)	23.7	0.78
Peak power (W)	5% of 5RM	1126 (252)	12.6	< 0.001
	10% of 5RM	978 (259)	13.2	0.56
Mean power (W)	5% of 5RM	456 (106)	21.1	0.010
	10% of 5RM	413 (116)	18.1	0.38

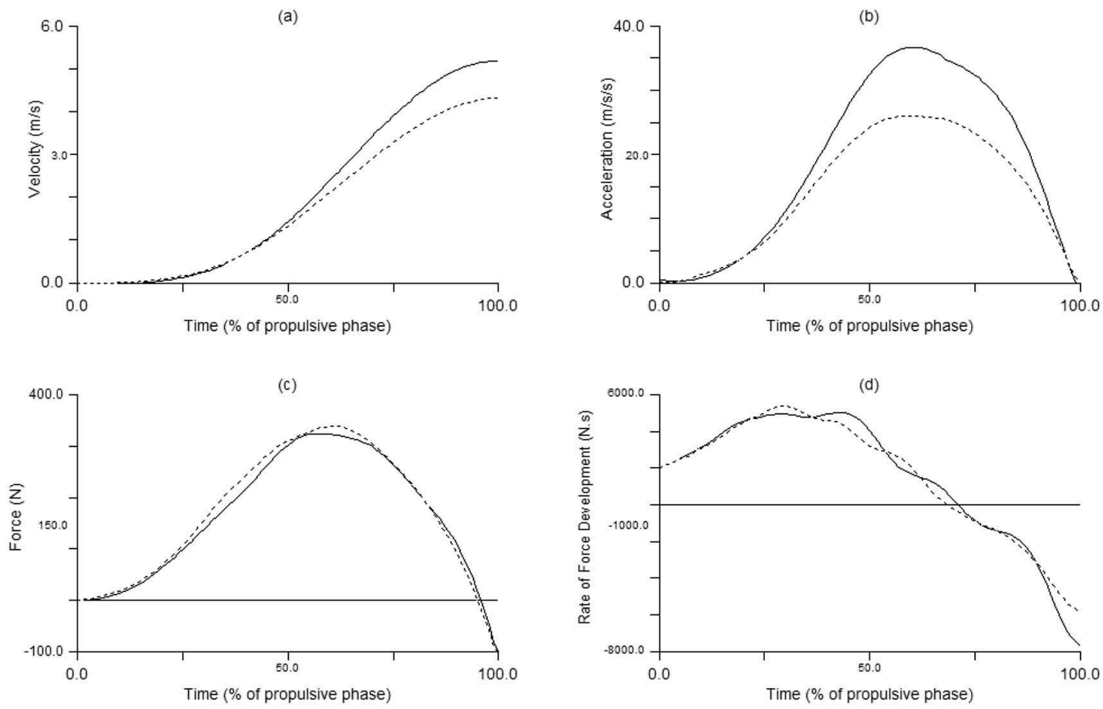

Figure 1. Mean time series data for (a) vertical ball velocity, (b) vertical ball acceleration, (c) vertical force and (d) rate of force development during medicine ball push press throws for loads representing 5% (solid line) and 10% (dashed line) of 5RM. Data are normalised with respect to the propulsive phase.

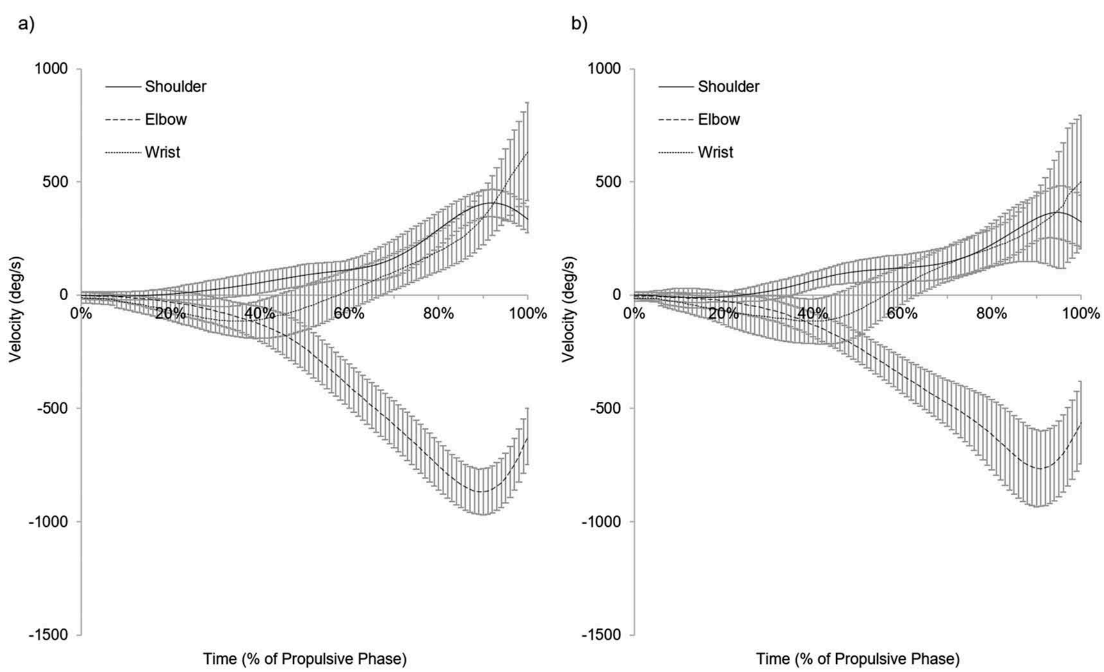

Figure 2. Mean angular velocity time series data for the key upper body segments for the medicine ball push press throws at loads representing 5% (a) and 10% (b) of 5RM bench press strength. Data are normalised with respect to the propulsive phase.

Discussion

In this study we assessed upper body kinematics and power production during vertical MBP-P throws at loads representing 5% and 10% of 5RM. The key findings in this project were first, that despite *large* significant reductions in both Vel_{peak} and $Accel_{peak}$ occurring from the lighter to the heavier medicine ball throw, neither F_{peak} nor RFD_{peak} changed significantly between loads. Additionally, this project highlights that over a series of ballistic MBP-P throws trained athletes produce similar outcome variables using a variety of movement strategies.

The reductions in Vel_{peak} and $Accel_{peak}$ from the 5% to 10% loads were anticipated and, given the negligible non-significant changes in F_{peak}, are a reflection of the well-established inverse relationships between acceleration, force and mass (i.e. *Newton's Second Law of Motion*). The non-significant change in F_{peak} is a reflection of the gross nature of variables derived from force platforms during multi-segment movements (Cross et al., 2017; Jaric, 2015), and is not based on Hill's (1922) well-established non-linear relationship between force and velocity during contractions in isolated muscle fibres.

Although some care should be taken to avoid over interpreting data from just two data points, our participants produced the most power during MBP-P throws using the lightest of our test loads. These loads represent only 2–4% of 1RM bench press (i.e. 5% of 5RM) and provide a stark contrast to data indicating that maximal power during ballistic BP-T is generated at loads representing 30% to 70% of 1RM bench press (Argus et al., 2014; Baker et al., 2001; Bevan et al., 2010; Cronin et al., 2001). This discrepancy is consistent with the body of literature indicating that the "optimal load" for ballistic movements is highly specific to the movement patterns involved (for an extensive review see Cormie, McGuigan, & Newton, 2011). Accordingly, while BP-T and MBP-P throws appear similar, differences in loading patterns and acceleration profiles between these activities no doubt account for the vast differences in the loads required to produce maximal power during each activity. Strength and conditioning coaches need to be aware of this phenomenon, particularly when training and/or testing athletes who must push/throw light loads at high velocity as part of performance in their chosen sport.

Participants in this study produced similar values for the various medicine ball and force and power variables to those reported previously for a similar cohort (Sayers & Bishop, 2017). The increased CV% for some of these data (RFD_{peak} in particular) may indicate that despite several familiarisation sessions, the current population was less experienced in the MBP-P than the earlier sample. Regardless, the consistent relatively low CV% values for F_{peak}, Vel_{peak} and $Accel_{peak}$ indicates that these variables can be reliably quantified using the vertical MBP-P test protocol. Conversely, all participants presented with high inter-trial variability for the assessed upper body kinematic variables. The stability of the gross outcome measures (e.g. F_{peak}, Vel_{peak}) in the presence of considerable variance in movement kinematics is representative of neurobiological degeneracy, a term used in ecological dynamics research to describe how the same outcome can be achieved using a variety of movement strategies (for an extensive review see Seifert et al., 2016). It would appear that during a vertical MBP-P throw the ability to generate greater F_{peak} or Vel_{peak} represents a "constraint" that is determined by the individual's current training status, with the underlying joint kinematics varying as part of a complex dynamic system (Seifert et al., 2013, 2014, 2017; Seifert, Komar, et al., 2016; Seifert, Wattebled, et al., 2016). Interestingly, the joints with the greater anatomical degrees of freedom (wrist and shoulder) also had higher inter-trial variability than the more anatomically constrained elbow. The limitations of our project precludes comment on whether the variability in these movement patterns will decrease with increased practice at the task, although it is likely that a degree of movement variability will remain regardless of skill level (Serrien & Baeyens, 2017). The question remains with our data as to whether participants had optimised their movement strategies for this task, or whether the variability of movement patterns was a function of developing expertise (Seifert et al., 2013, 2016).

From a practical perspective this study highlights the challenges with analysing data from ballistic light load activities such as vertical MBP-P throwing. While the strength coach can confidently and reliably monitor upper body power outcome variables such as F_{peak} or Vel_{peak} derived from vertical MBP-P throwing, the interpretation of these data poses a greater challenge. The latter poses a particular challenge if the coach is wanting to discriminate between changes in power production or task specific skill improvements. However, the strong interplay between technique and power production for these ballistic light load activities means that it is perhaps unnecessary to try and discriminate between them.

Conclusions

In this study we examined the interrelationships between upper body kinematics and power production during ballistic vertical MBP-P throws at loads representing 5% and 10% of 5RM. Despite significant reductions in gross outcome measures of ballistic vertical MBP-P throw performance between loads, several key measures of force production did not change significantly between conditions. This project also highlights the complexity of the interrelationships between upper body movement kinematics and gross outcome performance measures during light load ballistic throwing activities. Strength and conditioning coaches and sport scientists need to be aware of the nature of these complex relationships when testing and training athletes who perform light load, high velocity upper body movements.

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