Reliability of the Reactive Strength Index and Time to Stabilization During Depth Jumps

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Abstract

Flanagan, EP, Ebben, WP, and Jensen, RL. Reliability of the reactive strength index and time to stabilization during depth jumps. *J Strength Cond Res* 22(5): 1677–1682, 2008—The reliability of the reactive strength index (RSI) and time to stabilization (TTS) during maximal-effort plyometric depth jumps was examined. Twenty-two subjects performed three depth jumps from a height of 30 cm. Measures such as height of jump (JH), ground-contact time (CT), RSI, and TTS were obtained and analyzed for reliability using Cronbach alpha reliability coefficient and intraclass correlations. The JH, CT, and RSI were shown to be highly reliable from trial to trial (evidenced by high Cronbach reliability coefficients ($\alpha > 0.95$) and high single- and average-measures intraclass correlations (>0.9). Time to stabilization was not reliable from trial to trial, as evidenced by a low Cronbach reliability coefficient ($\alpha < 0.7$) and poor single- (<0.5) and average-measures (<0.7) intraclass correlations. The RSI was observed to be consistent for single measures, suggesting that coaches dealing with large numbers of athletes can conduct only a single trial from each depth jump height when attempting to optimize plyometric depth jump heights for their athletes. Time to stabilization could be a useful tool for strength and conditioning investigators to quantify the landing portion of plyometric exercises, but the protocol used in the current study to measure this variable did not prove to be reliable. Investigators wishing to use this measurement in such a context in future research studies may need to allow subjects appropriate habituation periods and control for arm movement during the landing phase of the exercise.

Key Words plyometrics, balance, stretch shortening cycle

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Introduction

Plyometric exercises have been demonstrated to improve power output (5), agility (7), and running economy (13). These exercises use rapid, powerful movements that are preceded by a preloading countermovement that activates the stretch-shortening cycle. Depth jumps are one of the most commonly used plyometric exercises (14) and have been used in many published strength and conditioning studies (2,5,10,14). A depth jump requires the athlete to step from a measured drop height and, on landing on the ground, to perform a maximal-effort vertical jump, with a short ground-contact period.

The reactive strength index (RSI) has been developed as a mechanism to monitor the stress on the musculotendinous complex during plyometric exercises such as depth jumps (6). The RSI describes an individual's ability to change quickly from an eccentric to concentric muscular contraction (16) and expresses athletes' explosive capabilities in dynamic jumping activity. The index can be used to provide recommendations for optimal drop height in plyometric exercises (6), to compare athletes' plyometric capabilities, or to monitor plyometric training progress (6). The RSI is calculated by dividing the height jumped in a depth jump by the time on the ground developing the forces required to make that jump (6). The components of RSI, the jump height (JH) and the ground-contact time (CT), also provide usual information to coaches. Jump height is a simple outcome measure that can be used by coaches to assess plyometric performance. Contact time provides key information regarding the manner in which jumps are performed. Short ground-contact times are encouraged in depth jumping, and monitoring CT can provide a useful feedback tool (6).

The RSI can be readily determined via force platforms or more simply in the clinical setting using contact mats. Although the measure seems to be growing in popularity in both the practical and research setting, definitive reliability data of the variable have not been produced. Flanagan and Harrison (3) have presented reliability data suggesting that RSI is a reliable measure during dynamic jumping activity. However, in this study, subjects performed one-legged drop jumps on a force sledge apparatus. The force sledge apparatus provides strong control of eccentric loadings and minimizes the contribution of extraneous factors such as arm swing and contralateral leg action (3), potentially increasing trial-to-trial reliability. As a result, these findings may not be generalizable to plyometrics performed outside the constraints of the force sledge. Additionally, the study of Flanagan and Harrison (3) used a relatively small sample size ($n = 10$), which may result in an overestimation of reliability (8).

Whereas the RSI describes the performance of the athlete during the jumping phase of a depth jump, the nature of the landing from such a jump can also be quantified. Time to stabilization (TTS) is a recently developed measure of neuromuscular control that incorporates sensory and mechanical systems to complete the task of a landing after a jump (15). More specifically, TTS can be derived through force plate data and used to evaluate postural stability as the body transitions from a dynamic to a static state (15). The TTS can be calculated by measuring the time taken for vertical ground-reaction force to reach and stabilize within 5% of the subject's body weight after the landing from a jump (15).

TTS has been used in a number of research studies investigating variables such as the effect of functional ankle instability on balance (12), differing fatigue protocols on balance (15), differences between bracing and taping techniques on ankle stability (4), and to compare the biomechanical factors between kicking and stance limbs (11).

One area in which the TTS variable could be used would be as a means of quantifying the instability of the landing portion of plyometric exercises. The National Strength and Conditioning Association outlines balance as an important requirement before participating in plyometric training (1, p. 438). Athletes are recommended to have a stable base of support on which they can safely perform the plyometric exercises (1, p. 438). The measure of TTS could provide researchers with a mechanism with which to assess the relative importance of balance to the landing phase of each plyometric exercise, and understanding the TTS associated with a variety of plyometrics will help to further quantify the intensity of these exercises. To date, research has primarily attempted to quantify the jumping phase of plyometrics, and the landing portion of plyometric exercises has been largely neglected. Unfortunately, no previous research study has thoroughly investigated the reliability of the TTS measure.

The purpose of the current study was to examine the trial-to-trial reliability of the RSI and TTS in the jump-landing task of plyometric depth jumps. To our knowledge, this has not been established in the literature. Establishing the reliability of the RSI and its components (JH and CT) allows strength and conditioning coaches to use these variables to optimize their athletes' depth jumps and monitor their progress through plyometric training programs. Establishing the trial-to-trial reliability of the TTS measure opens up the possibility for strength and conditioning researchers to use this variable to quantify the landing portion of plyometric jumps, which has not been previously established in the literature.

Methods

Experimental Approach to the Problem

This experiment tested the hypothesis that measures of RSI and vertical TTS calculated during plyometric depth jumps and landings would be reliable from trial to trial. A repeated-measures experimental design was implemented with subjects performing three depth jumps from a fixed height of 0.30 m in a nonfatigued state. The study examined the dependent variables of JH, CT, RSI, and TTS. The reliability of each of these variables was statistically assessed.

Subjects

Twenty-two NCAA Division I athletes who participated in track and field in a major conference (20.43 ± 2.43 years, 92.80 ± 17.19 kg, 175.6 ± 9.1 cm) volunteered to serve as subjects for the study. Twenty of 22 subjects were involved in throwing events (discus, javelin, hammer), and 2 of 22 subjects were involved in sprinting. The study was conducted during the subjects' off-season. Subjects were participating in off-season training including Olympic weightlifting and multi-joint lower-body exercises such as the squat. All subjects were experienced in plyometric exercise including depth jumps but were not performing these exercises at the time of the study. Subjects gave informed consent before participating. Approval for the use of human subjects was obtained from the university office of research compliance before commencing the study. Subjects had performed no strength training in the 48 hours before data collection.

Procedures

Warm-up before the plyometric depth jumps consisted of 3 minutes of low-intensity exercise on a stationary cycle ergometer. This was followed by dynamic stretching, including at least one exercise for each major muscle group of the lower limbs. Subjects were then given a visual demonstration of a depth jump. They were instructed that when performing a depth jump, they step forward off the box without stepping down, or jumping up and on contact with the force platform to jump as high as possible, as quickly as possible. It was emphasized that subjects should minimize their time in contact with the ground and think of the force plate as a "hot plate." For determination of the measure of TTS, subjects were instructed to "stick" their landing and to stabilize as quickly as possible while facing straight ahead and remaining motionless for a period of 7 seconds. Arm position was not controlled throughout the jumping and landing movements because we wanted to keep the plyometric activity as close as possible to that experienced in the training environment.

Subjects then practiced the test jump at approximately 75% of their self-perceived maximum effort. After this warm-up, subjects were allowed at least 5 minutes of rest before testing with the plyometric exercise. Subject performed three plyometric depth jumps. A 1-minute rest interval was maintained to ensure sufficient recovery between each jump (10). After performing the depth jumps, subjects were instructed to stand motionless on the force platform for measurement of body mass.

Data Analysis

The plyometric exercises were performed by taking off from and landing on a 60 × 120-cm force platform (BP6001200, AMTI, Watertown, Mass), which was bolted to the laboratory floor according to manufacturer specifications and mounted flush in the center of a 4 × 8-foot weightlifting platform. The size of the platform and its flush-mounted configuration were thought to ensure that the subjects' jump landings were on target and safe. Kinetic data were collected at 1000 Hz, real-time displayed, and saved with the use of computer software (BioAnalysis 3.0, Advanced Mechanical Technologies, Inc., Watertown, Mass) for later analysis. Ground-reaction force data were collected for the sample period and used to calculate several variables from the vertical force components (Fz).

Instants of initial foot contact, take-off, and landing were identified from the vertical ground-reaction force datasets (see Figure 1). Flight time, the time subjects spend "airborne" in each jump, was calculated as the time between the points of take-off and landing. Using the flight time, JH was calculated as (9.81 × flight time^2)/8. Ground-contact time, which was defined as the time subjects were in contact with the ground immediately preceding each jump, was calculated as the time between initial foot contact and take-off. Calculations of RSI were also performed and determined as JH divided by CT. Vertical TTS was established as the time from the point of landing to when the vertical force component reached and stayed within 5.0% of the subject's body weight for a 1-second duration (see Figure 2).

Statistical Analyses

All statistical analysis of the data was carried out in SPSS (version 12.0.1). Trial-to-trial reliability analysis of recorded variables used the Cronbach alpha reliability coefficient and both single- and average-measures intraclass correlations to absolute agreement. A repeated-measures analysis of variance was used to determine possible differences between trials. The criterion for significance was set at an alpha level of $p \leq 0.05$. The dependent variables were JH, CT, RSI, and TTS.

Results

Table 1 displays the trial-to-trial reliability of all dependent variables measured during depth jumps. The measures of JH and CT were shown to be highly reliable from trial to trial as evidenced by high Cronbach reliability coefficients ($\alpha > 0.95$), high single-measure intraclass correlations (>0.9), and high average-measures correlations (>0.95). Because these two variables constitute the measure of RSI, the following analysis of this variable also demonstrated very high reliability, with a high Cronbach reliability coefficient ($\alpha > 0.95$) and single- and average-measures intraclass correlations observed (>0.95).

Time to stabilization was not reliable from trial to trial, as evidenced by a low Cronbach reliability coefficient ($\alpha < 0.7$) and poor single- (<0.5) and average-measures (<0.7) intraclass correlations.

Figures 3 and 4 display the RSI and TTS data (mean ± *SD*) for each of the three trials. The group demonstrated a mean RSI of 1.12 ± 0.49 across all depth jumps from 30 cm. The mean TTS after landing was 0.97 ± 0.46 seconds. The repeated-measures analysis of variance detected no significant differences between trials 1, 2, or 3 for the measures of RSI ($p = 0.40$), CT ($p = 0.98$), JH ($p = 0.25$), or TTS ($p = 0.56$).

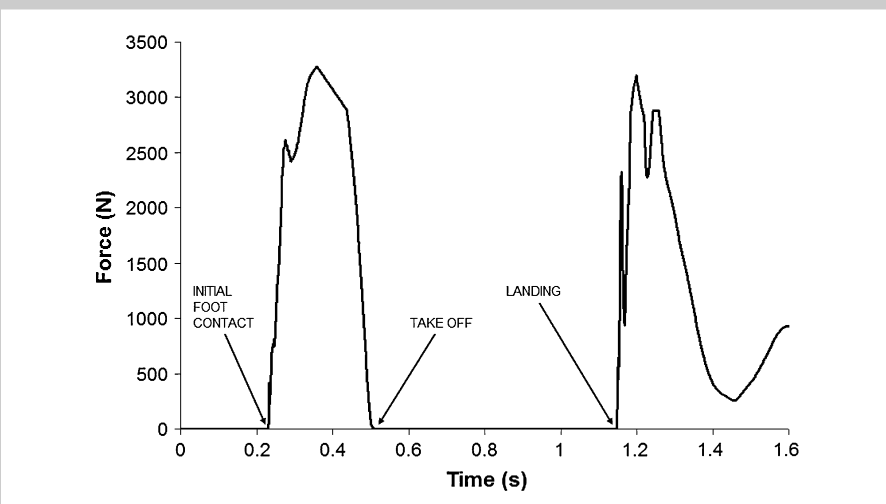

Figure 1. Graphical representation of acquired vertical ground-reaction force traces and identified action points used to calculate reactive strength index during the plyometric depth jump.

Discussion

This study is the first to examine the reliability of both RSI and TTS during the jumping and landing phase of depth jumps. The RSI provides an indicator of stress on the musculotendinous complex during plyometric exercises (6). One of the primary benefits of measuring the RSI is its ability to optimize the height from which plyometric depth jumps can be performed from both a performance and injury-risk-minimization perspective. McClymont (6) has described this process in which athletes perform three jumps from each of three different drop heights (15, 30, and 45 cm), with the RSI calculated for each

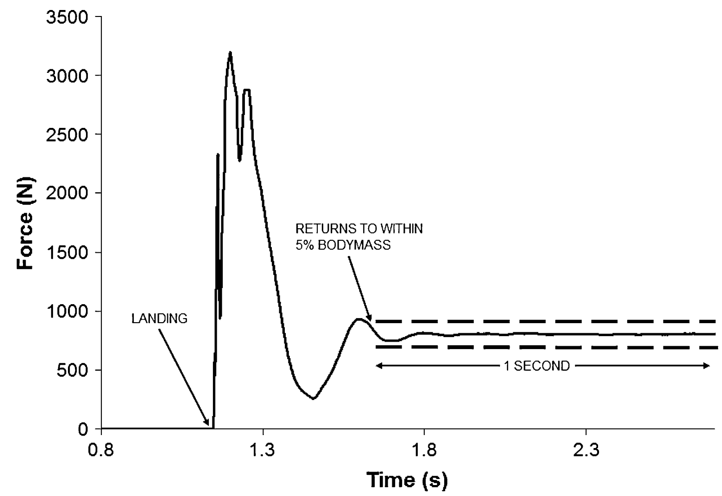

Figure 2. Graphical representation of acquired vertical ground-reaction force traces and identified action points used to calculate time to stabilization during the landing phase of the plyometric depth jump.

jump. When the RSI is maintained or improves with an increase in drop height, it is assumed that an individual's reactive strength capabilities are sufficient at that height of depth jump. The height at which the RSI decreases indicates a depth jump height that may represent a heightened injury risk for that individual or that might provide a suboptimal training stimulus.

In the present study, the measure of RSI was determined to be highly reliable across trials of depth jumps. To our knowledge, despite the increasing use of RSI in the practical and research setting, this finding had not previously been established in plyometric depth jumps. Significantly, the intraclass correlations revealed the RSI to be consistent for single measures. This is an important finding for strength and conditioning coaches or researchers using RSI to assess large numbers of athletes at once. Conducting only a single trial from each depth jump height, rather than repeated measures, could save significant time. Thus, RSI is a quick and convenient tool to use to monitor plyometric progress or to optimize drop heights in depth jump training.

The individual components that make up RSI, CT, and JH were also found to be highly reliable. These variables may be useful for strength and conditioning coaches or researchers as different means to provide feedback or determine intensity of various exercises. For example, McClymont and Gibson (6) investigated the use of enthusiasm and augmented feedback on performance in depth jumps. After each jump, athletes in an experimental group were given enthusiastic feedback via their ground-contact times and their jump height. This augmented feedback significantly increased performance, as measured through RSI, compared with a control group. Consequently, the present study provides strength and conditioning coaches with the knowledge that they can use the measures of ground-contact time or height jumped as a reliable means of feedback to enhanced plyometric training performance.

Intensity of plyometric activity may also be measured by the difficulty of a landing task (9), which may be quantified by TTS (15). The mean TTS observed in the present study of 0.97 $\pm$ 0.46 seconds is considerably lower than data reported by Wikstrom et al. (15) of approximately 2.2 seconds. This finding suggests that the current landing task was easier than those used in other research. Yet, despite this decreased difficulty, a large degree of variability between trials was observed in the present study. The protocol to measure TTS that was used in this study varied from those in previously published literature in a number of ways. Previous research examining TTS employed a 70-cm horizontal jump during which subjects were required to reach up and touch a fixed overhead target, land on one leg, and stabilize as quickly as possible with their hands on their hips. We chose to allow use of the arms, to not standardize the jump height, and to allow two-legged landings to more closely simulate actual plyometric exercises. These factors may partially account for lower values of TTS than previous studies. However, despite not controlling these

TABLE 1. Reliability data for all measured variables.

		Intraclass correlation	
	Reliability α	Single measures	Average measures
Jump height	.989	0.968	0.989
Ground-contact time	.976	0.934	0.977
Reactive strength index	.989	0.967	0.989
Time to stabilization	.683	0.423	0.687

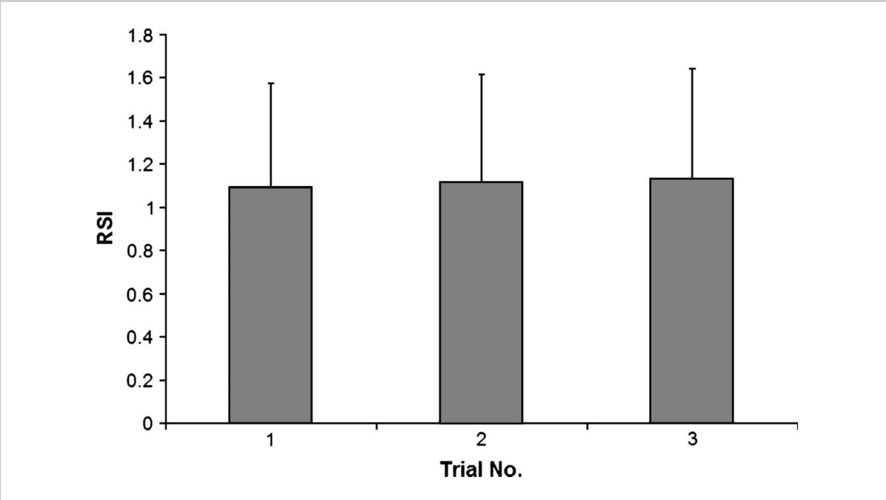

Figure 3. Mean reactive strength index (RSI) during the depth jumps. No significant differences were observed between trials ($p > 0.05$).

variables, extremely high trial-to-trial reliability was observed for jump height in each plyometric exercise. Accordingly, we do not feel that variability in jump height contributed to the lack of reliability observed in TTS. Thus, we discount these differences because, theoretically, these should make the landing task easier to accomplish and, therefore, more consistent from trial to trial.

The major methodological factor that may have negatively influenced the reliability of the measure of TTS is the habituation period given to the subjects in the current study. Subjects were afforded only one practiced repetition of the protocol before data collection. Ross et al. (12) allowed their subjects three practice trials before data collection, whereas Wikstrom et al. (15) allowed subjects "as many practice trials as required to ensure consistent performance before beginning the actual experimental trials."

Practical Applications

This research has demonstrated that the RSI, CT, and JH are reliable measures as assessed during depth jumps from 30 cm. These variables are valid for coaches to use to optimize the height from which depth jumps can be performed, to compare athletes' plyometric capabilities, or to monitor plyometric training progress. These data suggest that for coaches attempting to conduct this process with large numbers of athletes, it may be sufficient to take just a single measure of RSI from each drop height, rather than repeated trials.

Time to stabilization could potentially be a useful tool for strength and conditioning researchers to attempt to quantify the landing phase of plyometric exercises, which has not previously been established in the literature. However, the methodological procedures used in the present study produce a measure of TTS that is not reliable and, thus, renders it unsuitable for use in the research or coaching setting. To improve reliability, a greater habituation period may need to be allowed. Subjects should be afforded multiple practice jumps or a prolonged period of familiarization before data collection to ensure consistent performance during the experimental trials. Some degree of control for arm position/movement during the landing phase should also be applied. To maintain specificity of the plyometric exercises, researchers may wish to allow arm movement during the jumping action, but to improve reliability, subjects should be instructed to place their hands on their hips when landing. These suggested methods of increasing TTS reliability were not implemented in this study because maintaining exercise specificity was a principle aim. However, the lack of reliability

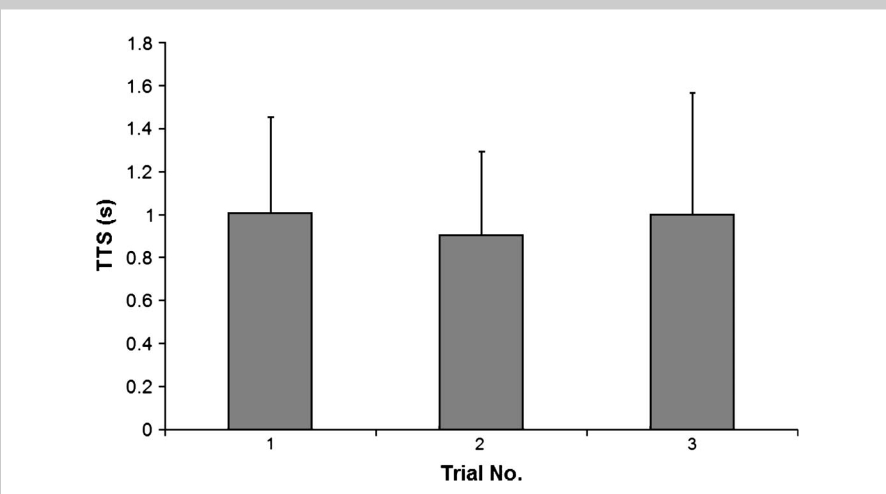

Figure 4. Mean time to stabilization (TTS) during the depth jumps. No significant differences were observed between trials ($p > 0.05$).

observed in TTS may suggest that, for this variable to be used by investigators to quantify the landing phase of plyometric exercise, some compromise between specificity and experimental control should be made.

References

1. Potach, DH and Chu, DA. Plyomtric training. In: *Essentials of Strength and Conditioning*. TR Baechle and RW Earle, eds. Champaign, IL: Human Kinetics, 2000. pp. 427–470.
2. Chimera, NJ, Swanik, KA, Swanik, CB, and Straub, SJ. Effects of plyometric training on muscle-activation strategies and performance in female athletes. *J Athl Train* 39: 24–31, 2004.
3. Flanagan, EP and Harrison, AJ. Muscle dynamics differences between legs, in healthy adults. *J Strength Cond Res* 21: 67–72, 2007.
4. Jacobs, N, Boucher-Mokha, M, Ludwig, K, and Krkeljaas, Z. Do ankle stabilizers influence dynamic stability in persons with functional ankle instability? In: *Proceedings of the XXIV International Symposium of Biomechanics in Sports*. H. Schwameder, G. Strutzenberger, V. Fastenbauer, S. Lindinger, and E. Müller, eds. Salzburg: 2006. 1: 383.
5. Luebbers, PE, Potteiger, JA, Hulver, MW, Thyfault, JP, Carper, MJ, and Lockwood, RH. Effects of plyometric training and recovery on vertical jump performance and anaerobic power. *J Strength Cond Res* 17: 704–709, 2003.
6. McClymont, D. Use of the reactive strength index (RSI) as an indicator of plyometric training conditions. In: *Proceedings of the 5th World Conference on Science and Football*. T. Reilly, J. Cabri, D. Araújo, eds. Lisbon, 2003. pp. 408–416.
7. Miller, MG, Herniman, JJ, Ricard, MD, Cheatham, CC, and Michael, TJ. The effects of a 6-week plyometric training program on agility. *J Sports Sci Med* 5: 459–465, 2006.
8. Morrow, JR, Jr, and Jackson, AW. How "significant" is your reliability? *Res Q Exerc Sport* 64: 352–355, 1993.
9. Potach, DH, and Chu, DA. Plyometric training. In: *Essentials of Strength Training and Conditioning*. R.W. Earle and T.R. Baechle, eds. Champaign, Ill: Human Kinetics, 2000. pp. 427–470.
10. Read, MM, and Cisar, C. The influence of varied rest interval lengths on depth jump performance. *J Strength Cond Res* 15: 279–283, 2001
11. Ross, S, Guskiewicz, KM, Prentice, W, Schneider, R, and Yu, B. Comparison of biomechanical factors between the kicking and stance limbs. *J Sport Rehabil* 13: 135–150, 2004.
12. Ross, SE, Guskiewicz, KM, and Yu, B. Single-leg jump-landing stabilization times in subjects with functionally unstable ankles. *J Athl Train* 40: 298–304, 2005.
13. Saunders, PU, Telford, RD, Pyne, DB, Peltola, EM, Cunningham, RB, Gore, CJ, and Hawley, JA. Short-term plyometric training improved running economy in highly trained middle and long distance runners. *J Strength Cond Res* 20: 947–954, 2006
14. Walsh, M, Arampatzis, A, Schade, F, and Brüggeman, G-P. The effect of drop jump starting height and contact time on power, work performed, and moment of force. *J Strength Cond Res* 18: 561–566, 2004.
15. Wikstrom, EA, Powers, ME, and Tillman, MD. Dynamic stabilization time after isokinetic and functional fatigue. *J Athl Train* 39: 247–253, 2004
16. Young, W. Laboratory strength assessment of athletes. *New Stud Athletics* 10: 88–96, 1995.