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Yongmin Xie, Fan Peng, Xinyu Pan & Qinchang Sun

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Prediction of Individual Optimal Drop Height in Drop Jump from Anthropometric and Strength Variables

Yongmin Xie[1]*, Fan Peng[1] , Xinyu Pan[1], Qinchang Sun[1]
1.School of Strength and Conditioning Training, Beijing Sport University, Haidian 100084, China.
*Corresponding author:
Yongmin Xie
School of Strength and Conditioning Training, Beijing Sport University, Haidian 100084, China.
E-mail: xieyongminbsu@163.com

ABSTRACT

This study aimed to investigate the associations between individual optimal drop height (ODH), as determined by the reactive strength index (RSI) method, and selected anthropometric and strength parameters, and to develop a prediction model for ODH based on these variables. A total of 49 participants were recruited, and measurements included body height, body mass, maximal muscle strength (MSmax), lower limb stiffness, reactive strength ratio (RSR), countermovement jump (CMJ) height, and ODH. Pearson correlation analysis was conducted to examine the relationships between ODH and the assessed variables. A multiple linear regression model was constructed in a stepwise manner to predict individual ODH. Significant correlations were observed between ODH and relative MSmax ($r = 0.827$, $P < 0.001$), RSR ($r = 0.703$, $P < 0.001$), body mass ($r = -0.481$, $P < 0.01$), body height ($r = -0.430$, $P < 0.01$), and CMJ height ($r = 0.487$, $P < 0.01$). Relative MSmax, CMJ height and RSR collectively explained 78.4% of the variance in ODH ($R^2 = 0.784$). The final prediction equation was: ODH = -45.602+31.027*relative MS_{max} +0.548*CMJ height +5.549*RSR ($R^2 = 0.784$, $F(3, 36) = 48.190$, $p < 0.001$). Coaches should consider body height, body mass, RSR, relative MSmax, and CMJ height when prescribing drop jump height. Moreover, an individual's ODH should be adjusted when changes in CMJ height or relative MSmax occur. Finally, this study provides a practical prediction equation for estimating individual ODH using relative MSmax and CMJ height as input variables.

Key words: plyometric training; training intensity; reactive strength; optimal drop height

INTRODUCTION

Drop jump (DJ), consisting of stepping or dropping from a raised platform and, upon landing, immediately performing a vertical jump, has always been a popular training method to improve the performance of stretch-shortening cycle (SSC) movements in the last few decades(Addie et al., 2019; Barr & Nolte, 2014; Makaruk et al., 2010; Matic et al., 2015; Peng, Song, Wallace, et al., 2019). In DJ training, one significant factor that can determine the training effects of DJ and that coaches need to consider when designing the programs is the drop height, which is generally used as an effective way to manipulate the intensity of DJ training(Byrne et al., 2016; Hubert & Tomasz, 2011). Based on previous research, both excessively high and low drop heights are detrimental to plyometric performance and depth jump (DJ) training adaptation. When the drop height is too great, the Golgi Tendon Organ (GTO) may be activated by sudden and excessive braking forces, triggering the body's protective mechanisms that reduce tension in muscles and tendons while suppressing stretch reflex activity(Turner & Jeffreys, 2010). Concurrently, the amortization phase of the SSC is significantly prolonged, leading to dissipation of elastic energy stored during the eccentric phase(Wilson & Flanagan, 2008). Both factors can negatively affect training outcomes.In contrast, if the drop height is too low, the mechanical stress is not sufficient enough for the neuromuscular system, thereby leading to inefficient exploitation of SSC and reducing the possible extent of adaptation(P. J. Byrne et al., 2010; Schuster et al., 2019). Previous studies found that proper plyometric and heavy resistance training can induce specific neural adaptations, most notably the desensitization of the GTO, which weakens this inhibitory reflex (Cormie et al., 2010). This neural adaptation enables well-trained athletes to tolerate greater eccentric forces and maintain potent stretch reflex facilitation at higher drop heights. Therefore, the individual optimal drop height (ODH) that could produce the best performance should be identified before DJ training to maximize the plyometric performance and prevent injury(Byrne et al., 2016).

To date, the reactive strength index (RSI) method has been extensively utilized by a several researchers to prescribe the individual ODH, which is defined as the drop height eliciting the maximum RSI. (Byrne et al., 2016; P. J. Byrne et al., 2010; Ramirez-Campillo et al., 2018). In this method, athletes are required to perform an incremental DJ test, in which the RSI profiles are measured; and then the respective height that can produce the maximum RSI value is considered the ODH(P. J. Byrne et al., 2010). One reason the RSI method is considered effective in identifying the ODH may be its requirement for testers to provide immediate feedback on both contact time and flight height for each jump(Flanagan & Comyns, 2008). This is particularly relevant given that some researchers argue optimal jump height has limited significance if ground contact time (GCT) is not concurrently considered(Flanagan & Comyns, 2008; Walsh et al., 2004).In addition, the ODH identified by the RSI method has been demonstrated to be effective in enhancing the transition capacity of muscles from eccentric to concentric phases (i.e., fast SCC)(Flanagan & Comyns, 2008). Even though the RSI method can individualize the DJ training intensity, it takes considerable time to identify ODH, especially when testing large squads. A prediction model based on easily accessible variables (e.g., CMJ height, relative strength) could serve as a time-efficient screening tool and also help coaches identify modifiable factors to increase an athlete’s ODH. Therefore, this paper believes that if the individual ODH could be predicted by a model constructed based on athletes' training background and plyometric ability, the testing process would be optimized and time saved.

Few studies have examined the factors influencing ODH in DJ training, despite extensive research on ODH itself. Maximal muscle strength (MSmax) affects drop height(Barr & Nolte, 2014; Matic et al., 2015), with athletes having higher relative MSmax performing better from greater heights ($p \leq 0.05$)(Beattie et al., 2017). Body mass and height should also be considered. Overweight athletes should not jump from heights above 46 cm due to increased joint loading and injury risk(Kulas et al., 2008). Taller athletes may face greater knee valgus angles during landing, suggesting higher injury risk (Nilstad et al., 2015). Higher countermovement jump (CMJ) performance (Van Hooren & Zolotarjova, 2017), lower limb stiffness(Brazier et al., 2019; Walshe & Wilson, 1997), and reactive strength (Healy et al., 2018; Matic et al., 2015) improve the muscle-tendon transition during SSC movements. Although how these factors affect ODH is unclear, they likely contribute to identifying it. More research is needed to identify reliable predictors of ODH.

Thus, the current investigation aimed to to identify the optimal set of predictors (model) that can be used most accurately to estimate ODH. Specifically, we evaluated objective measures including body mass, body height, MSmax, lower limb stiffness, and reactive strength. It is hypothesized that all these parameters are related to individual ODH and the combination of these parameters could predict ODH well.

METHODS

Experimental Approach to the Problem

A cross-sectional study was conducted to explore the associations of ODH with strength and anthropometric variables. The formal tests were divided into three stages(Figure 1). At least a 48-hour recovery period was arranged between each stage. Before the formal test, a familiarization session was scheduled to inform the athletes of the testing procedures and requirements for each movement involved. The interval between the familiarization session and the formal test was at least seven days. Prior to the commencement of each strength variable test, participants were required to undergo a standard warm-up protocol consisting of cycling (5 minutes), dynamic stretching of lower limbs, and muscle activation. In this study, all test items were scheduled between 2:00 p.m. and 6:00 p.m., and the laboratory temperature was kept at 18–24□.

Insert Figure 1 about here

Subjects

Forty male elite athletes with varying training backgrounds—specifically in basketball(N = 7), volleyball(N = 4), sprinting(N = 5), gymnastics(N = 9), freestyle combat(N = 13), Rugby(N = 1) and Trampoline(N = 1)—participated in this study (age: 20.35 ± 2.67 years; range: 18–26). "Elite" was defined as competing at national-level championships or in professional leagues. All participants were healthy and had no history of lower limb injury within the past six months. They were tested during the off-season and were instructed to maintain their regular training routines throughout the testing period. Inclusion criteria required at least two years of consistent strength training (weekly frequency ≥3 sessions) and prior experience in plyometric training, including drop jumps (DJ). Typical resistance training exercises included barbell back squats, bench presses, deadlifts, power cleans, and snatches. Characteristics of study participants are shown in Table 1.

Insert Table 1 about here

All participants were required to maintain a regular diet, refrain from any vigorous physical activity within 24 hours prior to testing, and fast for at least 2 hours before each test session. All tests were administered by the same instructor to minimize non-systematic measurement error. Participants were fully informed of the study′s objectives, potential risks, benefits, and procedures before providing written informed consent. The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Review Committee of Beijing Sport University (No. 2024332H). All participants read and understood the experimental instructions and provided written informed consent prior to the commencement of the experiment.

Procedures

Anthropometric and Maximal Strength Test

A digital stadiometer (Inbody BSM170, Korea) and a digital scale (Model 05, G-Tech, China) were used to measure the height (1 mm) and weight (0.1 kg) of the subjects, respectively. Each variable was measured three times to obtain an average value for statistical analysis.

Participants underwent a standardized warm-up protocol comprising the following sequence:First, foam rolling was applied to the quadriceps, hamstrings, glutes, and calves for 1minute per muscle group to alleviate muscle tension.Next, dynamic stretching was performed, including walking quad stretches (30 seconds per leg), Superman stretches with contralateral limb reach (10 seconds per side), and the world′s greatest stretch (10 repetitions per leg with a thoracic rotation).This was followed by hip and lower body activation exercises, consisting of glute bridges (15–20 reps), lateral band walks (20 steps per side), and hip rotations (15 reps per side).Finally, neural activation was incorporated through depth jumps (2 sets of 6 repetitions from a 30 cm platform). Following the warm-up, participants completed the testing procedure, which consisted of CMJ and five hopping jumps, followed by a 2-minute rest period. They then performed 3 CMJs on the force platform with 30 seconds between trials (Haff et al., 2016; McGowan et al., 2015).

Lower body absolute MSmax was assessed using the barbell back squat (1RM)and normalized to body weight (relative MSmax). Before testing, participants completed a standard warm-up and 10 back squats with a barbell, followed by a 5-minute rest. During the test, they flexed hips and knees until thighs were parallel to the ground, with controlled descent speed to avoid bouncing between phases. In the concentric phase, participants stood up as quickly as possible. Three investigators provided spotting: one behind the participant and two beside the barbell. The procedure, rest intervals, and load progression followed the NSCA's true 1RM testing protocol (Haff et al., 2016).

CMJ and Hopping test

CMJ height was measured using the FD4000 Dual Force Platforms (ForceDecks, Brisbane, Australia~~London, UK~~) at a sampling frequency of 1000 Hz. During each jump, participants placed their hands on their hips, performed a rapid pre-squat, and executed a maximal vertical jump with full extension of the hips, knees, and ankles. Pre-squat depth was self-selected to maximize jump height. Knee and hip flexion during flight was not allowed. Participants performed 3 maximal CMJ trials with 30 seconds of rest between trials. A trial was discarded and repeated after 30 seconds of additional rest if the participant: (a) removed hands from hips, (b) exhibited noticeable knee or hip flexion during the flight phase, or (c) failed to land stably within the force platform boundaries. No participant required more than 5 total attempts to complete 3 valid trials. CMJ height for each trial was automatically calculated by the ForceDecks software (VALD Performance, Windows v2.2.0, Brisbane, Australia~~ForceDecks, London, UK~~) using an impulse–momentum approach based on vertical ground reaction force data, and the average of the three trials was used for statistical analysis. A 3-minute rest followed the test.

In the hopping jump test, RSR and lower limb stiffness were measured using the ForceDecks platform at 1000 Hz (Comyns et al., 2019). Participants performed 11 consecutive maximal hops; the first jump was excluded as it resembled a CMJ(Comyns et al., 2019). They were instructed to jump as quickly and as high as possible during the landing-to-takeoff transition, minimizing contact time and maximizing flight height. Hands were kept on hips, and landings occurred in the same position with extended lower limbs. Contact and flight times from the five best jumps (shortest contact time, highest jump height) were automatically recorded. Reactive strength ratio (RSR) was calculated as the ratio of flight time to ground contact time:

$$\mathrm{RSR} = \frac{\mathrm{FT}}{\mathrm{CT}}$$

Where FT is flight time (s), CT is ground contact time (s).Lower-limb stiffness (K_{leg}) was calculated using a time-based spring–mass model (Maloney & Fletcher, 2021):

$$K_{leg} = [M \bullet \pi\,(T_f + T_c)]/\,[T_c^2(\frac{T_f + T_c}{\pi} - \frac{T_c}{4})]$$

Where M is body mass (kg), T_f is flight time (s), and T_c is ground contact time (s). The average values were used for statistical analysis.

Drop Jump Test

The individual ODH, defined as the height yielding maximal RSI, was determined using a depth jump (DJ) test with wooden boxes at incremental heights (30–75 cm in 5 cm increments) and the FD4000 Dual Force Platform sampled at 1000 Hz. DJ height for each trial was automatically calculated by the ForceDecks software (ForceDecks, London, UK) using an impulse–momentum approach based on vertical ground reaction force data, and the average of the three trials was used for statistical analysis.Drop heights were selected based on previous research (P. J. Byrne et al., 2010). Participants completed a standard warm-up, ankle hops, and submaximal DJs, followed by a 2-minute rest. They performed three rebound-style DJs from each height in ascending order to minimize injury risk (P. J. Byrne et al., 2010; Comyns et al., 2019; Kipp et al., 2018). It is worth noting that drop jumps can be performed using different techniques—such as bounce, countermovement, or mixed styles—which may influence reactive strength and stiffness outcomes (Struzik et al., 2016). In this study, participants were instructed to perform a rebound-style (bounce) DJ with minimal knee and hip flexion during ground contact, consistent with protocols used in prior RSI-based studies (Byrne et al., 2010; Comyns et al., 2019).A 30-second rest separated jumps, and a 1.5-minute rest separated height changes. Adequate rest and real-time feedback helped reduce fatigue effects. During each DJ, participants minimized contact time and maximized jump height while maintaining landing stability. Additional requirements included: (a) hands on hips; (b) landing on the same spot with both feet; (c) minimal knee and hip flexion during first and second landings; (d) maintaining post-landing stability on the platform.; (e) contact time < 250 ms. Trials violating any requirement were repeated, with no more than five attempts per height. After each jump, jump height and contact time—automatically recorded by ForceDecks software—were provided immediately, allowing athletes to adjust and optimize performance for maximum RSI. RSI was calculated for each of the three jumps at all 10 heights using the equation:

$$\mathrm{RSI} = \frac{\mathrm{Height}}{\mathrm{CT}}$$

Where Height is DJ Height, CT is ground contact time (s).The height producing the highest RSI was identified as the individual ODH.

Statistical Analysis

Participant characteristics are presented as mean ± SD or number (%) as appropriate. Normality of variables was assessed using the Shapiro-Wilk test. Pearson′s correlation was used to evaluate associations between ODH and independent variables: body height, body weight, MSmax, RSR, leg stiffness, and CMJ height. The effect sizes of Pearson’s correlation coefficient were interpreted as almost perfect ($0.9 \leq r \leq 1$), very large ($0.7 \leq r < 0.9$), large ($0.5 \leq r < 0.7$), moderate ($0.3 \leq r < 0.5$), and low ($0.1 \leq r < 0.3$). A stepwise multiple linear regression model was built to predict individual ODH for drop jump training, using body weight, body height, CMJ height, absolute MSmax, relative MSmax, RSR, and LLS as candidate predictors. Multicollinearity among predictors was checked using variance inflation factor (VIF < 5) and tolerance (> 0.2) (Hair, 2010).

Residual diagnostics (including tests for normality and homoscedasticity) and influence statistics (Cook's distance) were examined to verify that the linear regression assumptions were met and to identify any influential outliers that could bias the model. Agreement between measured and estimated values was examined using Bland–Altman analysis, reporting mean bias (measured − estimated) and 95% limits of agreement (Bias ± 1.96 SD). To assess the predictive performance and potential optimism of the regression model, internal validation was performed using the predicted residual sum of squares (PRESS) statistic with leave-one-out cross-validation (LOOCV).

All statistical analyses were conducted using SPSS version 20.0 (IBM SPSS Inc., IL, USA), and graphs were generated using GraphPad Prism 7.0 (GraphPad Software, La Jolla, CA). Statistical significance was set at $p < 0.05$.

RESULTS

All continuous variables in this study were normally distributed with no outliers.Each participant's ODH can be identified using the RSI method, and the RSI profiles of ten participants were selected randomly and presented in Figure 2.

Insert Figure 2 about here

Pearson correlation analyses revealed that ODH was negatively associated with body height(r = −0.43, p = .006 and body weight (r = −0.48, p = .002), and positively associated with CMJ height (r = 0.49, p = .001) relative MSmax (r = 0.83, p < .001), and RSR (r = 0.70, p < .001) (Table 2).

Insert Table 2 about here

Three stepwise multiple regression models were built to predict the individual ODH. The detailed information of the models is shown in Table 3.

For the model 1, ODH = - 31.117 + 43.031*relative MS_{max} ;$R^2 = .676$, F (1, 38) = 82.197, p < .001. The Bland-Altman presented in Figure 3

For the model 2, ODH = -47.584+39.172*relative MS_{max} +0.575*CMJ height ;R^2 = .758, F (2, 37) = 62.008, p < .001. Bland-Altman plots depicting agreement between measured and predicted ODH are presented in Figure 3.

For the model 3, ODH = -45.602+31.027*relative MS_{max} +0.548*CMJ height +5.549*RSR; R^2 = .784, F (3, 36) = 48.190, p < .001. Multicollinearity diagnostics for Models 1–3 are reported in Table 4. The Bland-Altman presented in Figure 3

Across the final three-predictor model (n = 40), Cook's distance ranged from 0.000 to 0.237 (M = 0.032, SD = 0.050). Using conventional cutoffs, four cases exceeded D > 4/n = 0.10 and three exceeded the more stringent D > 4/(n − k − 1) = 0.111 (k = 3); no case exceeded 1. Residual diagnostics are shown in Figure 4. To complement these in-sample checks with an out-of-sample estimate, internal validation via PRESS (LOOCV) yielded RMSE = 6.43 and R^2 = 0.675, compared with the apparent in-sample SEE = 5.50 and R^2 = 0.810, indicating modest optimism in the apparent estimates.

Insert Table 4 about here

Insert Figure 3 about here

Insert Figure 4 about here

DISCUSSION

This study systematically investigates the factors influencing individual optimal drop height by integrating both anthropometric and strength parameters within a unified analytical framework. Forty participants were enrolled in the experiment. Each participant's optimal drop height (ODH) for depth jumps (DJ) was determined using the reactive strength index (RSI) method during an incremental DJ protocol. This approach has been utilized in prior research(P. J. Byrne et al., 2010; Ramirez-Campillo et al., 2018) and has demonstrated high intraday and interday reliability (D. J. Byrne et al., 2017; Markwick et al., 2015).

However, the RSI trend observed in the current study (Fig. 2) resembles a parabolic curve, although it does not perfectly follow a standard parabolic shape.This trend is consistent with

Schuster et al. (Schuster et al., 2019), who found that from low drop height to the optimal height, the RSI value increased by 9% ($p < 0.001$) and decreased by 5% ($p < 0.008$) from optimal height to the high drop height, also with Addie et al.(Addie et al., 2019), who observed that the RSI increased with drop heights between 30-60cm and decreased when the height increased more than 60cm. However, this trend of RSI in the current research (Figure 2) is approximately equal to a standard parabolic curve instead of being a standard parabolic curve. This phenomenon may be caused by the increment of boxes (i.e., 5cm) used in this study, smaller than those of previous studies(Byrne et al., 2016; Ramirez-Campillo et al., 2018; Schuster et al., 2019). The participants were only instructed to jump as quickly and as highly as possible during the test, so the jump performance mainly depended on their subjective consciousness. Any slight differences in DJ techniques (such as more knee flexion and ground contact time) may result in more significant changes in the RSI(Pedley et al., 2017). In other words, the smaller increment of drop heights could easily cause the fluctuation of RSI. Considering Byrne's suggestions that increments of 0.15 m or 0.2 m in drop heights may be too large(P. J. Byrne et al., 2010), it seems that an increment of 10cm would be better in order to get a more standard parabolic curve.

According a serious of study, body weight is one of the factors that can determine the training intensity of plyometric exercises(Haff et al., 2016; Külkamp et al., 2012, 2015, 2020). Our data showed that the individual ODH demonstrated a negative correlation with body weight ($r = -0.481$, $p < 0.01$), which means that the ODH may decrease if the subject's body weight increases. This association may be partly attributed to the rise in ground reaction force resulting from increased weight. Fowler et al. (1994) observed that 0.26 m loaded DJs (8.5 kg) revealed higher ground reaction force than those performed without any additional loads from the same height. The increased ground reaction force would put excessive pressure on muscles, connective tissues, and joints, which is associated with the increased injury risk(Kulas et al., 2008) Besides, if a subject's body weight increase but the strength remains unchanged, the added load would also impair the transfer capability of the muscle from eccentric contraction to concentric contraction. Makaruk et al.(Makaruk et al., 2010) observed that the amortization time significantly increased, but the peak power and velocity at peak power decreased in the loaded group (5% of body weight), which indicates that the efficacy of SSC may decrease. Therefore, the NSCA suggested that athletes weighing over 100 kg should avoid the DJ from heights greater than 46 cm(Haff et al., 2016).

Participants' body height in a more extensive range (165.5–200.7 cm) was negatively correlated with individual ODH. This link can be explained in part by increased knee valgus. Nilstad et al. (Nilstad et al., 2015)proposed that taller individuals were more likely to have greater peak knee valgus in the drop-jump landing because longer lever arms demanded more muscle strength to stabilize the knee joint. This conclusion may be supported by our results, which showed that participants with higher body height had lower MS_{max} ($r = -0.430$, $p < 0.01$), and lower strength can increase the knee valgus when performing the dynamic movements(Claiborne et al., 2006). Besides, the subjects' body height in our research is negatively correlated with body mass ($r = -0.613$, $p < 0.01$), which would also deteriorate drop jump performance because of the increase of the landing force according to our previous analysis. Thus, the drop height for taller athletes should be chosen carefully to prevent potential sports injury. However, the exact mechanisms of how body height affects drop height and the suggested maximum drop height (i.e., over which it should be forbidden) for tall athletes remain unknown.

As previous research investigated, subjects with greater relative MS_{max} of the lower limb tended to have higher ODH(Beattie et al., 2017; Dymond et al., 2011; Matic et al., 2015), which is in accordance with our results that the relative MS_{max} is highly correlated with individual ODH ($r=0.827$, $p<0.001$). However, no association between absolute maximum strength and the ODH was not found in this research. Matthew et al.(Barr & Nolte, 2014) revealed that the peak eccentric force relative to body weight for DJs nearly doubled when the drop height increased from 24 to 84 cm ($4.15\pm0.91 \sim 8.18\pm0.99$), and at a height of 84 cm it reached more than eight times body weight. Similarly, Peng et al.(Peng, 2011) pointed out that the peak vertical ground reaction force (vGRF) and the landing impulse during the contact phase significantly increased with the drop height and the peak vGRF of the dominant leg even exceeded three times the body weight during DJ from the height of 50 and 60cm. Both findings indicate that individuals capable of performing better in depth jumps from greater heights should possess superior eccentric strength to withstand the high eccentric loading (Cormie et al., 2010).Specifically, strong eccentric strength would directly assist lower limb stiffness and reactive strength, help to prevent the muscle from overstretching under high eccentric load; then facilitate the concentric contraction at the next moment(Fukutani et al., 2017). Or else, the weaker had to increase the contact time to overcome the increased stretching load, which led to the decrease of RSI(Barr & Nolte, 2014). Even if the eccentric strength was not measured In this study, previous research has found a very large correlation ($r = 0.90$) between concentric and eccentric strength (Spiteri et al., 2014). Relative MSmax emerged as the most substantial predictor of optimal drop height (Std. $\beta = 0.596$). Theoretically, higher relative strength indicates that the nervous system is better prepared to withstand greater tension in the musculotendinous unit, which may potentially delay or attenuate the inhibitory response of the GTO during sudden eccentric loading (Aagaard et al., 2002). Furthermore, the contributions of CMJ height (Std. $\beta = 0.289$) and RSR (Std. $\beta = 0.237$) to the model likely reflect the neuromuscular efficiency of the SSC. Specifically, these values suggest a superior capacity to utilize the stretch reflex (e.g., muscle spindle excitation) to enhance concentric force production, allowing for a rapid and forceful transition from the yielding phase (Taube et al., 2012). Therefore, compared with the relatively weak athletes, subjects with larger relative MSmax tend to be more effective in plyometric exercises and perform better in DJ from higher heights(Dymond et al., 2011) , which may mean their ODH should be higher than that of Weaker individuals.

The findings also imply that CMJ height is moderately associated with the ODH ($r = 0.487$, $p < 0.01$) and can be used to predict individual ODH. As we know, CMJ belongs to SSC movements, which usually involve a rapid eccentric contraction immediately before a fast concentric contraction(Van Hooren & Zolotarjova, 2017). Accordingly, the CMJ height could reflect the muscle's ability to perform SSC movements (i.e., the transition ability from eccentric contraction to concentric) to a certain degree(Peng, 2011), which is also necessary for DJ performance. Therefore, the CMJ value indicates better utilization of SSC, in particular the stretch reflex. Besides, the height of CMJ can also reflect the relative force and power strength of the lower limbs(ĆopiĆ et al., 2014). Matic et al. (Matic et al., 2015)indicated that the drop height should be adjusted based on the individual neuromuscular capacity. Therefore, individuals who achieve greater CMJ heights may demonstrate enhanced performance during drop jumps from increased heights. That could explain why the percentage of CMJ height (e.g., 100% of CMJ height) can be used as the ODH in DJ (Peng, Song, & Wallace, 2019). Furthermore, after an athlete's CMJ height has been increased, the drop height may need to be adjusted.

Previous studies have indicated that better DJ performance requires athletes to have the ability to bear large eccentric load and the ability to convert from eccentric to concentric contraction quickly (Komi, 2000; Komi & Gollhofer, 1997). Thus, the metric reactive strength was introduced to assess the muscle's ability to switch rapidly from eccentric to concentric muscle action under stretching load(Healy et al., 2018). The rapid and powerful SSC of highly trained individuals in ground contact phase is achieved by stronger quasi-isometric muscle movements (such as knee extensors and ankle flexors), full utilization of elastic structures, and a higher rate of force development (RFD)(Douglas et al., 2018). Reactive strength directly influences the lower limb stiffness, prompting athletes to hit the ground with a more rigid lower limb during DJ (i.e., reducing elastic deformation)(Kipp et al., 2017). Thus, individuals with better reactive strength are more likely to have a greater capacity to bear the eccentric load caused by higher drop heights and show shorter ground contact times and larger flight heights than their less capable peers(Matic et al., 2015).

At present, the association between lower limb stiffness and the drop height of DJ is still unclear. Theoretically, athletes with higher lower limb stiffness can store more elastic energy during the amortization phase and generate more force during the take-off phase when performing SSC movements, which would help to increase jump height(Brazier et al., 2019). Conversely, Walshe et al.(Walshe & Wilson, 1997) proposed that the stiffer the musculotendinous units (MTU) are, the lower the performance is when executing deep DJ at higher drop heights. In current study, we didn't find any relationship between the lower limb stiffness and the ODH. Perhaps this difference could be partly explained by the measuring method utilized In this study, in which the lower limb stiffness was calculated using Dalleau's formula (Dalleau, 2004). As Dalleau et al. (Dalleau, 2004) pointed out, the formula might lead to discrepancies between computed and actual values, which could skew the study's conclusions. Thus, more research into this relationship should be done using a formal method to measure lower limb stiffness.

To predict individual ODH, a stepwise multiple regression model was developed. Based on our testing experience, it would take about 30 minutes for one participant to identify the ODH using the RSI method due to the complicated process. Compared with the traditional method, our prediction model can save time for athletes by using relative MSmax and CMJ height, which are easily accessible in daily training. However, despite significant correlations between ODH and body height, weight, and RSR, these variables were not included in the model, which could be attributed to high collinearity (e.g., RSR and body height). The results revealed that only relative MS_{max} and CMJ height provided the best explanation, explaining 78.4% of the observed variance in individual ODH (Table 3). As a result, coaches and athletes should prioritize these two parameters while selecting the ODH before DJ training. Furthermore, the moderate predictive power may also indicate that other indicators, such as the eccentric strength, should be incorporated into the model in future research.

Study Limitations

The regression model explained 78.4% of the variance. Although key predictors were included, this level of explanatory power may still be insufficient for precise practice-oriented guidance. Moreover, the optimal drop height is influenced by multiple factors—such as an athlete's training status and stress levels—that were not incorporated into the present model. Additionally, lower limb stiffness was estimated using a kinematic formula (Dalleau, 2004), which, while practical, may not fully align with values derived from force-time curve analysis (e.g., via force platforms). Future studies could incorporate direct force-based stiffness calculations to enhance accuracy. A further limitation concerns the estimation of drop jump performance using the reactive strength index (RSI). Jump height, and consequently RSI, was derived from force- or flight-time–based methods, whose accuracy has been previously questioned when initial drop height parameters are not directly quantified. Although consistent procedures were applied across conditions, potential errors in jump height estimation may have affected the precision of the predicted optimal drop height. Future studies should consider direct kinematic measurement to improve estimation accuracy.

PRACTICAL APPLICATIONS

This findings indicate that when prescribing drop jump training height, coaches should consider an athlete's body height, body mass, RSR, CMJ height, and relative MSmax. The individual ODH should be adjusted, particularly when changes occur in CMJ height or relative MSmax. Furthermore, this study provides coaches and exercise scientists with a practical equation to estimate athletes' ODH in DJ training: ODH = -45.602+31.027*relative MS_{max} +0.548*CMJ height +5.549*RSR . Given that these two variables are widely used in training monitoring and readily accessible in routine practice, the ODH can be determined more efficiently than with traditional methods. However, future research should include additional variables to improve the model’s predictive accuracy. Moreover, due to the inherent design limitations of this study, the underlying mechanisms linking drop height to anthropometric and neuromuscular characteristics warrant further investigation.

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Table 1. Characteristics of study participants (n=49)

	Mean (±SD)	Minimum	Maximum
Body height (cm)	182.82±9.72	166.5	200.7
Body weight (kg)	79.74±15.83	50.3	122.4
Absolute MS_{max} (kg)	140.38±24.01	88.0	193.0
Relative MS_{max}	1.78±0.21	1.44	2.29
CMJ height (cm)	40.61±5.94	26.70	52.90
RSR	2.45±0.48	1.60	3.66
Lower limb stiffness (KN/M)	29.09±6.61	16.79	44.29
Optimal drop height (cm)	45.5±11.28	20	75

SD-standard deviation; MS_{max}-maximal muscle strength; CMJ height-countermovement jump height; RSR-reactive strength ratio

Table 2. Pearson correlation coefficients matrix between individual ODH and selected variables

	BH	BW	AMS_{max}	RMS_{max}	CMJH	RSR	LLS	ODH
BH	1							
BW	0.578**	1						
AMS_{max}	0.316*	0.809**	1					
RMS_{max}	-0.543**	-0.459**	0.134	1				
CMJH	0.055	-0.259	-0.081	0.245	1			
RSR	-0.567**	-0.619**	-0.206	0.675**	0.221	1		
LLS	-0.062	0.397*	0.577**	0.205	-0.100	0.323*	1	
ODH	-0.430**	-0.481**	-0.019	0.827**	0.487**	0.703**	0.126	1

BH-body height; BW-body weight; AMS_{max}-absolute maximal muscle strength; RMS_{max}-relative maximal muscle strength; CMJH-CMJ height; RSR-reactive strength ratio; LLS-lower limb stiffness; ODH-optimal drop height.
**p<0.01; *p<0.05.

Table 3. Summary of stepwise multiple regression models of individual ODH[a]

model		Regression coefficients					
		β	Std. β*	p	R^2	Adj.R^2	p
1	Constant	-31.117		<.001	0.684	0.684	<.001
	relative MS_{max}	43.031	.827	<.001			
2	Constant	-47.584		<.001	0.770	0.758	<.001
	relative MS_{max}	39.172	.753	<.001			
	CMJH	.575	.303	<.001			
3	Constant	-45.602	8.145	<.001	0.801	0.784	<.001
	relative MS_{max}	31.027	0.596	<.001			
	CMJH	0.548	0.289	<.001			
	RSR	5.549	0.237	0.025			

a-Dependent Variable: optimal drop height (cm); relative MS_{max}-relative maximal muscle strength; CMJH-countermovement jump height; RSR-reactive strength ratio.

Table 4 Multicollinearity diagnostics for Models

Model	Dimension	Eigenvalue	Condition Index	Tolerance	VIF
1	Constant	1.993	1.000		
	relative MS_{max}	0.007	16.487	1.000	1.000
2	Constant	2.979	1.000	0.940	1.064
	relative MS_{max}	0.014	14.561	0.940	1.064
	CMJH	0.007	20.789		
3	Constant	3.958	1.000		
	relative MS_{max}	0.025	12.523	0.535	1.869
	CMJH	0.011	18.706	0.934	1.070
	RSR	0.005	27.739	0.541	1.847

relative MS_{max}-relative maximal muscle strength; CMJH-countermovement jump height; RSR-reactive strength ratio.