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Submission type: Original investigation

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Running head: Validation of systems for CMJ

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Abstract

Countermovement jump (CMJ) height is an important parameter in physical performance. This study compared CMJ height measured using ChronoJump contact mat (CJ), and Myotest accelerometer (MT) systems with a force platform (FP). Thirty recreationally-active adults (32.1 ± 10.4 years, 75.9 ± 12.0 kg, 173.2 ± 6.3 cm) completed a CMJ protocol where height was simultaneously recorded using the three systems. CJ and MT measures were strongly and significant correlated ($r = 0.65, 0.66$, respectively; $p < 0.05$) with FP. CJ-derived measures were not significantly different to FP measures ($p > 0.05$), yet MT-derived measures were significantly different from those obtained using the FP ($p < 0.05$). Systematic bias was observed between FP and the CJ and between FP and MT. This study demonstrate the validity of CJ and MT systems for the assessment of CMJ height. Systematic bias and between-device differences in measurement should be considered when interpreting and comparing data from these devices.

Keywords: accelerometry; countermovement jump; performance; force plate

Introduction

Assessment of lower limb functional performance is important in athletic, and non-athletic populations. A commonly used measure of lower limb functional performance is the countermovement jump (CMJ) (Comfort, Stewart, Bloom, & Clarkson, 2014; Fernandez-Santos, Ruiz, Cohen, Gonzalez-Montesinos, & Castro-Pinero, 2015; Holsgaard Larsen, Caserotti, Puggaard, & Aagaard, 2007; Janot, Beltz, & Dalleck, 2015; Rittweger, Schiessl, Felsenberg, & Runge, 2004), which relies on the ability of the lower limb muscle groups to elevate the body's centre of gravity, and is considered a measure of lower body power (Shetty & Etnyre, 1989). Among athletic populations, there is a strong association between CMJ performance and high-intensity efforts in sports such as sprinting (West et al., 2011; Wisloff, Castagna, Helgerud, Jones, & Hoff, 2004) and weightlifting (Carlock et al., 2004). Furthermore, CMJ performance is used as a screening tool to monitor neuromuscular fatigue (Gathercole, Sporer, Stellingwerff, & Sleivert, 2015), to monitor performance improvements following training interventions (Garcia-Pinillos, Soto-Hermoso, & Latorre-Roman, 2015), and to differentiate between elite and non-elite athletes (Gabbett, 2002). CMJ performance has also been used to assess functional capacity in older adults (Holsgaard Larsen et al., 2007; Rittweger et al., 2004). Given the associations with functional performance in a variety of populations, valid and reliable measures of CMJ which can be used in field or clinical settings are important.

In general, force platforms are considered the gold-standard instrument for assessment of CMJ performance characteristics (Mauch et al, 2014). However, due to their high cost, their use is frequently limited to research centres, elite sports facilities, or academies and institutes of sport. Coaches and clinicians working in the field seek instruments that provide valid and reliable measure of CMJ performance, without the cost and complexity associated with laboratory- or elite sport-based tools. In response to this need, and with the emergence of novel technologies, a number of portable devices are now available to assess CMJ height including contact mats (Pagaduan & De Blas, 2004), photoelectric cells (Bosquet, Berryman, & Dupuy, 2009), smart phone applications (Balsalobre-Fernández, Glaister, & Lockey, 2015) and accelerometric systems (Casartelli, Muller, & Maffiuletti, 2010). Among these devices, the Myotest (Myotest SA, Sion, Switzerland) (MT) and ChronoJump (Bosco Systems, Madrid, Spain) (CJ) are among the options available to field based practitioners.

The MT uses an accelerometer which is attached at waist level via a purpose built Velcro belt (Casartelli et al., 2010; Castagna et al., 2013; Choukou, Laffaye, & Taiar, 2014). The MT calculates CMJ height based on the acceleration of the centre of mass during the vertical displacement (Castagna et al., 2013). Previous research examining the validity (Casartelli et al., 2010; Choukou et al., 2014) and reliability (Choukou et al., 2014) of the MT has resulted in variable outcomes, dependant on the comparator, and the model of Myotest device. In contrast to the accelerometer-based MT, the CJ system consists of a contact mat and timing device, which calculates CMJ height from flight time, using standard equations (de Blas, Riu, del Amo, & Bálic, 2012; Pagaduan & De Blas, 2004). De Blas and colleagues (2012) describe the development and validity of the CJ to assess flight time, using a fibreglass contact mat. However, like the MT, studies examining the validity of contact mat systems are dependent on the type of mat and comparator device (García-López, Morante, Ogueta-Alday, & Rodríguez-Marroyo, 2013). Data such as these make it difficult to confirm the usefulness of portable devices such as MT and CJ to determine CMJ performance, and subsequently make recommendations to clinicians and coaches.

One method to directly compare devices with the gold-standard FP, is to perform CMJs on a FP overlayed with a contact mat system, while the performer wears the MJ accelerometer. Such a study would allow direct, simultaneous comparison of both devices with the FP and therefore provide useful information to coaches as clinicians as to the suitability of each device for use in the field. Therefore the aim of the present study was to compare the CMJ height obtained from the MT and CJ compared to a gold-standard force platform in a broader population.

Methods

Subjects

Thirty recreationally active adults from the University community were recruited via face to face contact. For the purpose of the present study, recreationally active was defined as having been engaged in regular sport or recreational activities for a minimum of 12 months prior to inclusion in the study. An overview of the study outlining the purpose, and the potential risks and benefits of participation was provided to all subjects. All subjects were screened for injury and health concerns that may have impeded study participation using Stage 1 of the Adult Pre-exercise Screening System (APSS) (ESSA, 2011) prior to participation, and written informed consent was obtained from all subjects. The study was approved by the Institutional Human Research Ethics Review panel prior to the commencement of the study.

Design

A cross sectional, comparative design was used. CMJ performance (jump height) was simultaneously assessed using CJ and MT, with both methods compared to the FP. For the CJ and FP, CMJ performance was determined from flight time using the following equation; $h = t^2 \times 1.22625$ (Bosco, Luhtanen, & Komi, 1983). For the MT, CMJ height was determined using proprietary software. To ensure the generalisability of our findings, a convenience sample from the local University community was used as subjects.

Methodology

Following assessment of body mass and height, subjects completed a standardised warm-up protocol comprising 5-minutes cycling at 50W on a Monark 828e cycle ergometer (Monark Exercise AB, Vansbro, Sweden), followed by 5-minutes of static and dynamic stretching of the quadriceps, hamstrings and gastrocnemius/soleus muscles. Subjects then performed three CMJ attempts, separated by 60 seconds rest, which acted as familiarisation attempts. For each of the three warm up attempts, the intensity increased with each attempt until maximal effort was exerted on the final attempt of the warm-up. For the final warm up, and for each testing attempt, subjects were instructed to stand erect, with the feet placed shoulder width apart. Commencing with the hands on the hips, the subject performed a partial squat to a self-determined depth, followed by a rapid amortisation phase and explosive concentric phase in attempt to maximise vertical displacement of the body. Following the completion of warm up attempts, two maximal effort trials were recorded and the mean of the two trials was used for subsequent analysis. Each attempt was visually inspected by a member of the research team to ensure correct technique and landing position. No repeat attempts were required for any participant.

Following a further 3-minute rest, subjects performed two maximal effort CMJ attempts, separated by 3-minute of passive (seated) rest. Subjects stood on an AMTI force plate (BP600900-1000, Advanced Mechanical Technology Incorporated, Watertown, MA), interfaced with an AMTI MSA-6 amplifier (Advanced Mechanical Technology Incorporated, Watertown, MA). Data were sampled at 1000Hz, filtered using a 2nd order low pass Butterworth filter with a cut-off frequency of 10Hz, and data were collected for 5 seconds using custom written Labview software (Version 2013, National Instruments, Austin, TX).

CMJ height was calculated from flight time using the following equation; $h = t^2 \times 1.22625$ (Bosco et al., 1983). This method shows strong correlation with a modified Wingate test ($r=0.87$) and 60m sprint ($r=0.86$). The force plate was zeroed prior to the participant standing on the force plate and flight time was defined as the time the vertical ground reaction force (vGRF) was below 10N (Linthorne, 2001).

The force plate was overlaid with a Din A2 (420 x 594 mm) sized contact mat (Bosco Systems, Madrid, Spain) connected to a Chronopic 3 timing interface (Bosco Systems, Madrid, Spain). Data were collected using Chronojump software (Version 1.6.1.0; Bosco Systems, Madrid, Spain). For this type of device, the contact mat operates as a simple on/off switch and triggers timing of the duration the switch is in the closed position such as when a participant is standing on the contact mat, or in the open position; for example when a participant is in the air as in the performance of a CMJ. Timing is based on the internal clock of the computer on which the software is installed.

For each CMJ attempt, subjects also wore a Myotest Pro accelerometer system (Myotest SA, Sion, Switzerland), secured over the subject’s right hip using the proprietary elasticized band in accordance with manufacturer’s instructions. The Myotest Pro is a small (54.2 x 10.7 x 102.5mm) light weight (59 g) device containing a triaxial accelerometer (± 8 g) which records acceleration at 500 Hz. Prior to use, the Myotest Pro was programed with the subjects height and weight using Myotest Pro software (Version 1.988, Myotest SA, Sion, Switzerland). For the Myotest Pro, CMJ height was determined using proprietary software. The exact method by which the MT determines CMJ height is unclear, however, Choukou and colleagues (2013) report flight time as the time between maximal vertical velocity and minimal vertical velocity after touchdown, which must in turn be derived from the integration of acceleration data.

Statistical analysis

Descriptive statistics (mean ± standard deviation (SD)) were used to report subject and jump characteristics. Normality was assessed by Kolmogorov-Smirnov test, and skewness and kurtosis z-scores. Pearson's correlations were used to independently examine the validity of the CJ and MT devices, and interpreted as 0.00-0.19 = very weak, 0.20 – 0.39 = weak, 0.40 – 0.59 = moderate, 0.60 – 0.79 = strong, and 0.80 – 1.00 = very strong (Evans, 1996). Fisher's r-z transformations were used to examine the significance of any difference between the correlation coefficients. Differences in mean CMJ performance between CJ and FP, and between MT and FP were examined using paired samples t-tests, with Bonferroni adjustments for multiple comparisons. The magnitude of difference between mean jump heights were also assessed using Cohen's d where $d > 0.8$ is a large effect, $d = 0.5 – 0.8$ is a moderate effect; $d = 0.2 – 0.5$ is a small effect; and $d < 0.2$ is a trivial effect (Cohen, 1988). Finally, agreement between CJ and FP, and between MT and FP were examined using Bland-Altman plots, with mean differences (systematic bias) calculated as FP – CJ and FP – MT, respectively. All statistical analyses were performed using Statistical Package for the Social Sciences (SPSS) Version 22 (IBM Corp, Armonk, NY). Bland Altman plots were constructed using Microsoft Excel 2013 (Microsoft Corp, Redmond, WA). Statistical significance (two-tailed) was set at an alpha level of 0.05.

Results

Thirty jump heights registered by each device were analysed. Mean jump heights were 20.96 ± 6.88 cm, 26.22 ± 6.96 cm, and 22.15 ± 6.13 cm for the CJ, MT and FP, respectively. Figure 1 shows a strong, statistically significant correlation between jump height derived from the CJ and FP ($r = 0.65$, $p < 0.01$). Paired samples t-test revealed no statistically significant difference between jump height derived from the CJ and FP ($t(29) = 1.19$; $p > 0.05$; $d = 0.18$, *trivial*). Bland Altman plot depicting limits of agreement between CJ and FP is shown in Figure 2. Compared to FP, CJ underestimates CMJ height by 1.18 ± 5.46 cm.

INSERT FIGURE 1 ABOUT HERE

INSERT FIGURE 2 ABOUT HERE

Figure 3 shows a strong, statistically significant correlation between jump height derived from the MT and FP ($r = 0.66$, $p < 0.01$). Paired samples t-test revealed a statistically significant difference between jump height derived from the MT and FP ($t(29) = 4.09$; $p < 0.001$; $d = 0.64$, *moderate*). Bland Altman plot depicting limits of agreement between MT and FP is shown in Figure 4. Compared to FP, MT overestimates CMJ height by 4.07 ± 5.45 cm. Fisher's r-z transformation revealed no statistically significant difference between the correlation between CJ and FP, and between MT and FP ($z = -0.06$, $p > 0.05$)

INSERT FIGURE 3 ABOUT HERE

INSERT FIGURE 4 ABOUT HERE

Discussion

The present study examined the validity of the ChronoJump contact mat and Myotest accelerometer system compared to a laboratory-based force platform for measuring CMJ height, in recreationally active males and females. The main findings of this study were that: (1) CMJ height derived from both CJ and MT was strongly and significantly correlated with FP-derived measures; (2) CJ derived measures of CMJ were not significantly different to FP-derived measures, but MT-derived measures were; and (3) MT overestimates CMJ height, whilst the CJ marginally underestimates CMJ height, compared to the FP.

The findings from the present study are in agreement with the those reported by Castagna and colleagues (Castagna et al., 2013) who found the difference between FP and an optical-based measure of flight time, to be small (d= 0.09), while differences between the MT and FP were moderate (d=0.54). Interestingly the present study, and that of Castagna and colleagues (2013), observed both a moderate effect size and larger systematic bias when using the MT, than a contact mat or optical timing system to assess CMJ height against a force platform. From a practical point of view, these results suggest the two systems provide different results, with the CJ measures of CMJ height closer to gold-standard values, and subsequently more accurate. In contrast, the MT appears to be affected by a greater systematic bias, which leads to an overestimation of CMJ height by approximately 4 cm.

In the present study, the Bland Altman plot show a systematic bias of -1.18 ± 6.87 cm in CMJ height between the CJ and FP. This data suggest good levels of agreement, which supports the validity of the CJ in measuring CMJ height when compared to the gold-standard. Previous studies comparing CMJ height measures using differing contact mats with force platforms (Enoksen, Tonnessen, & Shalfawi, 2009; García-López et al., 2013; Kenny & Comyns, 2012) and a 3-dimensional camera system (Leard et al., 2007) report mean differences ranging from -1.3 cm to 2.8 cm. The results of the present study compare favourably with Garcia-Lopez and colleagues (2013) who reported CMJ height was underestimated when using a contact mat compared to a force platform. In contrast, our results are in disagreement with the findings of Enoksen and colleagues (2009) who reported CMJ height was overestimated when comparing a contact mat with a force platform. As Buckthorpe and colleagues (2012) noted, the likely reason for discrepancies in CMJ height between contact mats and force platforms, is the methodology underpinning flight time and initial velocity measurement. When performing a CMJ on a contact mat, the timer starts when the subject leaves the ground, which may fail to capture the initial rise of the centre of mass before take-off. Furthermore, the flight time method assumes the take-off and landing positions will be identical, ensuring the duration of the ascending and descending phases of flight time are the same (Buckthorpe et al., 2012).In the present study, these discrepancies are evident by the presence of outliers. For example, Figure 1 shows one data point where CMJ height determined using the CJ was approximately 15cm, yet was approximately 34cm based on FP data. Such discrepancies may result from the use of a 10N threshold to determine contact times on the FP, the use of poor landing technique, or lack of reliability in CMJ performance. Taken together, these data may further explain the small systematic bias observed with the CJ and FP measures of CMJ height observed in the current study.

Similar to the CJ, the present study showed a strong significant correlation between MT and FP. However, mean jump heights were statistically significantly different. As observed in Figure 4, MT overestimated CMJ by 4.07 ± 6.96 cm. Previous studies have compared CMJ height assessed via MT, with both portable (Choukou et al., 2014; Mauch et al., 2014) and in-built force platforms (Monnet, Decatoire, & Lacouture, 2014), reporting mean differences between -1.09 to 4.8 cm. Similar to our findings, Monnet and colleagues (2014) reported a mean difference of 4.8 ± 6.90 cm when comparing CMJ height between the Myotest and a FP. The overestimation of CMJ height by the MT may be related to errors in flight time estimation (Choukou et al., 2014). Choukou and colleagues (2013) report that flight time is the time between maximal vertical velocity and minimal vertical velocity after touchdown. This equation cannot be verified from the device manual and to the best of our knowledge, no published study has fully described the known method for deriving flight time from accelometric data collected using the Myotest Pro device employed in the present study. Additionally, velocity is obtained from the integration of acceleration data and this mathematical manipulation may introduce errors magnified by downstream calculations, or as a result of variations in CMJ technique.

Alternatively, rotational effects on the MT, due to its placement on the hip may account for this overestimation, since any rotation of the pelvis during the CMJ will affect tracking of the body's centre of mass and thus its measurement of CMJ height (Mauch et al., 2014). Interestingly, Monnet and colleagues (2014) demonstrated a reduction in CMJ height bias from 4.8 ± 9.4cm to -1.3 ± 9.2cm after defining a new threshold to detect take-off and landing times. Thus, in the present study it is unclear if the measurement itself or the applied algorithm is producing the discrepancy in CMJ height. Nonetheless, this is a limitation that practitioners using the device need be aware of.

Another potential explanation for the finding of the present study may be the degree of sample homogeneity. The present study did not collect training age history as a demographic variable; rather, engaged recreationally active participants, operationalised as having been engaged in regular sport or recreational activities for a minimum of 12 months. Training history has recently been shown to affect the reliability of CMJ performance. Lombard and colleagues (2017) reported that reliability was greater for participants more accustomed to strength training. Therefore repeat testing is capable of detecting small differences in performance which may be clinically or functionally meaningful. Participants in the current study met the definition of 'trained' used by Lombard and colleagues (2017) based on training duration (>12 months), but not on training type (strength training specifically). Therefore replication of the present study in a more homogeneous athletic population may be warranted.

Practical applications

The present study compared CMJ performance using field measures (CJ and MT) with laboratory-based measures (FP) in a convenience sample of recreationally active University students. Results showed that the CJ is a valid, portable device to assess CMJ height.

Moreover, the differences between the CJ and FP were trivial considering the practical significance. In contrast, whilst the MT also demonstrates good validity, this device showed a moderate difference in CMJ height when compared to the FP. Despite these important findings, the confidence intervals are wide for both the CJ (12.10 – -9.73cm), and the MT (6.83 – -14.93 cm). Therefore the devices may lack the sensitivity to detect small changes in performance. Nonetheless, the use of the CJ in the present study offered several advantages for the assessment of CMJ height in the field, compared to the MT. These include lower purchase costs, reduced time to complete the test, and more rapid reporting of results. In addition, the software is free and open source, runs on multiple operating systems, and is available in multiple languages. Whilst the MT offers the advantage of being able to be used on a wider variety of surfaces, the significant overestimates of CMJ height, and the use of a Velcro belt to secure the MT unit to the subjects' hip reduces its potential usefulness. Collectively, this suggests the use of the MT for the rapid field evaluation of CMJ height may be limited compared to CJ. The results of the present study may have direct implications for strength and conditioning professionals, sport scientists and coaches who do not have direct access to performance laboratories.

Conclusions

Based on correlation coefficients, both the CJ and MT systems are valid instruments for the field assessment of CMJ height. However, CMJ height assessed using the MT is significantly different from that recorded using the FP. Additionally, the MT demonstrates greater systematic bias compared to the CJ. Because of these differences in measurement outcomes, coaches and clinicians should use caution when interpreting and comparing data from these devices. Users should be aware of systematic bias in both devices. To minimise bias and improve reliability, consistent measurement conditions including the use of the same device should be employed for all testing occasions.

References

Balsalobre-Fernández, C., Glaister, M., & Lockey, R. A. (2015). The validity and reliability of an iPhone app for measuring vertical jump performance. *Journal of Sports Science, 3*(15), 1574-1579. doi: 10.1080/02640414.2014.996184

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.

Bosquet, L., Berryman, N., & Dupuy, O. (2009). A comparison of 2 optical timing systems designed to measure flight time and contact time during jumping and hopping. *Journal of Strength and Conditioning Research, 23*(9), 2660-2665. doi: 10.1519/JSC.0b013e3181b1f4ff

Buckthorpe, M., Morris, J., & Folland, J. P. (2012). Validity of vertical jump measurement devices. *Journal of Sports Sciences, 30*(1), 63-69. doi: 10.1080/02640414.2011.624539

Carlock, L. M., Smith, S. L., Hartman, M. J., Morris, R. T., Ciroslan, D. A., Pierce, K. C., . . . Stone, M. H. (2004). The relationship between vertical jump power estimates and weightlifting ability: A field-test approach. *Journal of Strength and Conditioning Research, 18*(3), 534-539. doi:10.1519/R-13213.1

Casartelli, N., Muller, R., & Maffiuletti, N. A. (2010). Validity and reliability of the Myotest accelerometric system for the assessment of vertical jump height. *Journal of Strength and Conditioning Research, 24*(11), 3186-3193. doi:10.1519/JSC.0b013e3181d8595c

Castagna, C., Ganzetti, M., Ditroilo, M., Giovannelli, M., Rocchetti, A., & Manzi, V. (2013). Concurrent validity of vertical jump performance assessment systems. *Journal of Strength and Conditioning Research, 27*(3), 761-768. doi:10.1519/JSC.0b013e31825dbcc5

Choukou, M. A., Laffaye, G., & Taiar, R. (2014). Reliability and validity of an accele rometric system for assessing vertical jumping performance. *Biology of Sport, 31*(1), 55-62. doi: 10.5604/20831862.1086733

Cohen, J. (1988). *Statistical power analysis for the behavioral sciencies* (2nd ed.). Hillsdale, N.J.: Earlbaum.

Comfort, P., Stewart, A., Bloom, L., & Clarkson, B. (2014). Relationships between strength, sprint, and jump performance in well-trained youth soccer players. *Journal of Strength and Conditioning Research, 28*(1), 173-177. doi:10.1519/JSC.0b013e318291b8c7

de Blas, X., Riu, J. M. P., del Amo, J. L. L., & Bálic, M. G. (2012). Creation and validation of chronojump-boscosystem: A free tool to measure vertical jumps. *RICYDE. Revista Internacional de Ciencias del Deporte, 8*(30), 334-356. doi:10.5232/ricyde2012.03004

Enoksen, E., Tonnessen, E., & Shalfawi, S. (2009). Validity and reliability of the Newtest

Powertimer 300-series testing system. *Journal of Sports Sciences, 27*(1), 77-84. doi: 10.1080/02640410802448723

ESSA. (2011). *Adult pre-exercise screening system*. Exercise and Sports Science Australia, Brisbane.

Evans, J. D. (1996). *Straightforward statistics for the behavioral sciences*. Pacific Grove, CA: Brooks/Cole.

Fernandez-Santos, J. R., Ruiz, J. R., Cohen, D. D., Gonzalez-Montesinos, J. L., & Castro Pinero, J. (2015). Reliability and validity of tests to assess lower-body muscular power in children. *Journal of Strength and Conditioning Research, 29*(8), 2277-2285. doi:10.1519/jsc.0000000000000864

Gabbett, T. J. (2002). Physiological characteristics of junior and senior rugby league players. *British Journal of Sports Medicine, 36*(5), 334-339. doi:10.1136/bjsm.36.5.334

García-López, J., Morante, J. C., Ogueta-Alday, A., & Rodríguez-Marroyo, J. A. (2013). The type of mat (contact vs. photocell) affects vertical jump height estimated from flight time. *Journal of Strength and Conditioning Research, 27*(4), 1162-1167. doi:10.1519/JSC.0b013e31826520d7

Garcia-Pinillos, F., Soto-Hermoso, V. M., & Latorre-Roman, P. A. (2015). Acute effects of extended interval training on countermovement jump and handgrip strength performance in endurance athletes: postactivation potentiation. *Journal of Strength and Conditioning Research, 29*(1), 11-21. doi:10.1519/JSC.0000000000000591.

Gathercole, R., Sporer, B., Stellingwerff, T., & Sleivert, G. (2015). Alternative countermovement-jump analysis to quantify acute neuromuscular fatigue. *International Journal of Sports and Physiological Performance, 10*(1), 84-92. doi:10.1519/jsc.0000000000000912

Holsgaard Larsen, A., Caserotti, P., Puggaard, L., & Aagaard, P. (2007). Reproducibility and relationship of single-joint strength vs multi-joint strength and power in aging individuals. *Scandinavian Journal of Medicine and Science in Sports, 17*(1), 43-53. doi:10.1111/j.1600-0838.2006.00560.x

Janot, J. M., Beltz, N. M., & Dalleck, L. D. (2015). Multiple off-ice performance variables predict on-ice skating performance in male and female division III ice hockey players. *Journal of Sports Science and Medicine, 14*(3), 522-529.

Kenny, I. C., A, O. C., & Comyns, T. M. (2012). Validation of an electronic jump mat to assess stretch-shortening cycle function. *Journal of Strength and Conditioning Research, 26*(6), 1601-1608. doi:10.1519/JSC.0b013e318234ebb8

Leard, J. S., Cirillo, M. A., Katsnelson, E., Kimiatek, D. A., Miller, T. W., Trebincevic, K., & Garbalosa, J. C. (2007). Validity of two alternative systems for measuring vertical jump height. *Journal of Strength and Conditioning Research, 21*(4), 1296-1299. doi:10.1519/r-21536.1

Lombard, W., Reid, S., Pearson, K., & Lambert, M. (2017). Reliability of metrics associated with a counter-movement jump performed on a force plate. Measurement in Physical Education and Exercise Science, 21(4), 235-243. doi:10.1080/1091367X.2017.1354215

Linthorne, N. P. (2001). Analysis of standing vertical jumps using a force platform. *American Journal of Physics, 69*(11), 1198-1204. doi:10.1119/1.1397460

Mauch, M., Praxisklinik, R., Hans-Joachim, R., Praxisklinik, R., Xaver, J., & Praxisklinik, R. (2014) Reliability and validity of two measurement systems in the quantification of jump performance. *Schweizerische Zeitschrift für Sportmedizin und Sporttraumatologie, 62*, 57-63.

Monnet, T., Decatoire, A., & Lacouture, P. (2014). Comparison of algorithms to determine jump height and flight time from body mounted accelerometers. *Sports Engineering, 17*(4), 249-259. doi: 10.1007/s12283-014-0155-1

Pagaduan, J. C., & De Blas, X. (2004). Reliability of countermovement jump performance on chronojump-boscosystem in male and female athletes. *Sports SPA, 10*(2), 5-8.

Rittweger, J., Schiessl, H., Felsenberg, D., & Runge, M. (2004). Reproducibility of the jumping mechanography as a test of mechanical power output in physically competent adult and elderly subjects. *Journal of the American Geriatrics Society, 52*(1), 128-131. doi: 10.1111/j.1532-5415.2004.52022.x

Shetty, A. B., & Etnyre, B. R. (1989). Contribution of arm movement to the force components of a maximum vertical jump. *Journal of Orthopedic and Sports Physical Therapy, 11*(5), 198-201.

West, D. J., Owen, N. J., Jones, M. R., Bracken, R. M., Cook, C. J., Cunningham, D. J., . . . Kilduff, L. P. (2011). Relationships between force-time characteristics of the isometric midthigh pull and dynamic performance in professional rugby league players. *Journal of Strength and Conditioning Research, 25*(11), 3070-3075. doi:10.1519/JSC.0b013e318212dcd5

Wisloff, U., Castagna, C., Helgerud, J., Jones, R., & Hoff, J. (2004). Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *British Journal of Sports Medicine, 38*(3), 285-288. doi: 10.1136/bjsm.2002.002071

Figure 1. Correlation between CMJ jump height measured with CJ and FP

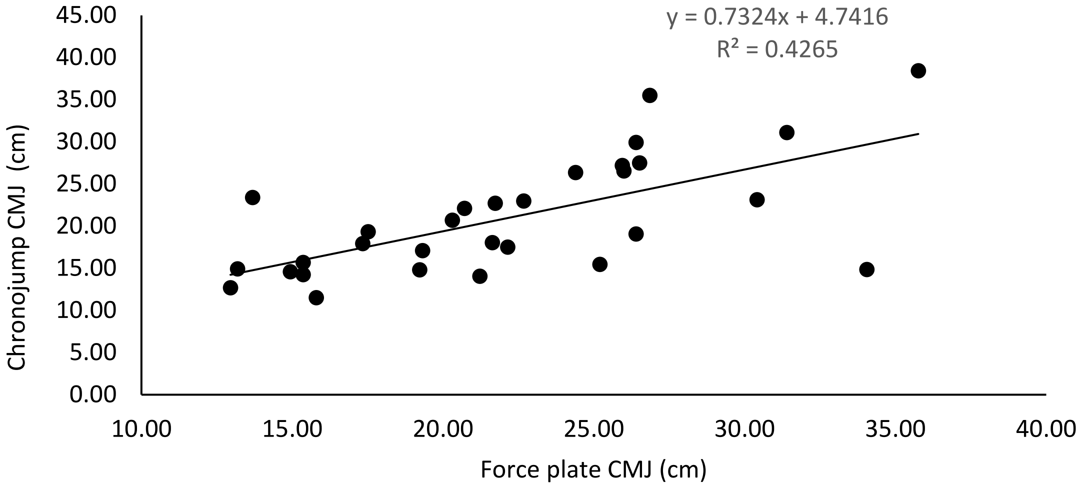


Figure 2. Bland and Altman Plot (n=30) comparing CJ and FP. Mean difference = 1.18 ± 5.46 cm, 95% CI = 12.10 – -9.73 cm

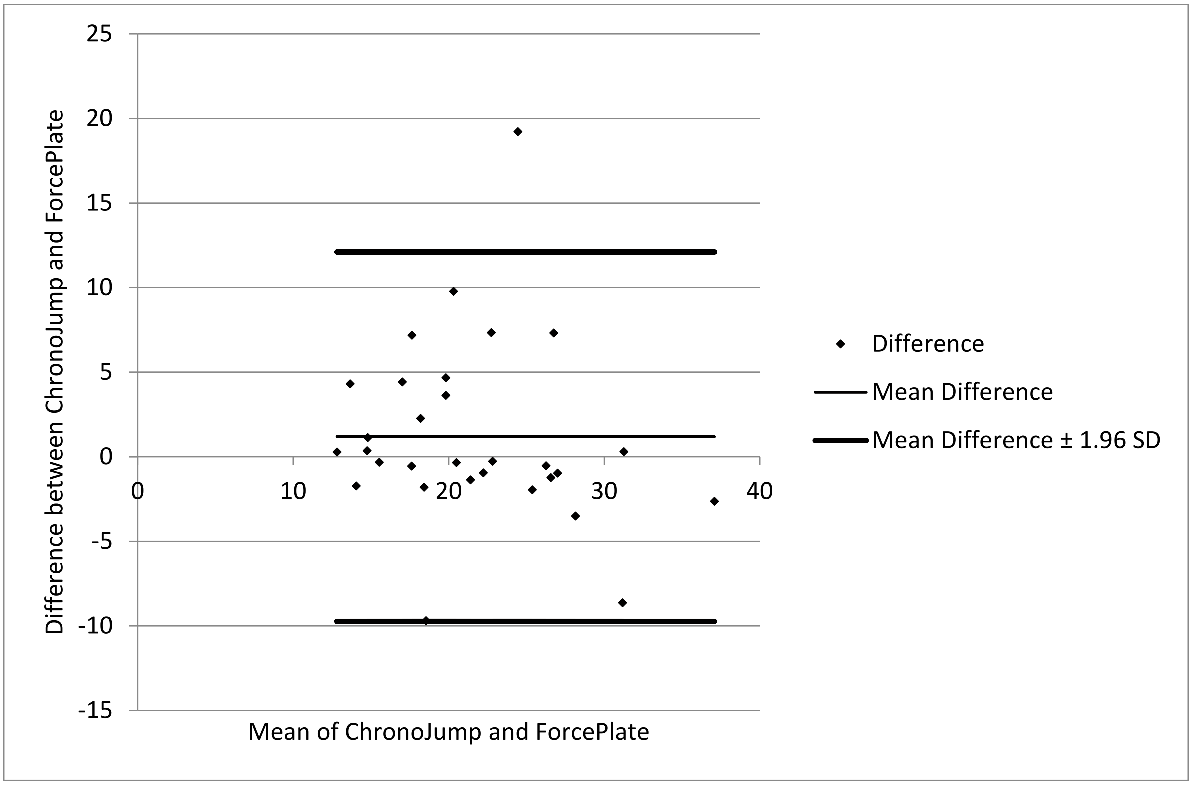
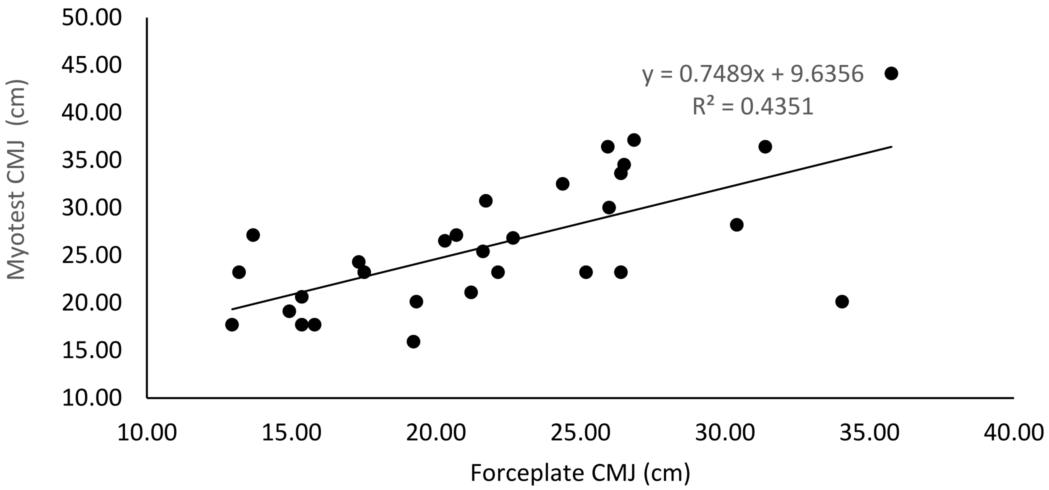


Figure 3. Correlation between CMJ jump height measured with MT and FP



468 Figure 4. Bland and Altman Plot (n=30) comparing MT and FP. Mean difference = -4.07 ±

469 5.45cm, 95% CI = 6.83 – -14.93 cm

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