Validation of an Electronic Jump Mat to Assess Stretch-Shortening Cycle Function

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Abstract

Kenny, IC, Caireallá in, AÓ, and Comyns, TM. Validation of an electronic jump mat to assess stretch-shortening cycle function. *J Strength Cond Res* 25(X): 000–000, 2011—The purpose of this investigation was to determine the concurrent validity of a commonly used electronic switch mat (ESM), or jump mat, compared with force plate (FP) data. The efficiency of collection and accuracy of data are paramount to athlete and player field testing for the strength and conditioning coach who often has access only to a jump mat. Ten subjects from 5 different sporting backgrounds completed 3 squat jumps (SJs), 3 countermovement jumps (CMJs), and 3 drop jumps (DJs). The jumps were performed on an AMTI FP operating at 1,000 Hz with an ESM positioned on top of the platform. All the subjects were experienced with the protocols involved with jump testing. The resulting absolute errors between FP and ESM data were 0.01, 0.02, and 0.01 m for CMJ, SJ, and DJ heights, respectively. However, the coefficient of variation for the DJ contact time (CT) was 57.25%, CMJ ($r = 0.996$), and SJ ($r = 0.958$) heights correlated very strongly with force platform data, and DJ data were not as strong ($r = 0.683$). Confidence interval tests revealed bias toward CMJ and SJ ($p < 0.05$). The jump mat can accurately calculate the CMJ height, SJ height, and reactive strength index for all the 3 jump protocols. However, the faster CTs and rapid movements involved in a DJ may limit its reliability when giving measures of CT, flight time, and height jumped for DJs. Strength and conditioning coaches can use such a jump mat device with the confidence that it is accurately producing valid measurements of their athlete's performance for CMJ and SJ slow SSC protocols.

Key Words force plate, jump mat, plyometrics, stretch-shortening cycle, validation AU2

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Introduction

The vertical jump is often used in strength and conditioning literature to gauge an athlete's lower body power (6,8,10,16). Hedrick and Anderson (12) have suggested that the vertical jump is most commonly used (a) to measure the improvements in jump height for sports such as basketball in which jumping ability will aid performances and (b) as a general measure of lower body power. To date, many researchers have investigated the relationship of the vertical jump with varying components of fitness and performance such as speed (23), maximal strength (2), agility (21), and weightlifting ability (6). Indeed Markovic et al. (18) described the countermovement jump (CMJ) and the squat jump (SJ) as being the most reliable and valid field test for the estimation of explosive power of the lower limbs in physically active men. Strength coaches and specialists are known to use jump tests, often on a daily basis, for 2 reasons: to assess lower body power performance improvements throughout a season and for prehabilitation and injury prevention related to fatigue, technique, and physiological state.

The vertical jump is in fact an expression of the stretch shortening cycle (SSC) and that vertical jump performance is representative of SSC performance (11). The SSC is a natural type of muscle function involving the combination of an eccentric with a concentric action, with the purpose of making the concentric action more powerful than that resulting from a concentric-only action. The prestretching phase provides an advantage for the subsequent concentric contraction (15). Investigations into the nature of the SSC have revealed that there are in fact 2 types: a long or slow and a short or fast SSC (19). A slow (or long) SSC is characterized by "large angular displacements in the hip, knee, and ankle joints and by a duration of more than 250 ms" (19: 383). Examples of this would be the CMJ or line-out jumping in rugby. A short (or fast) SSC action "shows only small angular displacements in the above cited joints (hip, knee and ankle joints) and lasts 100–250 ms" (19: 383). Sprinting, hopping, and drop jumping would be examples of a fast SSC action. Indeed, several researchers have stated that improved performance in simple SSC movements such as CMJs and drop jumps (DJs) are in direct relation to improvement in sprinting tasks (21,23). An understanding of the SSC has direct implications for this study, because the CMJ is representative of the slow SSC and the DJ is representative of the fast SSC.

Table 1. Electronic switch mat and force platform measures and calculations.*

Measure	Description
FT	Time between take-off and landing
CT	Time between the initial landing after a drop and the subsequent take-off point
HJ	Calculated from the FT for each jump using the second mathematical equation of linear motion: $s = \frac{1}{2}at^2$, where initial velocity = 0 ms^{-1}
RSI	RSI = HJ/CT

*FT = flight time; CT= contact time; HJ = height jumped; RSI = reactive strength index; s = displacement; t = time to the top of the jump; a = acceleration due to gravity.

In terms of vertical jump measurement, it has been stated that the accepted measure of vertical jump parameters is the hard-wired, very sensitive strain gauge or piezoelectric type embedded immobile systems that require subjects to be tested in the laboratory (22). Several methods exist for the measurement of the vertical jump in a field setting. Klavora (14) highlighted several field tests that are commonly used in research and training contexts and describes the methodology and relative advantages and disadvantages of using each test. The tests that are described include the jump and reach test, belt tests, and electronic switch mat (ESM) tests. Many coaches use ESMs to measure the height jumped (HJ) by their athletes because of the cost effectiveness and portability of such a device (7,14). However, the concurrent validity of the ESM has not been ascertained and widely published in relation to fixed force platform data. The purpose of this study was to determine the concurrent validity of a commonly used ESM against a ground mounted force platform for the purpose of measuring various parameters during 3 types of jump. The central practical objective of this work was to ascertain whether strength and conditioning coaches can confidently test their athletes' slow SSC function in the field using a readily available jump mat, thus enhancing the quality of the jump performance and training stimulus.

According to Klavora (14), electronic mats provide many advantages over traditional vertical jump and reach tests. Electronic mats are generally more efficient and can therefore accommodate larger subject numbers in shorter periods of time, crucial for the strength coach interacting with tactical coaches, each with a limited timeframe with the athletes and players. They also eliminate the need to measure the height of an athlete's reach, are easy to transport, and require very little storage space. Furthermore, no calculations are needed to be performed by the tester to derive the HJ (14). However, the validity of these electronic mats has not been widely established in the literature. It is hypothesized that the ESM produces data that do not vary significantly from that produced by a laboratory-based fixed forced platform. The purpose of this investigation was to determine the validity of a commonly used ESM, or jump mat, compared with force platform data.

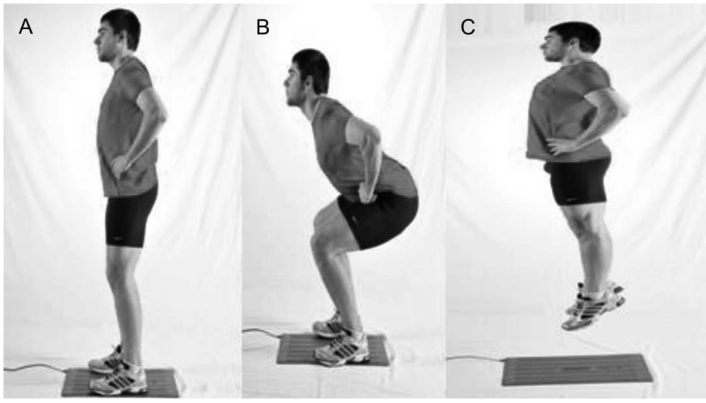

Figure 1. Body positioning during countermovement jumps (CMJs) and squat jumps (SJs).

Methods

Experimental Approach to the Problem

This study involved the subjects performing 3 SJs, 3 CMJs, and 3 DJs from a height of 30 cm. The jumps were performed on an AMTI OR6-5 force platform operating at 1,000 Hz. The jump mat was positioned on top of the force platform and the platform reset. The dependent variables used during this study to assess the SSC function

TABLE 2. Descriptive statistics for all the parameters measured by the jump mat and force plate.*

		Countermovement jump		Squat jump		Drop jump	
	Dependent variable	Mean ± *SD*	CoV	Mean ± *SD*	CoV	Mean ± *SD*	CoV
Jump mat	*H* (m)	0.32 ± 0.09	28.1	0.31 ± 0.09	29.0	0.22 ± 0.05	22.7
	FT (s)	0.51 ± 0.07	13.7	0.49 ± 0.08	16.3	0.42 ± 0.05	11.9
	CT (s)					0.24 ± 0.15	62.5
	RSI					1.12 ± 0.49	43.75
Force plate	*H* (m)	0.31 ± 0.09	29.1	0.29 ± 0.09	31.0	0.21 ± 0.06	28.6
	FT (s)	0.50 ± 0.07	14.0	0.48 ± 0.08	16.7	0.41 ± 0.06	14.6
	CT (s)					0.25 ± 0.13	52.0
	RSI					0.98 ± 0.47	48.0

*CoV = coefficient of variation; *H* = jump height; FT = flight time; CT = ground contact time; RSI = reactive strength index.

were flight time (FT) and HJ for both the CMJ and SJ. For the DJ, contact time (CT) and reactive strength index (RSI) were also measured in addition to FT and HJ. Descriptive statistics were used alongside regression models to analyze the correlation and any error between force platform data and ESM jump mat data. Determining the strength of the relationship (with absolute error, confidence limits, and intraclass coefficient correlations [ICCs]) between the jump mat and a gold standard fixed force platform enabled the practical question of concurrent validity and common use of the mat to be addressed.

Subjects

Ten subjects were recruited (age 23.6 ± 2.2 years, height 174.11 ± 16.63 cm, mass 77.37 ± 16.63 kg) who were all proficient with the 3 types of jump performed in this study. The subject base included 3 track and field athletes, 2 Gaelic hurling players, 2 Olympic weightlifters, 2 recreational runners, and 1 rugby union player. All the subjects routinely included gymnasium-based strength sessions in to their weekly training and had a minimum of 4 years experiences in the CMJ, SJ, and DJ. A 2-week period was identified for all the subjects during their competition season when they did not

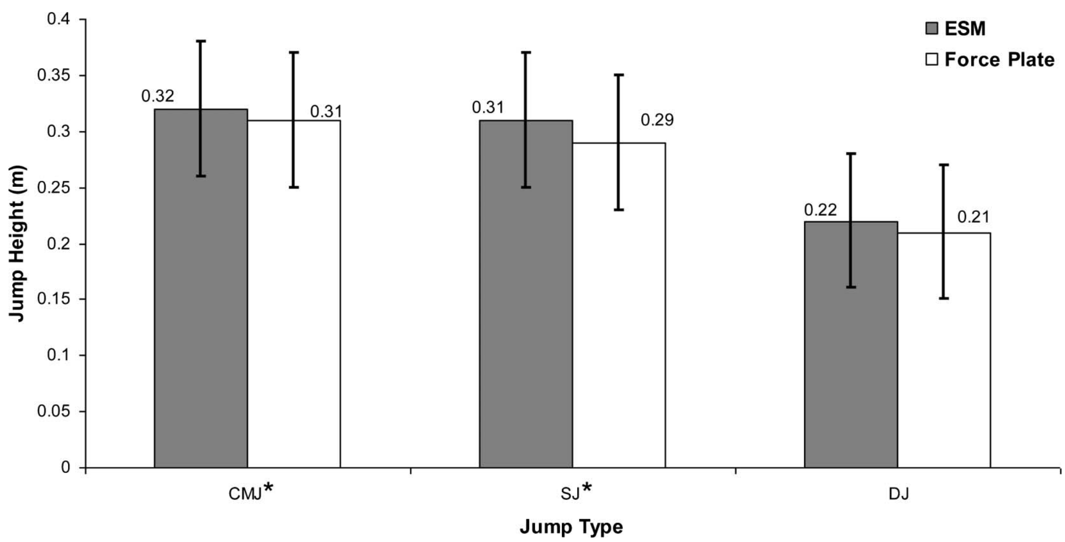

Figure 2. Mean ± 95% confidence interval jump height for countermovement jumps (CMJs), squat jumps (SJs), and drop jumps (DJs) measured by the jump mat and the force plate*.

Table 3. The ICCs for the jump height for the CMJ, SJ, and DJ measured by the jump mat and force platform.*

	CMJ	SJ	DJ
Jump mat	0.99	0.99	0.64
Force plate	0.99	0.99	0.75

*CMJ = countermovement jump; SJ = squat jump; DJ = drop jump; ICC = intraclass correlation coefficient.

have any competition or heavy training. The same time of the day was used for reliability reasons and to control for circadian variation. All the subjects were tested in the evening with at least 24 hours of rest from exercise before testing. Normal dietary intake was not to be deviated from 24 hours before testing, and the subjects were instructed to consume at least 500 ml of water in the 90 minutes before testing. Approval for the use of human subjects was obtained from the university review board of research compliance. The subjects were informed of the experimental risks and signed an informed consent document before the investigation. In addition, a Physical Activity Readiness Questionnaire was completed by the subjects.

Instrumentation

For the purpose of this study, an ESM was used (FLS JumpMat, Tyrone, Ireland). The ESM instrument includes a square mat attached to a hand-held monitor. With the aid of microswitches embedded in the mat, FT is measured as the interval between liftoff of the feet from the mat to landing of the feet back on the mat. The output displays both FT (0.01 seconds) and the height of the jump (14). When performing DJs, CT and RSI are also shown in the Output Box. A ground mounted AMTI OR6-5 force platform (sampled at 1,000 Hz) was used to gain the force plate (FP) results.

Test Procedure

All the subjects underwent an identical warm-up protocol consisting of 5 minutes of gentle jogging and 10 minutes of dynamic mobility exercises. Ten repetitions of the following exercises were performed: forward and backward leg swings, side-to-side leg swings, bodyweight squats, reverse lunges, lunges to the side, and high knee jogging. All the subjects wore t-shirts, running shorts, and running shoes during the duration of the testing sessions. The subjects were permitted 180 seconds between repeats of the same type of jump and 300 seconds between sets of different types of jumps to mitigate fatigue. Three trials of each jump type were executed. The order of jump type was randomly assigned. Data were tabulated from the AMTI force platform software 'Bioware' and recorded from the ESM output box and were used to calculate common jump parameters as shown in Table 1. The subjects were allowed to walk or sit during the rest interval between jumps and type of jumps, but they had to refrain from stretching and from doing any explosive plyometric movements. No feedback was given to the subjects during or after the testing intervention sessions regarding the jumping technique or performance results. In addition, no encouragement was provided to the subjects. At the end of each testing session, the subjects participated in a cooldown that consisted of 3 minutes of low-intensity jogging and static stretching of the major leg muscles. T1

The exact procedures that were followed for the CMJ, SJ, and DJ are as follows:

For the CMJ, (a) the subject stood on an electronic jump mat with feet shoulder width apart (Figure 1A); (b) hands were placed on the side of the hips; (c) subjects squatted until the thighs were approximately parallel to the floor (Figure 1B); (d) the downward movement was followed immediately by F1

Table 4. Pearson's correlation coefficients and RMSD for all the parameters measured by the ESM and force platform.*

	Countermovement jump		Squat jump		Drop jump	
Dependent variable	*r*	RMSD	*r*	RMSD	*r*	RMSD
H	0.996	2.040	0.958	8.240	0.683	0.000
FT	0.996	0.000	0.946	0.001	0.269†	0.010
CT					−0.173†	0.020
RSI					0.938	0.040

*r = Pearson's correlation coefficient; RMSD = root mean square deviation; H = jump height; FT = flight time; CT = ground contact time; RSI = reactive strength index.
†Not significant. All other Pearson's 'r' significant at the 0.05 level.

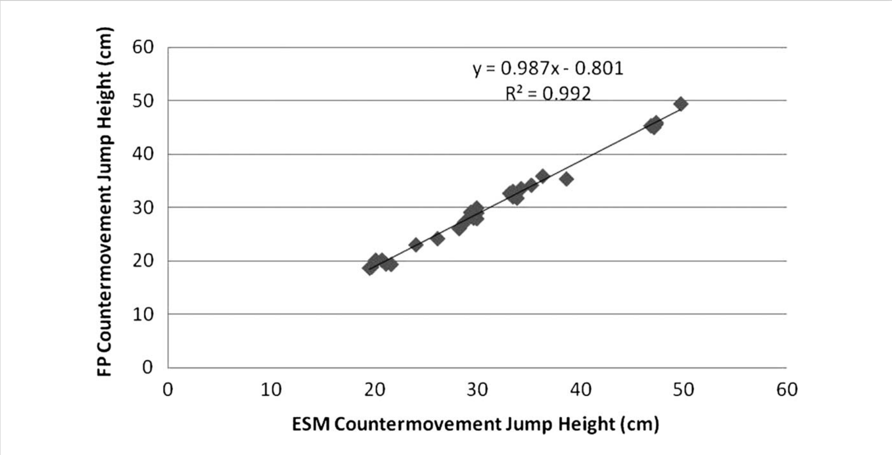

Figure 3. Regression analysis for jump mat and force plate jump height for countermovement jumps (CMJs).

an explosive upward vertical jump (Figure 1C); and (e) the subject landed with both feet completely on the jump mat for the jump to count. The subjects were instructed to land with their toes pointing downwards, with straight legs, immediately flexing the hips, knees, and ankles upon landing.

The SJ was performed as follows: (a) The subject stood on electronic jump mat with feet shoulder width apart. (b) Hands were placed on the side of the hips. (c) The subject squatted until the thighs were approximately parallel to the floor (Figure 1B). (d) The squat is held for a count of 3, after which the subject explosively extends vertically. (e) The only movement permitted during the explosive phase of the jump was upward (Figure 1C). No preparatory dip or countermovement was permitted. (If a countermovement was observed, the subject was requested to repeat that trial.) (f) The subject was required to land with both feet completely on the jump mat for the jump to be counted as valid. The subjects were instructed to land with their toes pointing downward, with straight legs, immediately flexing the hips, knees, and ankles upon landing.

The drop jump (DJ) was performed as follows: (a) The subject assumed the starting position standing on purpose-build jump box, which was 30 cm from the floor. (b) Hands were placed at the sides of the hips. (c) The subject was instructed to step from the jump box and explosively drive upward as soon as contact was made with the floor. (d) Hands were kept on the hips throughout. (e) For the jump to be counted as valid, the subjects had to keep their legs straight throughout the flight and landing phase of the jump. (f) The subjects were instructed to land with their toes pointing downward to standardize the landing technique throughout the sample population.

Calculation of the Dependent Variables

Table 1 highlights the methods that were used to calculate the dependent variables derived from testing session measurements. Performance measures commonly required by strength coaches tend to focus on the height achieved during SJ, CMJ, and DJ tests; therefore, these measures were the focus for dependent variables for this study. In addition, derived RSI (= HJ/ground CT) is commonly used in strength and conditioning research, providing an indirect measurement of an athlete's fast SSC ability, and was thus also calculated in this study (7).

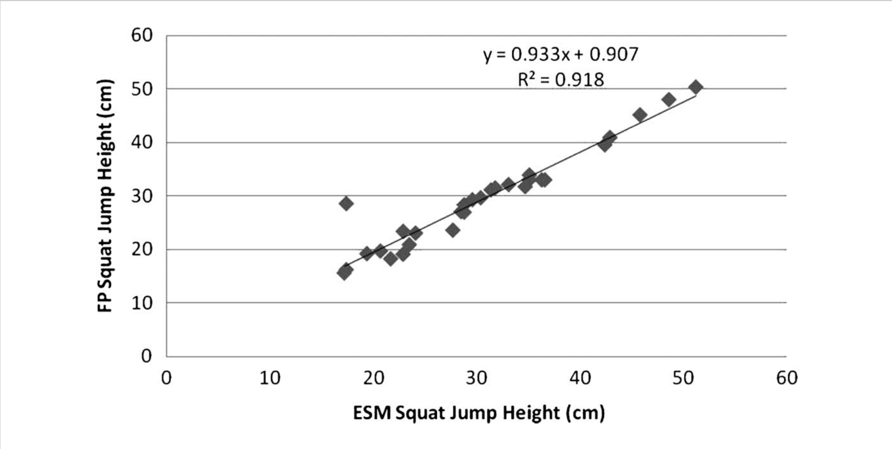

Figure 4. Regression analysis for jump mat and force plate jump height for squat jumps (SJs).

Statistical Analyses

All statistical analyses were conducted using a software package (SPSS for Windows, release 11.0.1; SPSS, Inc., Chicago, IL, USA). Correlation coefficients were used to identify the strength and directionality of the relationships between the various parameters that were calculated by the FP and ESM apparatus. The classification of correlations set out by Hopkins (13) was used to describe the strength of the relationships observed and common variance ($r^2 \times 100$), used for interpreting the meaningfulness of the

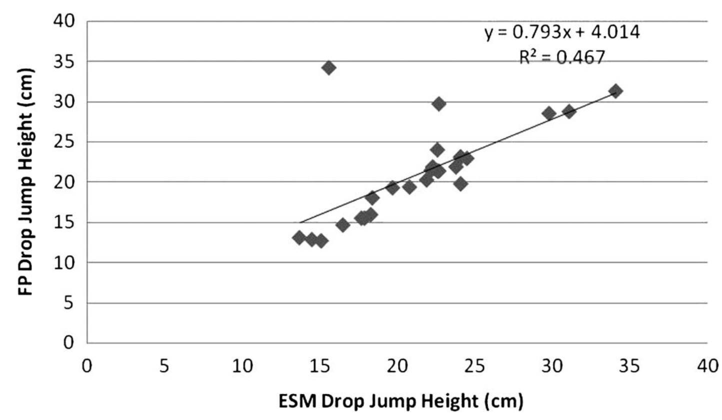

Figure 5. Regression analysis for jump mat and force plate jump height for drop jumps (DJs).

Table 5. Percentage difference and absolute error for CMJ, SJ, and DJ jump height measured by the jump mat and force plate.*

	CMJ height (%)	SJ height (%)	DJ height (%)
Jump mat	100	100	100
Force plate	96.23	98.04	97.96
%Difference	3.77	1.96	2.04
Absolute error (m)	0.01	0.02	0.01

*CMJ = countermovement jump; SJ = squat jump; DJ = drop jump.

relation, was applied (17). Thomas and Nelson (20) have suggested that 'when common variance between the 2 variables is <50%, it indicates that they are specific or somewhat independent in nature.' Force plate results were also shown as a percentage of the EMS results to estimate the percentage difference between the 2 sets of results, alongside absolute error and 95% confidence limits. The ICCs and coefficient of variation were calculated to test the reliability of the data and an analysis of variance model applied to jump scores from the ESM and FP to assess systematic bias ($p \leq 0.05$). Confidence limits were calculated using the p value derived from the differences between group sets (13).

Results

Descriptive statistics for all the parameters as measured by the jump mat and the ground mounted FP are presented in Table 2. Height jumped for all the 3 jumps follow a similar pattern in both the ESM and FP. The DJ height is lower than the CMJ and SJ heights. This is because of the reactive nature of the jump and the lower CT in the DJ when compared with the CMJ and SJ, respectively.

Absolute error and 95% confidence intervals are presented in Figure 2, showing no significant difference in the CMJ, SJ, or DJ height measurements by the jump mat and the FP. Confidence interval tests, however, revealed bias toward CMJ and SJ ($p < 0.05$). Furthermore, ICCs are presented in Table 3 for jump height for all 3 jumps. The ICCs indicate high test-retest reliability for only CMJ and SJ. As supported by Pearson's correlation coefficients shown in Table 4, the results are shown to differ significantly ($p < 0.05$) for DJ measurements indicating an inability by the jump mat to accurately report the DJ CT and thus the jump height.

Figures 3–5 illustrate the strength of the relationships for the key measure of HJ. It can be seen that the correlation between measurements of the SJ height and the CMJ height were extremely strong, whereas a weakening of the relationship was found when jump mat and FP measures were compared for the DJ height. Supporting the high test-retest reliability for CMJ and SJ, Figures 3 and 4 present strong R^2 and y-intercept error values of 0.992/−0.01 and 0.918/0.009 m, respectively. Although mean absolute error for the DJ (Table 5) purports only 0.01-m deviation between jump mat and force platform measurement, the confidence with which the DJ measurement can be predicted by the jump mat remains low. It should be noted that outliers remain with the data set in Figure 5, denoting nonadherence to maximal effort protocols by a subject. Coaches must ensure that the jump protocol, particularly the lesser-used DJ test, is also qualitatively assessed during testing. Calculations performed when outliers were removed demonstrated no significant alteration in the results presented here.

Discussion

Vertical jumping ability is important for achieving a good performance in sports. Coaches need exercises that consume little time and yet still help improve their athletes' jumping ability and subsequently speed and power (4). Coaches strive to find new exercises and means by which to increase an athlete's performance and not only do the methods have to provide gains, but they increasingly must also be very efficient to administer. Often, training sessions cannot be fully devoted to improving one specific element of performance in many cases because of lack of time and large numbers of athletes. Methods should also be safe and involve only minimal risk of injury. Thus, the emergence of jump mats that allow efficient, safe, and applicable measurement of jumping ability in the field is self evident. However, there are conflicting results here showing limitations to the protocols that can be accurately measured using jump mats, demonstrating good concurrent validity for CMJ and SJ but only moderate correlation against fixed force platform data for the DJ. The mean heights measured for the CMJ were similar on both the ESM and the FP (32 and 31 cm, respectively), as were the results for the SJs (0.31 and 0.29 cm, respectively) and the DJ heights (24 and 21 cm). The lower jump height in the SJ compared with the CMJ is consistent with the majority of the research in which the 2 types of jumps were compared (5). It can be seen that the FP yielded lower results in terms of the HJ across all the 3 jumps measured.

The results comparing the 2 instruments showed very strong correlations for the SJ height (0.985), SJ FT (0.946), CMJ height (0.996), and CMJ FT (0.996). Although the correlation between the 2 DJ heights was strong and significant (0.683), the correlation between CT and FT in the DJ was very weak (−0.173, and 0.269, respectively). Therefore, the ESM tested in this study is a valid instrument for measurements of HJ and FT in CMJ and SJ but will not produce accurate results when measuring DJs. A possible explanation for the low correlations found for CT and FT in the DJs is that the DJ involves a much smaller ground contact period that the relatively inexpensive ESM cannot accurately detect, that is, beyond its inherent precision and perhaps sampling rate. Drop Jump is a measure of fast SSC function, minimizing the ground CT and lag between the eccentric and concentric phases for short amortization (1,19). Therefore, to glean relevant information on an athlete's jump and derived power performance and train the specific systems, the coach must differentiate between CMJ, SJ, and DJ rationale (3). The SJ has been used to good effect in the development of methods of complex training (9) where a fixed inclined force platform was used. Validation results from this study therefore could further refine application of SSC training, but not that of fast SSC, through complex methods and SJs on an ESM jump mat.

The SSC is observed in a wide range of activities and seems to contribute favorably to the DJ in this study. In real-life situations, exercise seldom involves a pure form of isometric, concentric or eccentric actions (15). The natural form of muscle function is the SSC, and consequently, it is evident in basic locomotion activities, such as walking and running, and in more challenging actions including throwing and jumping and strength training exercises, such as cleans and snatches (11). Countermovement jumping and line-out jumping are examples of a long, or slow, SSC action and are shown here to be measured reliably via the ESM jump mat. A short, which is also known as a fast, SSC action lasts 100–250 milliseconds (19) and is evident in DJs. It is clear that the reduced CT associated with DJ in this study is not detected or measured with certainty by the ESM used here. A consequence of use of a cheaper, portable device such as the ESM seems to be that certain parameters within the DJ are not as well reproduced as with a force platform. Schmidtbleicher (19) commented that a short amortization phase is required for the subsequent concentric contraction to harness the advantages of stored elastic energy and the stretch reflex. Specifically, Schmidtbleicher (19) noted that, for a DJ, the effect is doubtful if the ground contact phase lasts too long. It is recommended that the athlete be instructed by the coach to consciously pretend that he or she will be landing on a hot plate (19). Anderson (1) commented that SSC effectiveness is influenced by the time lag between the eccentric and concentric phases. Consequently, for an effective SSC function, minimizing ground CT is important. Thus, the development of a fast SSC function leading to power and speed gains in the athlete by the strength coach via DJ protocols must inherently reduce ground CT. Caution therefore must be exercised if the coach wishes to use a portable jump mat (ESM) to measure small changes in an athlete's and players' drop jumping performance.

Overall, the commonly used jump mat (FLS JumpMat) tested in this study gave valid results of the vertical jump CMJ and SJ tests when compared with a ground mounted strain gauge force platform (AMTI OR6-5). This has implications for the strength and conditioning coach in that they can confidently test their athletes in the field from some jump protocols, thus avoiding bringing the athletes to the laboratory when relatively simple measures such as HJ and RSI are required. The jump mat may also be a useful resource for researchers carrying out large-scale investigations with a large number of subjects because the ESM will save time in information processing and experimental setup. However the ESM is not without its limitations, such as the reduced amount of data produced and errors associated with DJ protocols.

Practical Applications

Jump performance feedback that is provided by the ESM will enhance the quality of the training stimulus gained from SSC exercises. The results from this study suggest the ESM is an accurate device to measure slow SSC function (CMJ and SJ). Strength and speed coaches can confidently use such a jump mat in their daily and seasonal training sessions for CMJ and SJ protocols, assessing slow SSC and power development in their athletes. It is not, however, without its limitations compared with the FP in that it yields reduced amounts of data and errors associated with fast SSC (DJ) assessment. Some degree of caution is required when assessing small changes in jumping performance.

Overall, strength and conditioning coaches can confidently test their athletes' slow SSC function in the field, thus enhancing the quality of the jump performance and training stimulus. The ESM is a valid alternative to FP assessment in the laboratory and can thus be a useful resource for researchers conducting large-scale investigations with a large number of subjects. This study highlights the fact that the ESM can be a valid SSC assessment tool for both strength and conditioning coaches and researchers.

Acknowledgments

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