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ORIGINAL SCIENTIFIC PAPER

The Influence of Maximum Strength Performance in Seated Calf Raises on Counter Movement Jump and Squat Jump in Elite Junior Basketball Players

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Abstract

In basketball high intensity jumping and sprinting performance is of high importance. There seems to be a relationship between maximal strength (MSt) and jumping performance in general, but influence of MSt in the plantar flexors and jumping performance seems not to be investigated very well. Thus, the aim of this study was to investigate the influence of MSt in the plantar flexors on jumping performance. 37 young elite basketball players were included (age: 13.9±1.8 years; weight: 66.4±16.8 kg; height: 179.21±13.24 cm) and countermovement jump (CMJ) and squat jump (SJ) height as well as unilateral and bilateral maximal isometric contraction in the plantar flexors with bended knee joint were assessed. Pearson correlations were calculated for MSt and jumping performance and Bland-Altman Analysis was performed to determine the level of variance between bilateral MSt assessment and cumulated MSt value of unilateral measurements. This study shows a moderate influence of isometric MSt in the calf muscle on jumping performance, so it seems beneficial to include the training of the plantar flexors in the training routine of basketball players. When determining MSt, the bilateral force deficit must be considered, even though there was no influence on determined correlations.

Keywords: *Jumping performance, Athletic training, Plantar flexors, Basketball*

Introduction

There is high relevance of maximal strength in athletic performance and its influence on jumping and sprinting performance is widely investigated in many sports (Chen et al., 2022; Fry & Kreamer, 1991; Lum et al., 2020; Requena et al., 2014) such as lower-limb joint strength and the ability to rapidly generate force, may play an important role in leg-spring stiffness regulation. This study aimed to investigate the relationship between isokinetic knee and ankle joint peak torque (PT). Especially maximal strength in lower limb muscle is considered a fundamental determinant in high-intensity actions such as linear and change-of-direction (COD) sprint as well as standing long jump (SLJ) and vertical jump (Keiner et al., 2020; Möck et al., 2018, 2019). Effects of 10 months of speed, functional, and traditional strength training on strength, linear sprint, change of direction, and jump performance in trained adolescent soccer players. In basketball a high ratio of high intensity jumping and sprinting is required (Abdelkrim et al., 2007; Stojanovic et al., 2018). Players spent 8.8% (1%. Within a single game, basketball players are reported to change activity up to 3000 times. These athletes also show the highest frequency of lateral movements (up to 450 per game) in team sports (Taylor et al., 2017; Vázquez-Guerrero et al., 2019), while also performing more than 50 maximal jumps per game (Taylor et al., 2017). Consequently, vertical jump performance tests such as countermovement (CMJ) and squat jumps (SJ) are a vital

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component of most performance diagnostics in basketball (Delextrat & Cohen, 2008, 2009). On average, players demonstrating high level vertical jump performance will be picked earlier in the yearly NBA draft (Cui et al., 2019).

From this, measuring maximal strength plays an important role in monitoring batteries to investigate performance level. To investigate an athlete's performance, maximal strength testing is commonly used under isometric and dynamic conditions. While some authors point out a higher transferability of 1RM testing to the sport specific tasks such as jumping and sprinting, there are also several advantages listed for maximal isometric strength tests e.g. standardization of testing conditions (Lum et al., 2020; Lynch et al., 2021), minimizing risk of injuries (Lynch et al., 2021) and time economics (Mcguigan et al., 2010). While the influence of maximal isometric strength in the squat and isometric mid-thigh pull is well investigated, the literature search did not yield studies investigating maximal isometric strength in the plantar flexors on jumping height. Because there is a correlation of r=0.35 between 1RM testing in standing calf raise and jumping performance as well as correlations of r=-0.23-0.52 in standing calf raise and sprinting performance with distances covered up to 30m (Möck et al., 2019), inclusion of plantar flexors in sport specific tasks in basketball can be assumed. Keiner et al. (2021) as well as Möck et al., (2019) investigated the influence of calf muscle strength on jumping and sprinting performance with extended knee joint. Arampatzis et al. (2006) and Signorile et al. (2002) point out differences in involved muscle in plantar flexion dependent on knee joint angle, but, to the best of the authors knowledge, no studies could be found investigating the influence of maximal strength of the plantar flexors in bended knee joint on jumping performance.

Bilateral as well as unilateral muscle contractions can be assumed in basketball. Since task familiarity plays a crucial role in the extent of the bilateral force deficit and no studies could also be determined investigating the bilateral force deficit in basketball players, present study will examine level of variance between bilateral strength measurement and cumulated values of unilateral strength measurement (Skarabot et al., 2016). Van Dieën et al. (2003) determined an overall deficit of the bilateral knee extension of about 7%.

Jumping ability is of high relevance in basketball but there is lacking evidence regarding maximal strength measured under isometric conditions in the plantar flexors. Therefore, the aim of this study was to investigate correlations between maximal isometric strength in the plantar flexors with a bended knee joint on jumping performance, which is tested with the CMJ and SJ. Furthermore, since Skarabot et al. (2016) point out a potential influence of the bilateral force deficit on athletic performance, the presence as well as the influence of the bilateral force deficit in the plantar flexors on jumping performance is examined. Based on the literature, it can be hypothesized that there are moderate correlations between maximal strength in the calf muscle and jumping performance and, based on familiarity of basketball players with bilateral and unilateral contractions, little influence of bilateral force deficit.

Methods

The aim of this investigation was to examine the correlation between maximum isometric strength of the calf muscle and jumping performance measured via CMJ and SJ in elite youth basketball players. One week before testing, a familiarization session was performed to minimize learning effects.

Subjects

For the study 37 male high-level youth basketball players (age: 13.9±1.8 years with a range of 13-16 years; weight: 66.4±16.8 kg; height: 179.21±13.24 cm) were recruited from a German first league basketball club being part of U16 first national league or U14 league. All athletes have been involved in organized basketball training and competition since childhood and perform athletic and team training at least three times per week and were familiar with testing conditions. Also, all players did not conduct any physically demanding activities within the 48 hours before testing and were injury free for at least six months. Each participant and his parents were informed about the experimental risks involved with the research. All participants and their parents provided written informed consent to participate in the present study. Furthermore, this study was approved by the institutional review board (Carl von Ossietzky University Oldenburg, No. Drs.EK/2022/026-01). The study was performed with human participants in accordance with the Helsinki Declaration.

Testing procedure

Before testing started, the subjects performed a standardized warm up routine containing six linear runs of 15 meters each with progressive increased intensity. During the last three sideline-to-sideline runs, subjects performed ten repetitions of deep bodyweight squats when reaching the sideline. Subsequently, participants performed three sets of three squat jumps. The testing procedure contained CMJ, SJ and isometric maximal strength in seated calf raise with bended knees (90°) for both unilateral and bilateral testing. All participants had prior experience with performance diagnostics and the exercises as well as the measuring devices used.

Countermovement Jump

The force plate used to measure vertical jumping performance in this study had a surface area of 50x60 cm. The force transducer (company AST, Leipzig, model KAC) measures the vertical reaction forces. The strain gauges cover a measurement range of ± 5000N. The analog signals are amplified and subsequently converted by a 13-bit A-D converter. The specialized software (Carl von Ossietzky University Oldenburg, Germany) displays the force-time curves.

Subjects positioned themselves on the force-measuring plate with feet shoulder width apart with hands placed on the hips and an upright body meaning knee and hips fully extended. Participants were instructed to quickly descend to a self-selected depth and initiate the concentric phase with maximal-explosive effort to reach maximal height. During the flight and landing phase subjects had to keep their knees and hips fully extended, hands on their hips as well as toes elevated. CMJ height was determined via flight time. All participants had three attempts to reach maximal CMJ height with a break of one minute in between attempts.

Squat Jump

Subjects had to start from 90° knee joint angle and jump as high as possible without a countermovement. Subjects were instructed to remain motionless in this position until the starting signal was given. Equal to the CMJ, participants had to keep their knees and hips fully extended during the flight and landing phases as well as their hands on hips and toes elevated. For both jumps, height was determined via flight time using the force plate. All participants had three attempts with one-minute breaks in-between.

Maximal isometric strength in seated calf raise

To determine the isometric maximum strength in the seated calf raise, a standard seated calf raise machine was modified with small force plates on each of the footrests. Another software was used to display the force-time curves and calculate the MSt values. Subjects were placed on the seated calf raise machine with their knees and ankles in 90° positions and forefoot placed on the force plates. Subjects' knees were tightly fixed in place without any play by clamping a pad on top of their lower thighs. Participants were instructed to perform a maximal plantar flexion against the padding on top of their lower thighs after receiving an acoustic signal. Maximal isometric strength was held for three seconds. In-between attempts subjects rested for one minute. Each subject was tested until no further increases could be obtained. Therefore, maximal isometric strength in the plantar flexion was assessed in bilateral and unilateral plantarflexion with bended knee joint. All participants conducted at least five attempts.

Statistical analysis

The data were analyzed using SPSS 28.0. (IBM, IBM Corp., Armonk, New York, USA). The significance level for all statistical tests was set at <0.05. The descriptive statistics for all measures are presented as the mean (M) ± standard deviation (SD) with 95% CI. Reliability analyses were performed for test bests and the tests second best value using the Intraclass Correlation Coefficient (ICC) with 95% confidence interval (CI), the correlation coefficient (r) and the coefficient of variance (CV). Furthermore, a bivariate one-tailed Pearson correlation analysis was used to assess the relationship between maximal strength in the plantar flexors with 90° knee joint angle and CMJ and SJ height. To determine significant differences in the correlation coefficients between subgroups (different ages), the data were z'-transformed according to the Fisher method. The significant difference was calculated by the difference of the two transformed values after standardization ($z = \frac{z'_1 - z'_2}{\sqrt{\frac{1}{n_1-3}+\frac{1}{n_2-3}}}$). Benjamini and Hochberg's method was used to control the study wise false discovery rate to be 0.05 (Ferreira & Zwinderman, 2006)

To investigate the bilateral strength deficit, the maximal isometric strength measured in unilateral testing was cumulated and compared with the bilateral maximal strength test values. Comparison was performed by Bland-Altman Analysis and shown in a Plot, which is illustrated with "R". Furthermore, we performed Bland Altman analysis to show level of variance between SJ and CMJ. Correlations were analyzed via SPSS (IBM SPSS Statistics Version 28, IBM Corp., Armonk, New York, USA). Level of significance for all tests was set to p<0.005. Relationships were classified as follows: 0 = no correlation, 0<r<0.2 = very low correlation, 0.4<r<0.6=-moderate correlation, 0.6<0.8=high correlation, 0.8<r<1 = very high correlation (Cohen, 1988).Variance Exploration (r^2) was determined to clarify the influence of maximal strength in the plantar flexors on jumping performance. To examine the bilateral force deficit, variances between bilateral measurement and cumulated strength maximum for both unilateral measurements were compared with Bland-Altman-Analysis to show deviations between methods and to investigate agreement between both methods (Bland & Altmann, 1986). Mean absolute error (MAE) as well as Mean absolute percentage error (MAPE) are calculated with $\mathrm{MAE} = \frac{1}{n}\cdot\sum_{i=1}^{n}|x_i - y_i|$ and $\mathrm{MAPE} = \frac{100\%}{n}\cdot\sum_{i=1}^{n}\left|\frac{x_i - y_i}{x_i}\right|$.

Results

Testing for normal distribution using Shapiro-Wilk test shows that requirements for Pearson's product-moment correlation are fulfilled. ICC with 95% CIs, CV and correlations for the performance tests are listed in table 1.

Table 1: Reliability of used test items

	ICC (95%-CI)	CV
MSt	0.997 (0.995-0.998)	1.0±0.6% (0.8-1.18)
CMJ	0.988 (0.97-0.995)	1.6±0.9% (1.24-1.99)
SJ	0.967 (0.92-0.987)	1.9±1.5% (1.32-2.63)

With ICCs between 0.967 and 0.997 a good reliability can be assumed for maximal isometric strength measurements (Shrout & Fleiss, 1979). Table 2 shows descriptive statistics of measured values. Since the correlation coefficients age subgroups did not differ significantly, the correlations coefficients presented correspond to the entire group.

Table 2: Descriptive data for CMJ, SJ and SCR

	M±SD (95%CI)	Minimum	Maximum
MSt (in N)	2231.97±650.94 (2048.85-2456.38)	979	3649
MStR (in N)	1096.88±303.86 (997.38-1192.27)	509.77	1672.66
MStL (in N)	1049.56±300.12 (948.74-1144.3	458.13	1656.33
MStLR (in N)	2146.44±599.24 (1947.79-2333.15)	991.77	3312.98
CMJ (in cm)	34.88±6.89 (32.84-37.26)	22.7	50.00
SJ (in cm)	31.32 ±5.3 (29.67-33.34)	23.3	45.0

MSt-maximal isometric strength in bilateral measurement; MStRL-maximal isometric strength, cumulated value from right and left leg; MStR-maximal isometric strength in the right leg; MStL-maximal isometric strength in the left leg; CMJ-jumping height in counter movement jump; SJ-jumping height with the squat jump.

There are correlation coefficients between maximal isometric strength in the plantar flexors in bended knee joint and CMJ with r=0.52 (0.23-0.72) and r^2=27.04%, and SJ with r= 0.54 (0.26-0.73) and r^2=29.16%. Figure 1 and 2 showing correlations between bilateral MST and cumulated unliateral strength measurement and jumping performance to compare results and illustrate the bilateral strength deficit. Therefore, in Figure 3 results of Bland Altman Analysis are plotted to determine level of variance with 95%CI of about -200N to 400N. Bland Altman analysis shows a difference between both methods (Mean Error (ME)) of 85.53N corresponds to 4.45% and MAE=142.73, and a MAPE=6.33 %.

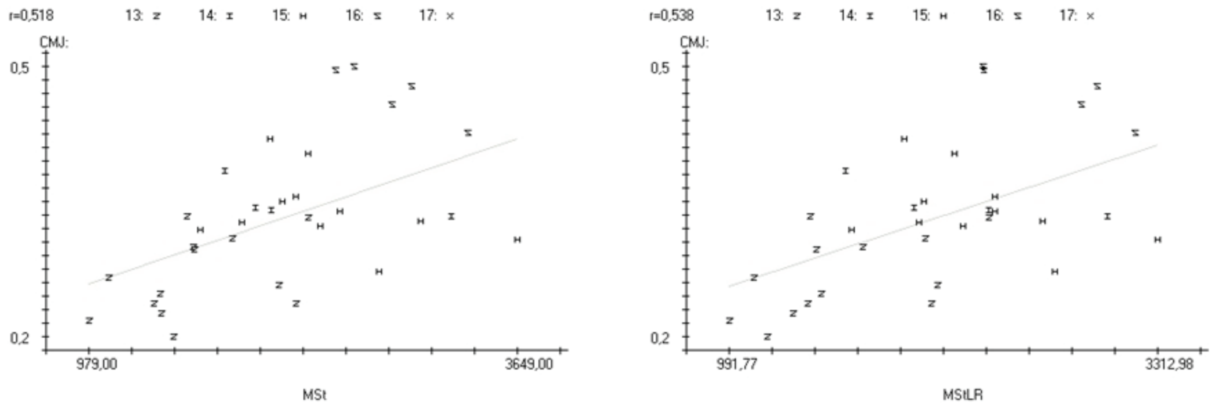

FIGURE 1: Scatterplot with linear trend line of countermovement jump with maximal strength measured bilateral (r= 0.52 [CI95%: 0.23-0.72]) and maximal strength measured with cumulated unilateral measurements (r=0.54 [CI95%:0.26-0.73])
Note MSt= maximal isometric strength in bilateral measurement, MStRL=maximal isometric strength, cumulated value from right and left leg, CMJ= jumping height with the counter movement jump.

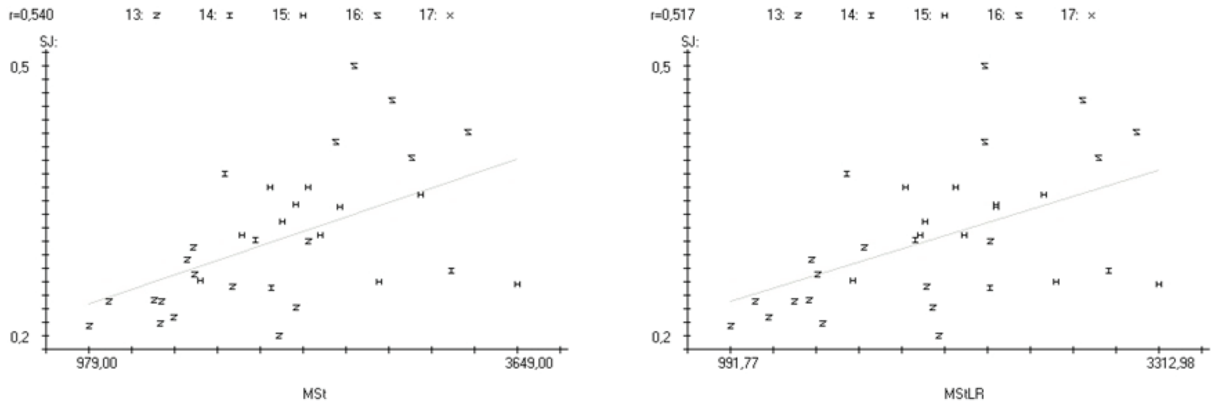

FIGURE 2: Scatterplot with linear trend line of squat jump with maximal strength measured bilateral (r= 0.54 [CI95%: 0.26-0.74]) and maximal strength measured with cumulated unilateral measurements (r=0.52 [CI95%:23-0.72])
Note MSt= maximal isometric strength in bilateral measurement, MStRL=maximal isometric strength, cumulated value from right and left leg, CMJ= jumping height with the squat jump

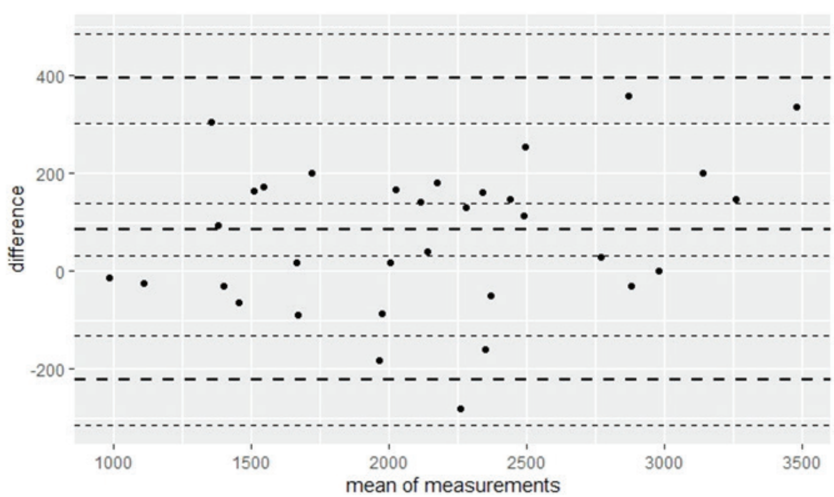

FIGURE 3: Bland Altman Plot for bilateral maximal strength measurement in the plantar flexion and cumulated unilateral maximal strength measurement

Discussion

The aim of the present study was to investigate the influence of maximal isometric strength in the plantar flexors with bended knee joint angle on jumping performance in CMJ and SJ in youth elite basketball players. Bland Altman Plot shows a variance with 95%CI of about -200 to +400N around the mean value with a mean difference between both methods of about 100N corresponding to 4.45% and MAE=142.73, and a MAPE=6.325 %

While the influence of multi joint exercises such as the squat on jumping performance is investigated in many sports, only few studies examined the influence of maximal strength in the calf muscle on jumping (Keiner et al., 2021) or sprinting performance (Möck et al., 2019). However, these studies investigated the influence of 1RM in standing calf raise. Since Arampatzis et al. (2006) and Signorile et al. (2002) showed difference between focusing muscle groups in the triceps surae while performing a plantar flexion dependent on knee joint angle, investigating the influence of calf muscle strength in different knee joint angles is relevant. It can be assumed that there is higher impact of the gastrocnemius to the power output when performing plantar flexion with extended knee joint, while there is more influence of the soleus in bended knee joint position. This is the first investigation pointing out the influence of isometric maximal strength with bended knee joint on jumping performance. Thus, it seems there is an influence of the triceps surae on sprinting (Möck et al., 2019) as well as on jumping performance (Keiner et al., 2021), independently of the knee angle. Since in SJ and CMJ a high influence of the quadriceps on strength production can be assumed, it is not surprising that correlations between maximal strength measured in the squat with r= 0.78 (Wisløff et al., 2004) and r=0.76 (Comfort et al., 2014) are higher than determined correlation in the present study, but there is still a moderate influence of the calf muscle in jumping and sprinting movements.

When performing bilateral movements, dependent on trainings status and commonly used training method, a bilateral force deficit can be assumed (Jakobi & Chilibeck, 2001; Skarabot et al., 2016). In basketball, both unilateral as well as bilateral jumping movements are commonly implemented in conditioning training (Arede et al., 2019), e.g. using barbell squats and unilateral strength exercises. Therefore, Bland Altman plot as well as Pearson correlations were performed for the bilateral measurement as well as the cumulated unilateral strength measurement. With r=0.52-0.54 and variance plotted in the Bland Altman plot in Figure 3 it can be hypothesized that the bilateral force deficit is not consistent in the measured population but comparable with previous studies determining bilateral force deficit in different muscle groups (Van Dieën et al., 2003). The present results show only little influence of bilateral force deficit in plantar flexors on jumping performance in basketball players.

The study is limited as Murphy & Wilson (1996) electro-myography data were collected from the triceps brachii and pectoralis major muscles to compare underlying neural characteristics between the isometric tests and dynamic movement. A group of 24 healthy male subjects performed two isometric tests in a bench press position, at elbow angles of 90-120%. From these data, the maximal force and rate of force development were determined. In addition, each subject performed a seated medicine ball throw as a measure of dynamic upper body performance. Correlations showed that isometric measurements of force (r =0.47-0.55 point out poor correlations between isometric and dynamic maximal strength testing. Thus, there may be some limitations in comparability between maximal isometric strength measured in the present study and maximal dynamic strength, e.g. evaluated by Möck et al. (2019) and Keiner et al. (2021). Assuming that there is higher transfer of 1RM testing because of higher agreement in central nervous aspects with athletic performance as jumping and sprinting, the correlations of this study may be underestimated. Another limitation is the age range, although the subgroup analysis makes it possible to consider the entire group.

Conclusion

Analyzed data show an influence of maximal strength of the plantar flexors on jumping performance with r^2=29.16% for the SJ and 27.04% for the CMJ in male high-level youth basketball players. From this, longitudinal studies to investigate the effects of isolated calf muscle strength training on jumping performance are requested to investigate whether an isolated strength training for the plantar flexors should be implemented in athletic training in basketball. Furthermore, attention should be paid to testing design (unilateral vs bilateral testing conditions) when the aim of the study is to examine maximum strength. Especially when monitoring performance in diagnostic in competitive sports, there is a need for valid, reliable and especially precise assessments, where ME between both methods of 100N corresponding to 4.45% and MAE=142.73, and a MAPE=6.33% with expected spread of the values between -200 to +400N in between of 95%CI seems not to be useful. From this, bilateral force deficit must be considered.

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Conflict of Interest
The author declares that there is no conflict of interest.

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