Accepted Article

J Musculoskelet Neuronal Interact 2024

Journal of Musculoskeletal and Neuronal Interactions JMNI

Original Article

Force Production Measurements During a Supine Medicine Ball Throw: a Reliability and Correlation Study

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Abstract

Objectives: This study aimed to examine the reliability of supine medicine ball throw peak force and rate of force development (RFD) measurements. A secondary aim was to investigate the correlations between these measurements and vertical jump height. **Methods**: Twenty young women (21±3 years) reported for experimental testing on two different occasions. Supine medicine ball throw assessments were performed during each testing session to assess peak force, RFDmax, and RFD at specific percentages of peak force (RFD30% and RFD40-80%). Vertical jumps were performed on a jump mat. The jump mat measured vertical jump height based on flight time. **Results**: Good intraclass correlation coefficients (≥0.82) and coefficients of variation (≤14.0%) were observed between sessions for peak force, RFDmax, and RFD40-80%, but not for RFD30% (0.55, 27.2%). There were significant correlations between jump height and peak force (r=0.483, P=0.031), RFDmax (r=0.484, P=0.031), and RFD40-80% (r=0.491, P=0.028). There was no significant correlation between jump height and RFD30% (r=0.359, P=0.120). **Conclusions**: Our results showed that supine medicine ball throw peak force, RFDmax, and RFD40-80% were reliable measures for assessing upper-body explosive strength in young adults. These measurements were significantly associated with vertical jump height and therefore, may be effective predictors of one's athletic ability.

Keywords: Explosive Strength, Peak Force, Rate of Force Development, Relationship, Upper Body

Introduction

Upper-body explosive strength is a critical factor for success in many sports. Athletes that can rapidly generate high amounts of force with their upper body during blocking, throwing, and striking-type activities are often capable of superior performance[1]. A common test used to assess upper-body explosive strength is the bench press throw[2]. Although this test has been reported to be a reliable assessment tool[3], it requires moving heavy loads (≥ 15 kg)[2], which may not be particularly relevant to upper-body sporting events where the object being thrown is relatively light (i.e., the mass of most thrown objects in sports is less than 7.5 kg)[4]. To address this limitation, several researchers have assessed the upper-body explosive strength capacities of participants by having them throw a lighter-weight medicine ball (1-6 kg)[5,6]. Research suggests that a medicine ball push-press throw from a standing or seated position simulates the actions required in a variety of different ball sports[5]. Unfortunately, this test relies on crude measures, such as throw distance, to estimate explosive strength[4]. Such measures may limit the consistency and interpretation of data[7].

Recent studies have proposed that performing a medicine ball throw test on a force plate in the supine position may yield more consistent results[1,4]. Additionally, such a test permits the calculation of multiple explosive strength measurements, including peak force and rate of force development (RFD)[4]. These measurements are important characteristics relevant to athletic performance[8]. A study by Sayers and Bishop[1] reported that peak force and maximum RFD (RFDmax) measurements during a supine medicine ball throw were reliable parameters. However, these authors[1] did not examine the reliability of RFD measurements calculated at specific percentages of peak force (i.e., RFD30% and RFD40-80%).

The authors have no conflict of interest.

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Edited by: G. Lyritis
Accepted 21 January 2024

Moreover, this study used relatively large medicine balls that were on average between 4.4 and 8.8 kg[1]. It is unclear if performing a supine throw with a smaller medicine ball (2.7 kg) will elicit reliable measures of peak force and RFD. It is also unclear if supine medicine ball throw peak force and RFD are associated with vertical jump height.

The height achieved during a vertical jump test is influenced by the strength capacities of the lower-body musculature[9]. Significant correlations have been reported between measurements of upper- and lower-body strength[10]. If upper-body strength is associated with lower-body strength, and lower-body strength is important for jumping, then upper-body peak force and RFD measurements from a supine medicine ball throw may be related to vertical jump height[8]. The vertical jump is a good indicator of athletic ability[11-13], and when properly conducted, this test is safe for most participants to perform[14]. However, there are special circumstances when vertical jump testing is contraindicated (i.e., during rehabilitation and recovery after a lower-body injury)[8], and the use of supine medicine ball throw tests to estimate jump height would be preferable. Thus, the correlation between the force produced during a supine medicine ball throw test and vertical jump height needs to be examined. Investigating such a correlation may help determine which medicine ball throw variables can be relied upon to predict vertical jump performance. Moreover, it is noteworthy that previous studies examining supine medicine ball throw measurements have only tested young adult men[6,15]. Additional research investigating supine medicine ball throw measurements in young adult women is needed. Thus, the purpose of the present study was to examine the reliability of supine medicine ball throw peak force and RFD measurements in young adult women. A secondary aim was to investigate the correlations between these measurements and vertical jump height. We hypothesized that supine medicine ball throw peak force and RFD would be highly reliable and significantly associated with the height achieved during a vertical jump test.

Methods

Participants

Twenty young women (mean ± SD; age = 21 ± 3 years; height = 163 ± 5 cm; mass = 67 ± 15 kg) volunteered to participate in the present study. All participants were tested in the muscular assessment laboratory at the university. None of the participants reported any current or ongoing neuromuscular diseases or musculoskeletal injuries specific to the upper and lower extremities. Participants were classified as being regular exercisers based on their self-reported volume of physical activity (9 ± 5 $h \cdot wk^{-1}$).

Procedures

Each participant visited the laboratory three times, separated by 2-7 days at approximately the same time of day (± 2 h). The first visit was a familiarization session, and the next two visits were experimental sessions (session 1 and session 2) from which data were collected and used for analysis. During the familiarization session, participants practiced the testing procedures by performing several vertical jumps and supine medicine ball throws. For each experimental session, participants performed three vertical jumps followed by three supine medicine ball throw assessments. Before the assessments, each participant completed a warm-up protocol, which consisted of five minutes of walking at a self-selected speed followed by five submaximal isometric knee extension and forearm muscle actions. Participants were instructed to refrain from any vigorous physical activity or exercise within 24 hours of each testing session.

Vertical Jumps

Vertical jump assessments were performed on a jump mat (Just Jump Technologies, Huntsville, AL) using methods similar to those described previously[14]. For the vertical jumps, participants stood on the jump mat with feet shoulder width apart and hands positioned on the hips. Participants were not allowed to take any steps before performing the vertical jump and a quick descending quarter-squat countermovement was allowed before the ascending take-off phase[16]. For all vertical jumps, participants were instructed to jump up as explosively as possible with both feet at the same time and land on the jump mat in the starting position. The jump mat measured vertical jump height (cm) based on flight time, which was the time that elapsed from the moment the feet left the mat until landing. A total of three jumps were performed with one minute of recovery between each trial, and the greatest vertical jump height of the three trials was used for subsequent analysis.

Medicine Ball Throws

Medicine ball throws were performed on a portable force plate (Accupower; AMTI, Watertown, MA) in accordance with the procedures described by Sayers and Bishop[1] (Figure 1). For the throws, participants laid on the force plate in the supine position with their hands on the ball and knees and hips flexed at 90° [4]. Participants started each throw with the ball positioned at their chest. The ball was held with both shoulders at approximately 90° of abduction and elbows flexed[17]. All throws were performed with a 2.7-kg medicine ball. Each participant performed one practice trial and three official trials of the medicine ball throw with one minute of recovery between each trial. For all trials, participants were instructed to throw the ball explosively upward with as much force as possible[4], using a motion similar to a basketball chest pass. As a precaution, a member of the research team stepped in to catch the ball once it was in flight[1].

For the medicine ball throws, the vertical force signal (N) from the force plate was sampled at 1200 Hz and processed offline using custom-written software (LabVIEW 11.0, National Instruments, Austin, TX). The force signal was low-pass filtered with a zero-phase lag, fourth-order

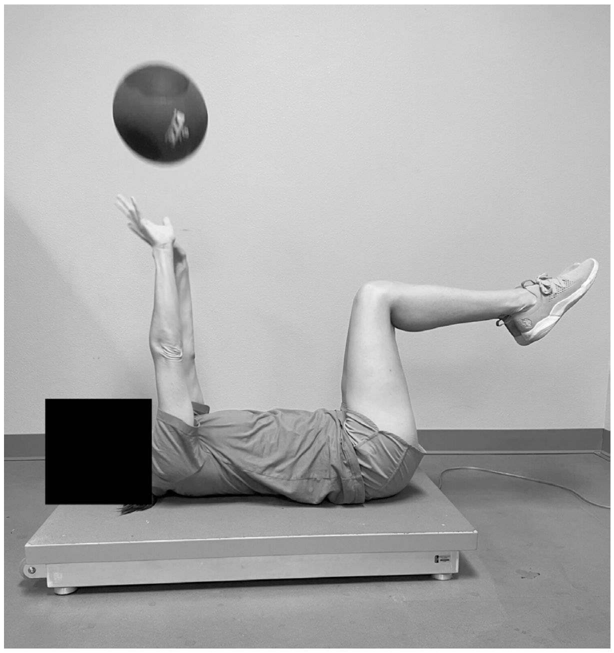

Figure 1. A participant performing the supine medicine ball throw. For each throw, participants laid on a force plate in the supine position with their hands on the ball and knees and hips flexed at 90°. Participants were instructed to throw the ball explosively upward with as much force as possible, using a motion similar to a basketball chest pass.

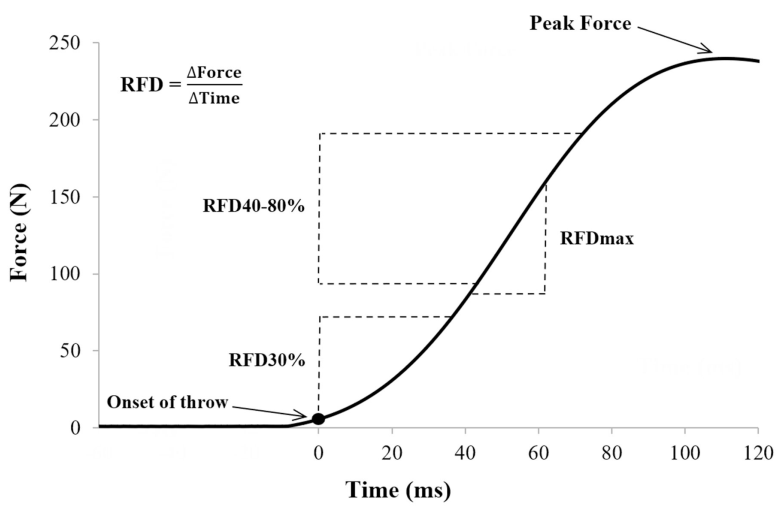

Figure 2. Example of a processed force signal taken from a supine medicine ball throw. The force signal produced during the throw was used to measure peak force and rate of force development (RFD) variables (i.e., RFDmax, RFD30% and RFD40-80%).

Table 1. Mean ± standard deviation (SD) and reliability statistics between sessions for supine medicine ball throw peak force and rate of force development (RFD) variables.

	Mean ± SD							
Variable	Session 1	Session 2	*P* value	$ICC_{2,1}$	SEM	SEM%	MD	CV
Medicine Ball Throw								
Peak Force (N)	161 ± 46	156 ± 49	0.288	0.88	16	10.2	45	9.1
RFDmax ($N \cdot s^{-1}$)	2223 ± 899	2019 ± 750	0.059	0.83	320	15.1	888	13.1
RFD30% ($N \cdot s^{-1}$)	1024 ± 582	936 ± 421	0.427	0.55	342	35.0	949	27.2
RFD40-80% ($N \cdot s^{-1}$)	2141 ± 901	1931 ± 729	0.054	0.82	323	15.8	894	14.0

P value = type I error rate for the paired samples t-test between sessions 1 and 2. $ICC_{2,1}$ = intraclass correlation coefficient, model 2,1. SEM = standard error of measurement, expressed as an absolute value and as a percentage of the grand mean. MD = minimal difference to be considered real. CV = coefficient of variation.

Butterworth filter at a cutoff frequency of 10 Hz[8]. The weight of the participant and the medicine ball was subtracted from the signal so that the force at baseline (prior to the throw) was 0 N[1]. All subsequent calculations were conducted on the filtered and weight-corrected force signal (Figure 2).

Peak force was calculated as the highest force value. RFDmax was calculated as the highest slope for any 20 ms epoch that occurred over the initial rising portion of the force signal. RFD30% and RFD40-80% were calculated as the linear slope of the force signal (Δforce/Δtime) from the onset of the throw to 30% peak force and from 40% to 80% peak force, respectively. These percentages were chosen because they represent RFD characteristics in the early (30%) and late (40-80%) phases of force production and have been shown to significantly correlate with numerous functional performance outcomes[18,19]. The contraction onset for the throw was set at a robust threshold of 5 N[20]. Of the three throws performed, the trial with the highest RFDmax was selected for analysis[8].

Statistical Analyses

Boxplots were used to identify outliers, defined as values that exceeded 1.5 times the interquartile range away from the top or bottom of the box[21]. Paired samples *t*-tests were used to verify the presence of systematic differences in medicine ball throw peak force and RFD variables between testing sessions 1 and 2. Reliability statistics were calculated to determine the consistency between sessions for each variable. These statistics included the intraclass correlation coefficient (ICC, model 2,1), standard error of measurement (SEM), minimal difference (MD) needed to be considered real, and coefficient of variation (CV). The methods for calculating these statistics have been reported elsewhere[22]. ICC values greater than 0.90 were considered excellent, values between 0.80 and 0.90 were considered good, and values less than 0.80 were considered poor[23]. CV values were interpreted with an analytical goal of 15% or below[24].

Pearson correlation coefficients (*r*) from data averaged across both sessions were calculated to examine the relationships between vertical jump height and medicine ball throw peak force and RFD variables. The calculations for the ICC, SEM, MD, and CV were performed using a custom-written spreadsheet (Microsoft Excel, Microsoft Corporation, Redmond, WA). All other statistical analyses were performed using SPSS software (version 29.0, SPSS Inc., Chicago, IL). An alpha level of $P \leq 0.050$ was considered statistically significant for all analyses.

Results

No outliers were identified for any of the variables in this study. Table 1 shows the means, SDs, and reliability statistics between sessions for medicine ball throw peak force, RFDmax, RFD30%, and RFD40-80%. There were no systematic differences ($P = 0.054$-0.427) between sessions for any of the variables. The ICC for medicine ball throw RFD30% was 0.55, which was considerably lower than the ICCs for the other variables (0.82-0.88). The CV value for medicine ball throw RFD30% was 27.2%, whereas the CV values for peak force, RFDmax, and RFD40-80% were all less than or equal to 14.0%.

The mean ± SD for vertical jump height was 33.9 ± 5.5 cm. There were significant correlations between vertical jump height and medicine ball throw peak force ($r = 0.483$, $P = 0.031$), RFDmax ($r = 0.484$, $P = 0.031$), and RFD40-80% ($r = 0.491$, $P = 0.028$); however, there was no significant correlation between vertical jump height and RFD30% ($r = 0.359$, $P = 0.120$). The scatterplots for these correlations are shown in Figure 3.

Discussion

In this study, we found good ICC (≥ 0.83) and CV (≤ 13.1%) values between sessions for peak force and RFDmax (Table 1). Sayers and Bishop[1] also showed good ICC (≥ 0.83) and CV (≤ 13.9%) values for these same variables. Collectively, these

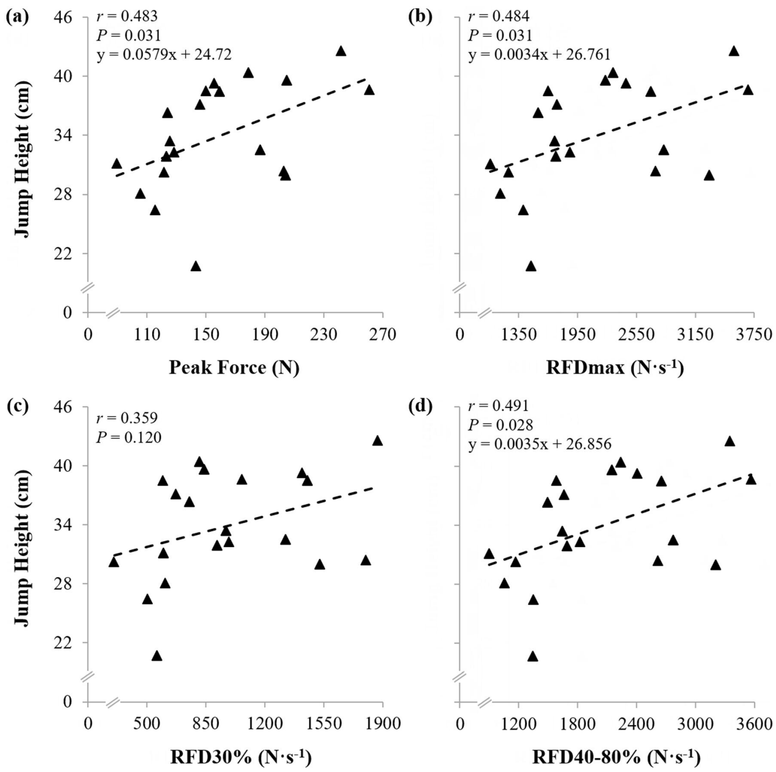

Figure 3. Scatterplots of the correlations between vertical jump height and supine medicine ball throw (a) peak force, (b) RFDmax, (c) RFD30%, and (d) RFD40-80%. The regression equations for predicting vertical jump height from peak force, RFDmax, and RFD40-80% are provided. RFD = rate of force development.

findings suggest that supine medicine ball throw peak force and RFDmax are reliable parameters for assessing upper-body explosive strength in young adults. A novel aspect of the present study was the assessment of RFD at specific percentages of peak force. Our findings revealed good reliability for RFD40-80% but poor reliability for RFD30% (Table 1). We calculated RFD30% as the linear slope of the force signal from the onset of the throw to 30% peak force (Figure 2). In time scale, this corresponded (on average) to the first 50 ms of the force produced during the throw. Previous studies investigating the reliability of explosive force production during isometric knee extension strength tests have reported ICCs of 0.60-0.73 and CVs of 23.5-33.7% for RFD at 0-50 ms[25,26]. These ICC and CV values are consistent with the poor values observed in the present study for RFD30% (ICC = 0.55, CV = 27.2%). It is possible that the slope of the force signal during an explosive strength test is more variable at smaller percentages (0-30%) of peak force. This greater variability may be attributed to neural factors[27] and could explain why poorer ICC and CV values were observed for RFD30% in the present study.

Upper-body strength has been shown to be significantly associated with the strength capacities of the lower-body musculature[10]. If upper-body strength is associated with lower-body strength, and lower-body strength is important for jumping[9], then upper-body peak force and RFD measurements from a supine medicine ball throw may be related to vertical jump height. Support for this is highlighted in the present study. We found significant positive correlations between vertical jump height and supine medicine ball throw peak force, RFDmax, and RFD40-80% (Figure 3). Kerr and Sayers[7] reported significant positive correlations between supine medicine ball throw explosive force measurements (peak force and RFDmax) and performance during a multiple repetition bench press test. There have been no previous studies that have examined the correlations between explosive force measurements from a supine medicine ball throw and performance during a vertical jump. It is possible that peak force, RFDmax, and RFD40-80%, given their significant correlation with vertical jump height in the present study, may be able to predict a person's jumping ability and overall athletic performance potential. Future studies with larger sample sizes are needed to confirm this hypothesis. It should be noted that our findings showed no significant correlation between RFD30% and vertical jump height (Figure 3). This non-significant correlation may be due to the aforementioned poor reliability for RFD30%. Poor reliability attenuates the correlation coefficient (*r*)[28] and thus, may be an important factor to consider when analyzing the relationships between variables.

A key finding of this study is the significant correlations between the supine medicine ball throw and vertical jump tests. From these correlations, we have developed regression equations (Figure 3). Although these equations need to be validated on larger populations, they may be used as a preliminary method for predicting vertical jump height. The predictive capacity of the supine medicine ball throw may have important implications. For example, using explosive strength measurements from a supine medicine ball throw to predict vertical jump height may be especially advantageous in the context of rehabilitation after lower-limb injury, where vertical jumping is contraindicated[29]. Given the importance of explosive strength to many sport-related tasks[1], coaches and other practitioners may want to consider using the supine medicine ball throw in their current test battery. This test may provide coaches with an additional evaluation tool to help in identifying athletes with superior dynamic performance abilities.

This investigation showed that supine medicine ball throw peak force, RFDmax, and RFD40-80% were reliable measures for assessing upper-body explosive strength in young adults. These measurements were significantly associated with vertical jump height and therefore, may be effective predictors of one's athletic ability. In contrast, RFD30% was unreliable and not significantly correlated with vertical jump height. As a result, this variable should not be used as a performance measure when conducting supine medicine ball throw assessments.

Ethics approval

This study was approved by the Texas Tech University institutional review board for human subject research (IRB # 2020-1010).

Consent to participate

Each participant was informed of the benefits and risks of the investigation before signing an informed consent document.

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