Concurrent validity of the FSL JumpMat for assessing leg extensor muscle function under stretch-shortening cycle conditions

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Abstract

The force plate has been the most commonly used device to assess leg extensor muscle function under stretch-shortening cycle conditions and is regarded as the gold standard in the measurement of vertical jump performance. Nonetheless, the cost and technical complexities of such a device precludes its routine use within many sporting environments spawning the development of many proposed alternatives. However, of these alternatives only contact mat devices can assess the full spectrum of muscle function due to their ability to quantify both jump height and ground contact time. PURPOSE: To determine the concurrent validity of the FSL JumpMat using a force plate as a criterion reference. METHODS: Four men (body mass 74.4±10.7 kg), competing in power sports (athletics, basketball, rugby) performed ten squat (SJ), countermovement (CMJ) and drop jumps (DJ) on the contact mat which was placed on a force plate. A force threshold of 5N was used to determine flight and contact phases. To ensure that measurements were not influenced by the weight of the contact mat the force plate was zeroed with the contact mat placed on the force plate. Flight time was used to quantify jump height using standard methods and the reactive strength index (RSI) was calculated as jump height divided by contact time. To examine the validity of the FSL JumpMat, the method of comparison as described by Bland and Altman was used. Differences were calculated by subtracting force plate measurements from those of the FSL JumpMat. RESULTS: Systematic bias was evident for all measures of jump performance ($p<0.01$), namely jump height and RSI. The existence of non-significant correlations ($p>0.05$) between the absolute differences in jump height and the means revealed no evidence of heteroscedasticity for both SJ and CMJ. The resulting error interval was 1.93±1.87 cm and 1.92±2.09 cm for SJ and CMJ heights, respectively. A significant correlation ($r=0.44$; $p<0.01$) between the absolute differences in RSI and the means revealed evidence of heteroscedasticity. Therefore, the differences in RSI were expressed as a percentage of the mean and revealed no further evidence of heteroscedasticity. The resulting error interval was 12.5±7.1 %. CONCLUSIONS: The results from the FSL JumpMat cannot be compared directly with other similar devices or used interchangeably with force plate measurements due to the significant bias evident. The bias may partially be explained by a lower sensitivity to force in the portable device when compared to a force plate. The measurement precision established for the portable device should be carefully considered when interpreting changes in vertical jump performance. PRACTICAL APPLICATIONS: The FSL JumpMat can be recommended to monitor adaptations to training in vertical jump performance as it possesses high applicability within field based sports testing. Changes in performance should be considered in absolute terms for SJ and CMJ whereas it is strongly advised that changes in DJ performance be expressed in relative terms as a percentage to account for the heteroscedasticity revealed in RSI.

Introduction

The stretch-shortening cycle (SSC) is a natural type of muscle function that involves a combination of eccentric and concentric contractions (Komi, 1984; Norman & Komi, 1979). The SSC has a well recognized purpose of augmenting performance during the final concentric phase when compared to an isolated concentric contraction (Komi, 2000). According to Schmidtbleicher (1992), the SSC as utilized in many sports can be classified as either long (>250 ms, e.g. basketball jump shot) or short (<250 ms, e.g. long jump takeoff). Furthermore, long and short SSC movements can be considered relatively independent motor qualities which has obvious implications for both the testing and training of athletes (Schmidtbleicher, 1992; W. B. Young, Pryor, & Wilson, 1995).

The production of force in many sporting activities such as sprinting and jumping involves rapid hip, knee and ankle extension thus highlighting the importance of leg extensor muscle function under SSC conditions (Bosco & Komi, 1982; W. Young, 1995). Although many assessment options have been proposed over the past three decades, the protocol introduced by Asmussen & Bonde-Petersen (1974) has been extensively used (Komi, 1984; Markovic, Dizdar, Jukic, & Cardinale, 2004; W. Young, 1995). The protocol consists of vertical jumping from three different starting positions: squat, countermovement and drop jump. The widespread use of these tests can be attributed to their ability to differentiate between the types of muscle function (e.g. pre-stretch augmentation and stretch load tolerance) and thus provide diagnostic information that may better inform training interventions (McGuigan et al., 2006; W. B. Young, Wilson, & Byrne, 1999).

The force plate has been the most commonly used device to assess leg extensor muscle function under SSC conditions within the discipline of sports science and is regarded as the gold standard in the measurement of vertical jump performance (Asmussen & Bonde-Petersen, 1974; Hori et al., 2009; Komi, 1984; Sayers, Harackiewicz, Harman, Frykman, & Rosenstein, 1999). Nonetheless, the cost and technical complexities of such a device precludes its routine use within many sporting environments spawning the development of suitable alternatives (Cronin, Hing, & McNair, 2004). Many portable and relatively cheap devices have been proposed such as jump and reach scales (Sargent, 1921), rotary encoder belts (Klavora, 2000) and contact mats (Bosco, Luhtanen, & Komi, 1983). However, only contact mat devices can assess the full spectrum of leg extensor muscle function under SSC conditions due to their ability to quantify both jump height and ground contact time.

Contact mat devices are used routinely in research projects and within many sporting institutions (Enoksen, Tonnessen, & Shalfawi, 2009; Hennessy & Kilty, 2001). One of the most commonly used contact mat devices to assess vertical jump performance is the FSL JumpMat (Allison, Bailey, & Folland, 2008; Rodacki, Fowler, & Bennett, 2001). Nevertheless, the validity of the measurements obtained from this device have yet to be demonstrated with some authors suggesting the hardware and software used in many contact mat devices may introduce unacceptable margins of error (Garcia-Lopez et al., 2005; Kibele, 1998). Furthermore, previous studies that have investigated the validity of such devices can be criticized for the statistical techniques adopted (Bland & Altman, 1986; Nevill & Atkinson, 1997). These techniques have included Pearson's correlation coefficients, paired *t*-tests, and repeated measures ANOVA (Aragon, 2000; Garcia-Lopez et al., 2005; Leard et al., 2007; Rodacki et al., 2001; W. B. Young et al., 1995). An alternative statistical technique based on the differences between the measurements of the two methods has been proposed which allows the sports scientist to make an informed decision regarding the acceptability of the bias and limits of agreement (Bland & Altman, 1986). Therefore, the purpose of the present study was to determine the concurrent validity of the FSL JumpMat using a force plate as a criterion reference.

Methods

Subjects

Four healthy male subjects (age 20.5 ± 0.5 yrs; body mass 74.4 ± 10.7 kg; height 177.2 ± 10.3 cm) were recruited to complete the study using a convenience sample. All subjects were required to be physically active and involved in jumping related sports such as athletics, volleyball, and various football codes. The study conformed to the policy statement of the American College of Sports Medicine (1998) for research involving human subjects that requires subjects to give free and informed voluntary consent prior to participation.

Instrument

The FSL JumpMat (FSL, Cookstown, UK) consists of a hand held electronic timer connected to a contact mat (Tapeswitch Signal Mat, model CVP 1723, Tapeswitch, Farmingdale, NY) with dimensions of 584 x 432 x 2 mm. The system resolution is 1000Hz with a threshold for operation of 5lbs. Jump height is calculated from the formula: $h = g \cdot t^2/8$ (where h is the jump height in metres; g is gravitation acceleration [9.81 $m \cdot s^{-2}$]; t is the flight time in seconds) (Bosco et al., 1983). The reactive strength index (RSI) is calculated as jump height divided by contact time (W. Young, 1995).

Test Procedure

The contact mat was placed on a force plate (Kistler type 9281B, Winterthur, Switzerland) that was connected to an amplifier system (Kistler type 9865A, Winterthur, Switzerland) to simultaneously measure flight and contact times with both systems. The force plate had a time resolution of 1000Hz, a force resolution of 0.1N and a force threshold of 5N was used to determine flight and contact phases (Garcia-Lopez et al., 2005). To ensure that measurements were not be influenced by the weight of the contact mat the force plate was zeroed with the contact mat placed on the force plate.

The jump testing procedure was preceded by a 10 minute warm-up period that consisted of 5 minutes of self-paced cycling on an electronically braked ergometer (SECA, Cardiotest 100, Hamburg, Germany), followed by light callisthenics and the execution of five sub-maximal efforts in the following order: squat jumps, countermovement jumps, and drop jumps. In all jumping tests outlined, the subjects were required to land on the same point as takeoff and rebound with straight legs when landing in order to avoid knee bending and subsequent alterations in measurements (Markovic et al., 2004). The hands were kept on the hips throughout the tests. Each test was measured with ten trials per subject giving a total of 40 pairs, providing an adequate sample size to extrapolate the data to a given population (Altman, 1991). A rest period of 30 seconds and 1 minute was used between trials and tests respectively.

The squat jump was performed from an erect stance with the subject lowering into a semi-squatting position to a knee angle of approximately 90°, holding the position for a period of 4 seconds, and then jumping. The imposed delay was deemed sufficient to ensure that the movement was performed without any augmentation from the prior stretch (Wilson, Elliott, & Wood, 1991). Trunk flexion and extension were kept to a minimum and subjects were instructed to attain a maximal jumping height (Bosco & Komi, 1979; Komi & Bosco, 1978). A trial was only accepted if no sinking or countermovement from the start position occurred. The countermovement jump was performed under the same conditions as the squat jump with the exception that the subjects were allowed to perform a rapid countermovement prior to jumping. The drop jump was performed from a box height of 30 cm and upon landing the subjects were instructed to jump in an effort to maximise the jump height/contact index. Performance feedback was provided after each trial, this is considered essential to enable the subject to determine the optimum combination of height and time (W. B. Young et al., 1995; W. B. Young et al., 1999).

Statistical Analysis

The normal distribution of all the data was tested using with a Shapiro-Wilk test. Bland-Altman plots were generated to provide a visual representation of heteroscedasticity by plotting the individual differences between the two methods against the mean of the two devices. A paired *t*-test was used to identify systematic bias. A Pearson's correlation coefficient was calculated to assess whether the differences have a tendency to either increase or decrease in magnitude as jump performance increases (Bland & Altman, 1986; Lamb, 1998; Nevill & Atkinson, 1997). If heteroscedasticity between the absolute individual differences and the mean of the two devices was evident then a percent *y* scale was used as recommended by Pollock (1992). The level of agreement between the two devices was calculated as

1.96 times the standard deviation of the differences between the two devices. Statistical significance was set at $p < 0.05$.

Results

Bland-Altman plots with bias and limits of agreement between the FSL JumpMat and force plate for jump heights are illustrated in Figures 1 and 2. Paired *t*-tests proved that the bias for both squat and countermovement jump heights were statistically significant ($p < 0.01$). The existence of non-significant correlations ($p > 0.05$) between the absolute differences and the means revealed no evidence of heteroscedasticity both the squat and countermovement jump. The resulting error interval was calculated to be 1.93 ± 1.87 cm and 1.92 ± 2.09 cm for squat and countermovement jump heights, respectively.

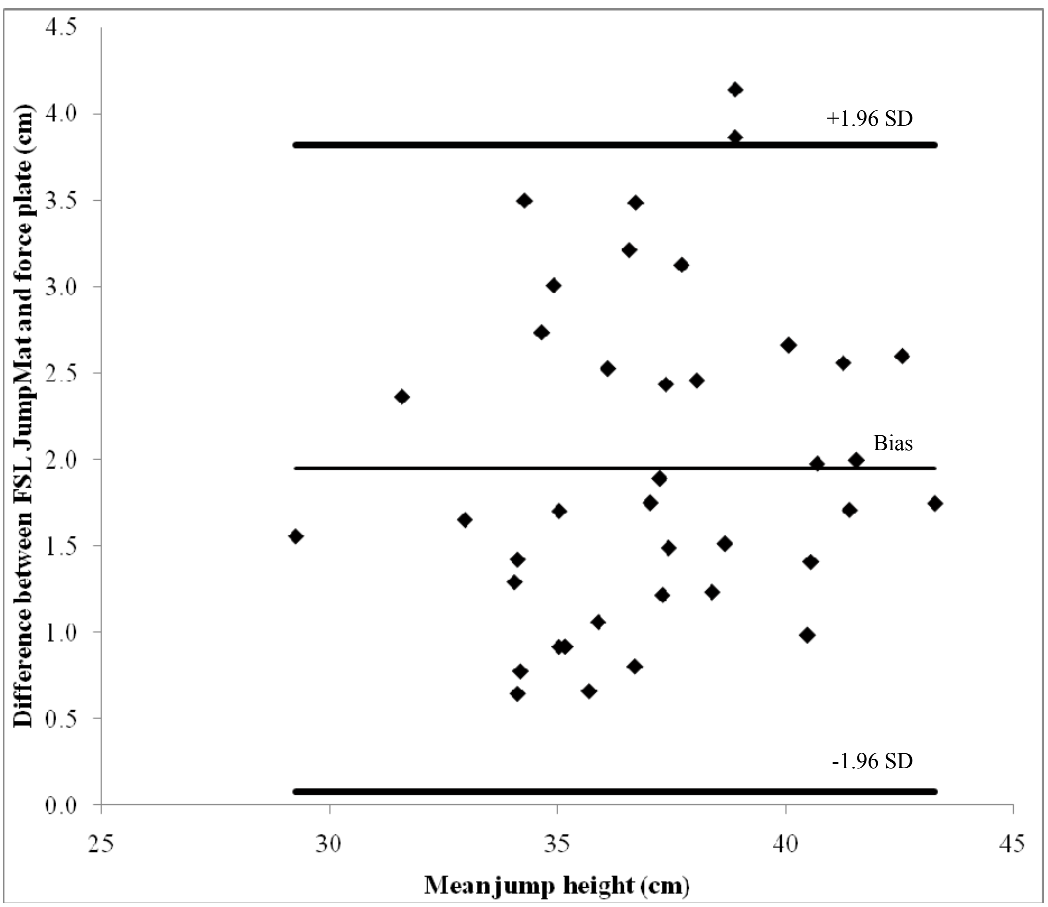

Figure 1. Bland-Altman plot with bias and limits of agreement between the FSL JumpMat and force plate for squat jump height. Thin solid line represents the systematic bias; thick solid lines represent 95% limits of agreement.

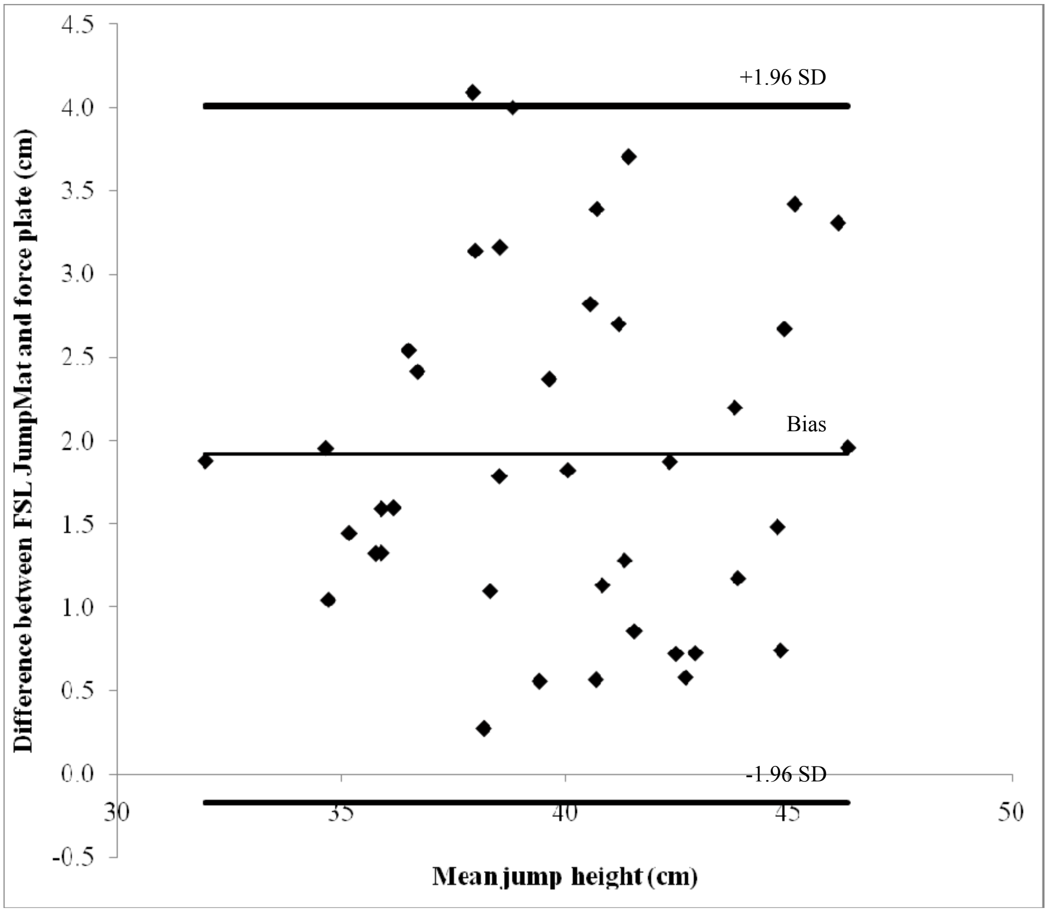

Figure 2. Bland-Altman plot with bias and limits of agreement between the FSL JumpMat and force plate for countermovement jump height. Thin solid line represents the systematic bias; thick solid lines represent 95% limits of agreement.

A paired *t*-test proved that the systematic bias was statistically significant for the RSI ($p < 0.01$). The existence of a significant correlation ($r = 0.44$; $p < 0.01$) between the absolute differences in RSI and the means revealed evidence of heteroscedasticity. Therefore, a percent *y* scale was used to display the data. The existence of non-significant correlation ($p > 0.05$) between the relative differences and the means revealed no further evidence of heteroscedasticity. A Bland-Altman plot with bias and limits of agreement between the FSL JumpMat and force plate for RSI is illustrated in Figure 3. The resulting error interval was calculated be 12.5 ± 7.1 %.

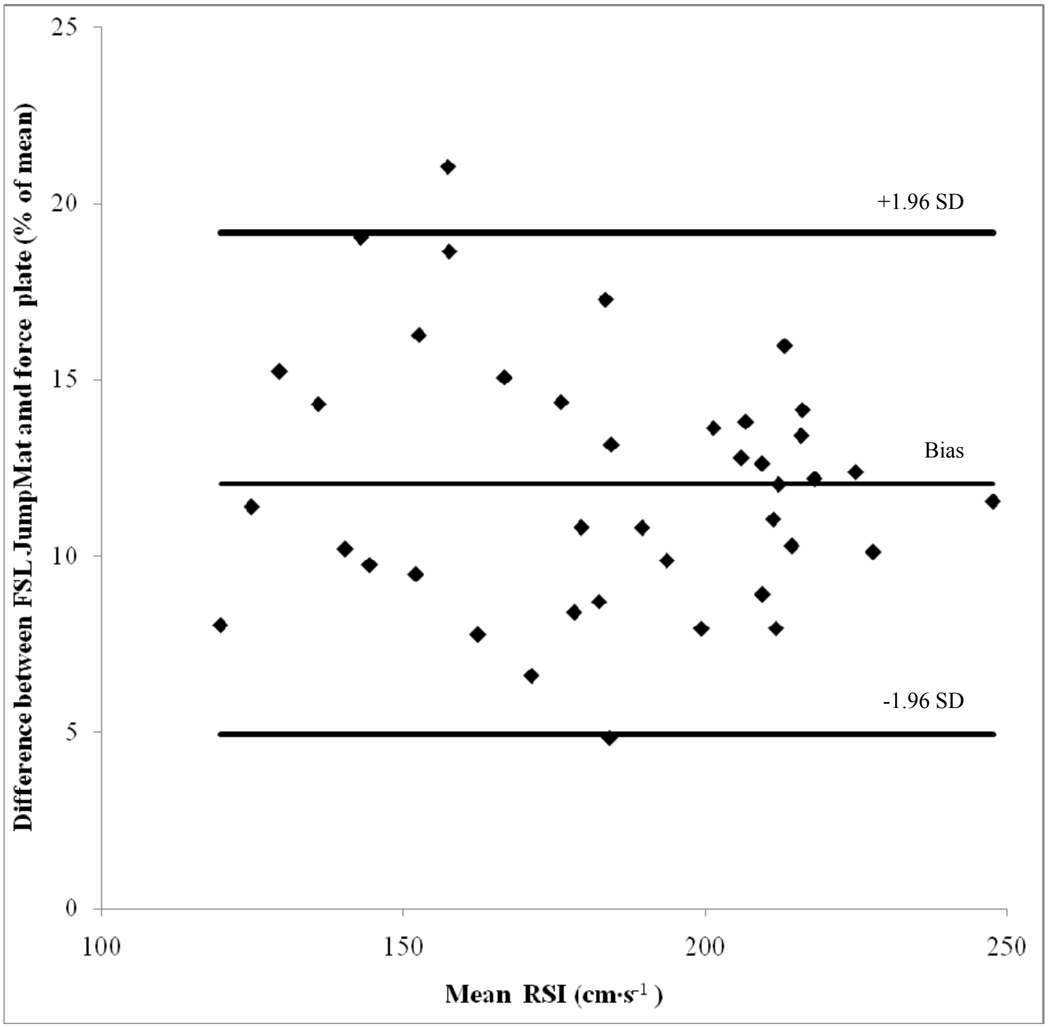

Figure 3. Bland-Altman plot with bias and limits of agreement between the FSL JumpMat and forceplate for reactive strength index. Thin solid line represents the systematic bias; thick solid lines represent 95% limits of agreement.

Discussion

It has been previously stated that estimates of jump height from flight time introduces errors because the takeoff and landing positions are different (Garcia-Lopez et al., 2005; Kibele, 1998). However the validity of the measurements obtained from contact mat devices has rarely been completed. Furthermore, previous studies that have investigated the validity of such devices can be criticized for the statistical techniques adopted (Bland & Altman, 1986; Nevill & Atkinson, 1997). The first objective of this study was therefore to compare measures of vertical jumping performance obtained using a force plate with the corresponding values obtained using the FSL JumpMat. It has been previously shown that the errors associated with the force plate are considered negligible and therefore its use as a criterion method is certainly justifiable (Hatze, 1998).

Paired *t*-tests showed significant systematic bias for all measures of jump performance ($p < 0.05$), and as such the results from each device cannot be used interchangeably. These results are in accordance with similar previous studies that have shown contact mat devices to significantly underestimate ground contact time (W. B. Young et al., 1995) and overestimate jump height (Enoksen et al., 2009; Garcia-Lopez et al., 2005) when compared to force plates. It has been proposed that the measurement errors may partially be explained by a lower sensitivity to force when compared to the force plate (W. B. Young et al., 1995). In essence, a slight delay occurs before a threshold is reached to trigger the start of the ground contact phase and similarly a threshold is reached early in the latter phases prior to takeoff when jumping vertically. However, adjusting the force plate threshold to determine flight and contact phases to 25N will still result in significant systematic bias ($p < 0.01$) with an error interval of 1.38 ± 1.96 cm for countermovement jump heights for example, based on retrospective investigation of the data. Additionally it has been demonstrated that increased body mass is related to smaller measurement errors relative to those from a force plate, which it has been proposed is due to high rates of loading and unloading (Garcia-Lopez et al., 2005). It should be noted however that such loading and unloading is mainly dependent on the individual jumping technique adopted which is clearly unrelated to body mass (Garcia-Lopez et al., 2005).

The systematic bias evident for all measures of jump performance may warrant the development of linear regression equations as is commonly done for field tests of percentage body fat (Williams & Bale, 1998). However, the systematic bias inherent in the FSL JumpMat is common among similar contact mats (Enoksen et al., 2009; Garcia-Lopez et al., 2005) and certainly in other field tests used within many sporting settings (Ramsbottom, Brewer, & Williams, 1988). Therefore, the sports scientist should not be overly concerned with generating regression equations to correct for any bias but should focus on the precision of the measurements made by equipment that is readily available for use in a practical field setting. When we consider the precision of the measurement for the heights obtained during squat and countermovement jumps (± 1.87 cm and ± 2.09 cm), it is apparent that they are of a magnitude that makes the FSL JumpMat a viable alternative to a force plate when working in a field based setting. Training interventions over a period of months are likely to result in elevations in jump capacity of 4-10 cm (Bobbert, 1990), which could easily be measured during a fitness testing session with an athlete using the FSL JumpMat. However, it should be noted that some degree of caution is required when measuring acute changes in the neuromuscular system as the magnitude of change will be quite small (≈1-3cm) (Oliver, Armstrong, & Williams, 2008) and may therefore be beyond the precision demonstrated by the FSL JumpMat.

The existence of heteroscedasticity ($r = 0.44$; $p < 0.01$) between the absolute differences in RSI and the means suggest it may be prudent to consider changes in drop jump performance in relative terms expressed as a percentage. Although only one training study has been published looking at RSI (W. B. Young et al., 1999), the specific training adaptations (30cm drop jump) are once again of a magnitude that could easily be measured using the FSL JumpMat (41 $cm \cdot s^{-1}$ or 21%). Again caution should be taken when looking at small changes that result from short term fatigue although no published data is available to provide direction with regard to this suggestion.

Conclusion

The FSL JumpMat can be recommended to monitor training adaptations in vertical jumping capacity based on flight and contact time measurements. The results from this investigation reveal that the FSL JumpMat is a relatively precise testing device. However, the significant difference between the FSL JumpMat and the force plate measurement highlights the importance of using the same equipment when comparison is intended or required. The lightweight portability of the device is advantageous as it possess high applicability within field based sports testing.

References

American College of Sports Medicine (1998). Policy statement regarding the use of human subjects and informed consent. *Medicine and Science in Sports and Exercise, 30*(7).

Allison, S. J., Bailey, D. M., & Folland, J. P. (2008). Prolonged static stretching does not influence running economy despite changes in neuromuscular function. *Journal of Sports Sciences, 26*(14), 1489-1495.

Altman, D. G. (1991). *Practical statistics for medical research* (1st ed.). London: Chapman and Hall.

Aragon, L. F. (2000). Evaluation of four vertical jump tests: methodology, reliability, validity, and accuracy. *Measurement in Physical Education and Exercise Science, 4*(4), 215 - 228.

Asmussen, E., & Bonde-Petersen, F. (1974). Storage of elastic energy in skeletal muscles in man. *Acta Physiologica Scandinavica, 91*(3), 385-392.

Bland, J. M., & Altman, D. G. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet, 1*(8476), 307-310.

Bobbert, M. F. (1990). Drop jumping as a method for jumping ability *Sports Medicine, 9*(1), 7-22.

Bosco, C., & Komi, P. V. (1979). Potentiation of the mechanical behavior of the human skeletal muscle through prestretching. *Acta Physiologica Scandinavica, 106*(4), 467-472.

Bosco, C., & Komi, P. V. (1982). Muscle elasticity in athletes. In P. V. Komi (Ed.), *Exercise and Sport Biology* (Vol. 12, pp. 109-117). Champaign, Ill.: Human Kinetics Publishers.

Bosco, C., Luhtanen, P., & Komi, P. V. (1983). A simple method for measurement of mechanical power in jumping. *European Journal of Applied Physiology and Occupational Physiology, 50*(2), 273-282.

Cronin, J. B., Hing, R. D., & McNair, P. J. (2004). Reliability and validity of a linear position transducer for measuring jump performance. *Journal of Strength and Conditioning Research, 18*(3), 590-593.

Enoksen, E., Tonnessen, E., & Shalfawi, S. (2009). Validity and reliability of the Newtest Powertimer 300-series (R) testing system. *Journal of Sports Sciences, 27*(1), 77-84.

Garcia-Lopez, J., Peleteiro, J., Rodgriguez-Marroyo, J. A., Morante, J. C., Herrero, J. A., & Villa, J. G. (2005). The validation of a new method that measures contact and flight times during vertical jump. *International Journal of Sports Medicine, 26*(4), 294-302.

Hatze, H. (1998). Validity and reliability of methods for testing vertical jumping performance. *Journal of Applied Biomechanics, 14*(2), 127-140.

Hennessy, L., & Kilty, J. (2001). Relationship of the stretch-shortening cycle to sprint performance in trained female athletes. *Journal of Strength and Conditioning Research, 15*(3), 326.

Hori, N., Newton, R. U., Kawamori, N., McGuigan, M. R., Kraemer, W. J., & Nosaka, K. (2009). Reliability of performance measurements derived from ground reaction force data during countermovement jump and the influence of sampling frequency. *Journal of Strength and Conditioning Research, 23*(3), 874-882.

Kibele, A. (1998). Possibilities and limitations in the biomechanical analysis of countermovement jumps: A methodological study. *Journal of Applied Biomechanics, 14*(1), 105-117.

Klavora, P. (2000). Vertical-jump tests: A critical review. *Strength and Conditioning Journal, 22*(5), 70-74.

Komi, P. V. (1984). Physiological and biomechanical correlates of muscle function: effects of muscle structure and stretch-shortening cycle on force and speed. *Exercise and Sport Sciences Reviews, 12*, 81-121.

Komi, P. V. (2000). Stretch-shortening cycle: a powerful model to study normal and fatigued muscle. *Journal of Biomechanics, 33*(10), 1197.

Komi, P. V., & Bosco, C. (1978). Utilization of stored elastic energy in leg extensor muscles by men and women. *Medicine and Science in Sports and Exercise, 10*(4), 261-265.

Lamb, K. L. (1998). Test-retest reliability analysis in quantitiative physical education research : a commentary. *European Physical Education Review, 4*, 145-152.

Leard, J. S., Cirillo, M. A., Katsnelson, E., Kimiatek, D. A., Miller, T. W., Trebincevic, K., et al. (2007). Validity of two alternative systems for measuring vertical jump height. *Journal of Strength and Conditioning Research, 21*(4), 1296-1299.

Markovic, G., Dizdar, D., Jukic, I., & Cardinale, M. (2004). Reliability and factorial validity of squat and counter movement jump tests. *Journal of Strength and Conditioning Research, 18*(3), 551-555.

McGuigan, M. R., Doyle, T. L. A., Newton, M., Edwards, D. J., Nimphius, S., & Newton, R. U. (2006). Eccentric utilization ratio: Effect of sport and phase of training. *Journal of Strength and Conditioning Research, 20*(4), 992.

Nevill, A. M., & Atkinson, G. (1997). Assessing agreement between measurements recorded on a ratio scale in sports medicine and sports science. *British Journal of Sports Medicine, 31*(4), 314-318.

Norman, R. W., & Komi, P. V. (1979). Electro-mechanical delay in skeletal muscle under normal movement conditions. *Acta Physiologica Scandinavica, 106*(3), 241.

Oliver, J., Armstrong, N., & Williams, C. (2008). Changes in jump performance and muscle activity following soccer-specific exercise. *Journal of Sports Sciences, 26*(2), 141-148.

Pollock, M. A., Jefferson, S. G., Kane, J. W., Lomax, K., Mackinnon, G., & Winnard, C. B. (1992). Method comparison - a different approach. *Annals of Clinical Biochemistry, 29*, 556-560.

Ramsbottom, R., Brewer, J., & Williams, C. (1988). A progressive shuttle run test to estimate maximal oxygen uptake. *Br J Sports Med, 22*(4), 141-144.

Rodacki, A. L. F., Fowler, N. E., & Bennett, S. J. (2001). Multi-segment coordination: fatigue effects. *Medicine and Science in Sports and Exercise, 33*(7), 1157-1167.

Sargent, D. A. (1921). Physical test of man. *American Physical Review 62*, 188.

Sayers, S. P., Harackiewicz, D. V., Harman, E. A., Frykman, P. N., & Rosenstein, M. T. (1999). Cross-validation of three jump power equations. *Medicine and Science in Sports and Exercise, 31*(4), 572-577.

Schmidtbleicher, D. (1992). Training for power events. In P. V. Komi (Ed.), *Strength and power in sport* (pp. 381-394). Oxford: Blackwell Scientific Publications.

Williams, C. A., & Bale, P. (1998). Bias and limits of agreement between hydrodensitometry, bioelectrical impedance and skinfold calipers measures of percentage body fat. *European Journal of Applied Physiology and Occupational Physiology, 77*(3), 271-277.

Wilson, G. J., Elliott, B. C., & Wood, G. A. (1991). The effect on performance of imposing a delay during a stretch-shorten cycle movement. *Medicine and Science in Sports and Exercise, 23*(3), 364-370.

Young, W. (1995). Laboratory strength assessment of athletes. *New Studies in Athletics, 10*(1), 89-96.

Young, W. B., Pryor, J. F., & Wilson, G. J. (1995). Effect of instructions on characteristics of countermovement and drop jump performance. *Journal of Strength and Conditioning Research, 9*(4), 232-236.

Young, W. B., Wilson, G. J., & Byrne, C. (1999). A comparison of drop jump training methods: Effects on leg extensor strength qualities and jumping performance. *International Journal of Sports Medicine, 20*(5), 295-303.