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THE EFFECT OF INITIAL KNEE ANGLE ON THE RELIABILITY OF VARIABLES DERIVED FROM A SQUAT JUMP

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Abstract

Introduction: Despite wide use of the concentric only squat jump (SJ) as a performance test, the reliability of contributing kinetic variables of the performance has not been well established. Furthermore, it is common for researchers to assess the reliability of one variable to make inferences about the reliability of others. Making such assumptions may lead to inappropriate interpretation of findings.

Objective: To determine the reliability across multiple variables (relative net impulse, flight time, peak velocity, peak force, peak power) at five different knee angles during performance of SJ.

Methods: Ten recreationally trained subjects performed three body weight squat jumps from knee angles of 90°, 100°, 110°, 120°, 130°, and a self-selected knee angle on two occasions. A one-way ANOVA was used to determine the difference in reliability of variables within a single knee angle; and to compare the reliability of a variable across knee joint angles. Statistical significance was set at $P \leq 0.1$ to reduce the likelihood of a type II error due to the small sample size involved.

Results: There were no significant differences in the reliability between variables within a single knee angle. However, significant differences were observed for the variables relative net impulse ($P = 0.002$) and flight time ($P = 0.010$) between the different knee angles.

Conclusions: Assessing the reliability of a single variable and making assumptions about the reliability of other variables appears to be appropriate when the variables are all interdependent.

Key words: *monitoring, testing, power, velocity, relative net impulse, flight time*

Introduction

Many practitioners utilize the concentric only squat jump (SJ) in the training and testing of athletes. The SJ has been shown to be related to sporting performance and is typically included in training to develop the concentric capabilities of the leg extensors [1-4]. Additionally, the SJ is often used in conjunction with other tests to help identify the underlying qualities of performance [5] e.g. the eccentric utilization ratio (EUR; the ratio between countermovement jump and SJ performance) and the dynamic strength deficit ratio (DSD; the ratio between isometric mid-thigh pull and SJ performance) [6,7]. Although the SJ has immense value to practitioners and researchers alike, there is a paucity of information detailing factors associated with performing the test reliably. Neglecting the reliability of this test may cause error in determining the effectiveness of a training program, and could potentially lead to errors in future prescription as a result, especially in high level athletes.

Within the literature, the SJ has been examined across a large range of knee angles (50°-140°) [e.g. 8,9]. While some knee angles are selected to replicate a sport specific movement, it appears that commonly the knee angle selected for assessment is arbitrarily chosen [e.g. 2]. Squat jumps performed at different knee angles have been shown to result in different kinetic and kinematic outputs [8,10-12]. However, there is currently little literature investigating the difference in reliability of the SJ performed from different knee angles. Furthermore, it is common for authors to assess the reliability of one variable to make inferences about others. For example, Cormie and colleagues [13] deemed a countermovement jump to be reliable by comparing peak power between two trials, thus assuming that the force and velocity data were also reliable. While it seems intuitive that as power is a product of force and velocity, then force and velocity should also be reliable; it may be questioned if force or velocity was assessed specifically, would different reliability outputs be produced? Additionally, from a practical application of strength training science research, it is also important to recognise different training modalities will impact differently on the force and velocity characteristics. Thus, understanding the reliability of all applicable variables is a relevant consideration for better comprehension of where training induced adaptation can occur. Selection of a knee angle with better reliability across a number of kinetic variables (e.g. force, velocity, power, flight time, etc) within a testing protocol allows practitioners to interpret data with greater precision.

While the knee angle that produces maximal performance in a SJ has been investigated [8,10-12], only one investigation reported reliability data, and only from a single knee angle [8]. La Torre and Colleagues [8] reported an ICC of 0.89 for SJ performed at a 90° knee angle. Unfortunately, the authors did not report which variable the ICC was calculated for e.g. force, velocity, jump height, etc. Furthermore, the set of jumps used to assess the reliability was performed only one hour following the first set of jumps. Additionally, La Torre and colleagues [8] reported the intra-set reliability (CV) of different knee angles across a range of measures. However, intra-set reliability does not provide practitioners with any information pertaining to what a 'real' change might be if you were to measure performance again on a later date. A longer time period, e.g. 1–7 days, is better suited to assess performance reliability. The reliability of a performance test seeks to measure the magnitude of biological variation in the performance which is largely attributed to mental or physical factors that have not had sufficient time to adapt as a result of training or nutritional/pharmacological intervention [14]. Establishing the inter-day reliability across a range of angles will help identify which knee angle(s) are the most appropriate for assessment and monitoring. Therefore, the aim of this investigation was to determine the reliability across multiple variables at five different knee angles during performance of SJ.

Methods

Experimental approach to the problem

To determine the reliability in a range of kinetic and kinematic variables on SJ performed from different depths, subjects were assessed on two occasions separated by one week and conducted at the same time of day. Each testing session consisted of a standardised warm-up followed by subjects performing body weight SJ from different knee angles at 90°, 100°, 110°, 120°, 130° and a self-selected depth. A Latin square design was utilised to randomise the knee angle order between subjects. Previous research has indicated that high levels of reliability can be achieved without the need for additional familiarisation sessions [15,16].

Participants

Ten recreationally trained athletes (mean ± SD; age, 23 ± 3 years; height, 180 ± 6 cm; weight, 80 ± 11 kg) without any current injuries or medical conditions volunteered to take part in this investigation. Subjects were all partaking in regular physical exercise from a range of activities including rugby union, touch rugby, orienteering, running, basketball, mountain biking, and weight training. Subjects provided written informed consent prior to any testing taking place [17]. The study was approved by the Australian Institute of Sport Research Ethics Committee. Subjects were requested to refrain from caffeine intake three hours prior to the time of testing and maintain their regular diet for the course of the investigation. Furthermore subjects were requested not to undertake any strenuous exercise in the preceding 24 hours to jumping. Based on previous data from our laboratory establishing the reliability of peak force produced at a knee angle of 110° we calculated that eight subjects would be required to detect the smallest worthwhile change of the between-subject standard deviation [7,18].

Procedures

Warm-up

On arrival to the laboratory, each subjects completed a standardised warm-up consisting of five minute cycling at a self-selected pace on a Wattbike ergometer (Wattbike Ltd, Nottingham, UK), followed by a range of lower body dynamic stretches. Subjects then completed three 10 m sub-maximal running efforts at 70, 80 and 90% of perceived maximal effort. Following two minute rest, subjects completed two sets of three SJ and two sets of three countermovement jumps from a self-selected depth at 70, 80 and 90% of perceived maximal effort in relation to height jumped. Following a two minute rest, subjects then completed a further two sets of three SJ from a range of knee angles (approximately 90°, 110° and 130°) with a one minute rest separating each set of three jumps. Ten minutes rest separated the final warm-up jump and the beginning of testing.

To ensure appropriate knee angles were reached, an electric goniometer (Measurand Inc., Fredericton, NB, Canada) was fitted to the lateral side of the subjects left leg using a series of anatomical landmarks to ensure both inter-subject and inter-session placement was consistent. Specifically, the mid-point point between the most anterior and posterior surfaces of the knee at the level of the inter-articular space on the lateral surface of the knee was marked. Straight lines were then traced from this point to the most superior surface of the greater trochanter of the femur and the most inferior point of the lateral malleolus. The goniometer was then secured in this position with the mid-point of the goniometer over the central mark on the inter-articular space of the knee and each end of the goniometer aligned in the direction of the distal and proximal landmarks. The goniometer was secured with Velcro strapping, and then the leg and goniometer were covered with tubular elastic net bandage (Surgifix®) for additional support. The position of the goniometer was checked prior to and

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following each jump. The knee angle was displayed on a monitor directly in front of the subjects throughout the session, except for the self-selected squat depth in which the subject was blinded to the knee angle. A portable force plate (9290AD Quattro Jump, Kistler, Switzerland) and linear position transducer (Ballistic Measurement System, Fitness Technology, Adelaide, Australia) were used to record ground reaction forces and vertical displacement. The position transducer was attached to a light-weight aluminium bar (0.3kg) using a tether [2]. Subjects were required to position the bar across the posterior deltoids at the base of the neck and to ensure that contact was maintained at all times during the jumping movement. The transducer and force plate were calibrated prior to each testing session. All experimental equipment (goniometer, forceplate and linear position transducer) were connected and synchronised via an 8 channel data aquistion system (ADInstruments, Australia) with PowerLab software (ADInstruments, Australia) sampling at 200 Hz to record ground reaction forces and vertical displacement. The variables of interest were determined using the custom analysis methods and macros of the operating software.

Squat Jump

Subjects performed three jumps with approximately 20 s separating each jump for each knee angle. Each jump consisted of subjects lowering themselves to the appropriate knee angle. Once the appropriate angle was obtained, subjects were instructed to hold this position for three seconds and then jump vertically with maximal effort. Two minutes rest separated jumps at different knee angles. A SJ was deemed appropriate if the knee angle was within 2° of the desired angle (excluding self-selected) and was not preceded with a countermovement which was defined as a drop in force greater than or equal to 10% of the subject's body mass prior to the initiation of the upward propulsive phase of the jump [19].

The following variables were determined from vertical ground reaction force and vertical displacement traces:

- Peak Velocity ($m.s^{-1}$):
  - Highest instantaneous velocity (peak value from Δdisplacement/Δtime trace)
- Peak Force (N):
  - Highest vertical force during concentric phase of jump
- Peak Power (W):
  - Highest force x velocity
- Relative Net Impulse ($m.s^{-1}$):
  - [Integrated force during concentric phase (N) – (body weight (N) x concentric time)]/body weight (kg)
- Flight Time (s):
  - Time from toe off to landing

Peak force, relative net impulse and flight time were determined directly from the force plate; velocity was determined from the linear position transducer; whereas was calculated as from the integrated force plate and linear position transducer data.

Data treatment

Data points three standard deviations outside the mean were removed, which resulted in one subject's jump at a self-selected knee angle being excluded from the analysis. Individual jumps were also removed from the subsequent analysis if they didn't meet the inclusion criteria, i.e. there was a countermovement detected. Two of the ten subjects could not perform a SJ without a countermovement at a knee angle of 130° within the three attempts. For both of these subjects, the invalid jumps were performed on the second testing session. Therefore, for analysis of the 130° SJ, only eight of ten subject's data were analysed. The jump that produced the greatest relative net impulse at each knee angle was selected for analysis.

Statistical analyses

Means (± standard deviation) were calculated for all variables across all knee angles for both testing sessions. Repeat measures *T*-Test was used to assess differences between sessions one and two. Data were log transformed and analysed using an Excel spreadsheet for reliability [20]. Relative and absolute reliability were assessed via intraclass correlation coefficients (ICC) and coefficient of variation (CV). An individual's CV was calculated as the standard deviation of an individual's repeated measurement expressed as a percent of their individual mean test score [14]. A one-way ANOVA was used to determine the difference in reliability of variables within a single knee angle, and to compare the reliability of a single variable across knee joint angles. Statistical significance was set at $P \leq 0.1$ to reduce the likelihood of a type II error due to the small sample size involved [21]. If a significant effect was observed a LSD post-hoc test was used to identify which angle(s) were different.

Results

The mean (± SD) self selected knee angle was 107° (± 9°) and 105° (± 7°) for sessions one and two, respectively. Table 1 presents mean (± SD) data for session one and session two, along with CV and ICC data for each of the different variables at each knee angle. There were no significant differences in the reliability between variables measured within a single knee angle. However, significant differences were observed for relative net impulse ($P = 0.002$) and flight time ($P = 0.010$) between knee angles (Table 1). Post hoc analysis indicated that the reliability of relative net impulse at 130° was significantly less reliable than all

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Table 1. *Differences in squat jumps performed from a range of different knee angles*

		Self Selected	90°	100°	110°	120°	130°
Rel. Net Impulse	Mean ± SD (Session 1)	2.35 ± 0.19	2.32 ± 0.22	2.32 ± 0.22	2.18 ± 0.25	1.95 ± 0.38	1.55 ± 0.25#
	Mean ± SD (Session 2)	2.33 ± 0.22	2.35 ± 0.19	2.27 ± 0.19	2.14 ± 0.31	1.98 ± 0.31	1.71 ± 0.29
	CV (%)	6.1*	2.2*	2.9*	2.8*	7.2*	5.6
	ICC	0.63	0.96	0.93	0.97	0.89	0.93
Peak Velocity	Mean ± SD (Session 1)	2.76 ± 0.35	2.91 ± 0.32	2.88 ± 0.40	2.55 ± 0.46	2.25 ± 0.62	1.69 ± 0.52
	Mean ± SD (Session 2)	2.80 ± 0.35	2.92 ± 0.40	2.94 ± 0.47	2.55 ± 0.46	2.27 ± 0.58	1.85 ± 0.48
	CV (%)	9.0	4.9	4.3	6.6	10.6	10.1
	ICC	0.59	0.89	0.94	0.91	0.90	0.92
Peak Force	Mean ± SD (Session 1)	2058.96 ± 305.82	1750.60 ± 198.23	1903.77 ± 262.94	288.84 ± 286.39	2311.58 ± 276.93#	2249.54 ± 380.68
	Mean ± SD (Session 2)	2031.78 ± 367.71	1735.99 ± 198.23	1874.85 ± 279.30	2071.80 ± 313.49	2233.36 ± 234.81	2323.17 ± 408.96
	CV (%)	6.0	4.1	5.0	6.5	4.0	3.9
	ICC	0.91	0.91	0.92	0.86	0.90	0.97
Peak Power	Mean ± SD (Session 1)	1917.53 ± 291.36	1708.63 ± 172.09	1809.03 ± 246.64	1897.46 ± 248.79	2076.81 ± 283.64	1943.04 ± 333.63
	Mean ± SD (Session 2)	1890.10 ± 327.98	1678.87 ± 207.02	1786.74 ± 280.14	1932.03 ± 311.49	2040.81 ± 289.83	2048.85 ± 420.92
	CV (%)	4.3	5.1	5.0	7.0	2.4	6.4
	ICC	0.95	0.85	0.92	0.84	0.98	0.93
Flight Time	Mean ± SD (Session 1)	0.44 ± 0.04	0.45 ± 0.05	0.45 ± 0.05	0.41 ± 0.07	0.36 ± 0.07	0.29 ± 0.06#
	Mean ± SD (Session 2)	0.44 ± 0.04	0.45 ± 0.04	0.45 ± 0.04	0.41 ± 0.05	0.38 ± 0.06	0.31 ± 0.06
	CV (%)	5.1*^	4.0*^	4.3*	3.6*^	7.5	6.1
	ICC	0.78	0.86	0.89	0.96	0.89	0.94

Note: Rel. Net Impulse, relative net impulse; CV, coefficient of variation; ICC, intraclass correlation coefficients; # significantly different from session 2; * significantly different from 130°; ^ significantly different from 120°.

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other angles tested ($P = 0.010$ to 0.000). The reliability of flight time at 130° was significantly less reliable than a self-selected depth ($P = 0.006$), 90° ($P = 0.003$), 100° ($P = 0.009$), 110° knee angle ($P = 0.002$). Furthermore flight time at 120° was significantly less reliable than a self-selected depth ($P = 0.085$), 90° ($P = 0.047$), 110° ($P = 0.033$).

Discussion

The present study demonstrated that examining the reliability of a single variable to make inferences about the reliability of other variables may be appropriate when the variables are all interdependent. It was observed that the reliability of a squat jump performed at a 130° knee angle for relative net impulse is significantly greater compared to the remained of assessed knee angles measured, while the reliability of flight time for jumps performed at 120° and 130° were significantly less compared to the range of acute knee angles (Table 1).

The reduced reliability of SJ performed from a 130° knee angle is likely due to an increased difficulty of motor adjustments required to execute the jump from this position. Indeed, Bobbert and colleagues [10] reported that adjustments are made in muscular recruitment patterns when performing squat jumps from different positions, assessed as changes in heights. Additionally, Bobbert and colleagues [10] noted that many of the subjects could not perform a squat jump from large knee angles without a small countermovement preceding the concentric phase. Although it has been previously reported that a familiarisation is not required for a squat jump [15,16], both of these studies only assessed reliability at a knee angle of 90°. Similar to reports by Bobbert and colleagues[10], many of the subjects in the current study reported difficulty in performing the jump without a small countermovement at the more obtuse knee angles; so much so that two subjects could not perform a 130° jump within the inclusion criteria. Interestingly, both subjects excluded jumps were on the second testing session. While it is inherent to many practitioners that it is difficult to perform a squat jump from large knee angles, especially without countermovement; this study provides evidence that the reliability of variables derived from a squat jump performed at greater knee angle (i.e. 130°) is poor and additional practice across multiple days is likely required.

The CV's in the current investigation were higher than previously reported in SJ performed at knee angles of 50°, 70° 90° and 110°, however these findings are likely due to methodological differences. Indeed, La Torre and colleagues [8] reported CV's ranging from 1.4-5.0% across different knee angles, however, the reliability was calculated via a intra-set CV. As such, there is likely to be less biological error affecting the reliability of the measure [14]. In contrast, La Torre and colleagues [8] also reported that the ICC of a 90° knee angle SJ performed one hour later was 0.89. Although, the authors did not report what variable was assessed, the ICC was similar to that reported in the current study for the SJ performed at 90° (0.85-0.96). Although not statistically significant to other variables measured, the somewhat higher CVs observed in the velocity data in the current study may be due to the data acquisition method. Velocity was obtained directly from a linear position transducer which was attached to a bar positioned across the subject's shoulders. Although knee angle was fixed, trunk flexion was not standardised. As such any differences in trunk flexion between tests may have affected the vertical velocity data.

While, findings from this study highlight that there were no significant differences in reliability of variables within a single knee angle, it should be noted that some variables at different knee angles had a larger CV, e.g. relative net impulse (2.8%) and peak force (6.5%). From a practical application perspective, understanding the typical variation will impact the selection and interpretation of variables for regular athlete monitoring. Indeed, when monitoring exercise performance, test-retest reliability provides valuable information to determine changes in performance that can be detected with the test (e.g. coefficient of variation) [22]; whereas the smallest worthwhile effect provides a practitioner with a smallest change in performance that is considered practically meaningful [23]. For valid interpretation of the change in a variable (e.g. due to training or intervention), the relationship between the error and the smallest worthwhile effect should be taken into account [23,24]. Indeed, the error associated with the measurement needs to be minimal, and ideally less than the smallest worthwhile effect for a change to be considered real [23] and more easily identified.

One must also give consideration to the monitoring of ratio type assessments (e.g. eccentric utilization ratio), where two separate jumps are compared as a single variable. Consolidating the data in such a way may lead to a compounding of the variance. Additionally, unequal weightings of variation (reliability) between performance tests may also lead to inaccurate conclusions.

Conclusion

Assessing the reliability of a single variable and making assumptions about the reliability of other variables appears to be appropriate when the variables are all interdependent. When performing squat jumps from large knee angles (e.g. 120°, 130°) additional familiarisation sessions are likely required.

Declaration of interest

The authors report no conflicts of interest.

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References

1. Harris NK, Cronin JB, Hopkins WG, et al. Relationship between sprint times and the strength/power outputs of a machine squat jump. *J Strength Cond Res* 2008; 22(3): 691-8.
2. Argus CK, Gill ND, Keogh JWL, et al. Effects of two contrast training programs on jump performance in rugby union players during a competition phase. *Int J Sports Physiol Perf* 2012; 7(1): 68-75.
3. Cronin JB, Hansen KT. Strength and power predictors of sport speed. *J Strength Cond Res* 2005; 19(2): 349-57.
4. Harris NK, Cronin JB, Hopkins WG, et al. Squat jump training at maximal power loads vs. heavy loads: effect on sprint ability. *J Strength Cond Res* 2008; 22(6): 1742-9.
5. McGuigan MR, Doyle TLA, Newton M, et al. Eccentric utilization ratio: Effect of sport and phase of training. *J Strength Cond Res* 2006; 20(4): 992-5.
6. Bobbert MF, Casius RLJ. Is the effect of a countermovement on jump height due to active state development? *Med Sci Sports Exerc* 2005; 37(3): 440-6.
7. Sheppard JM, Chapman D, Taylor K-L. An evaluation of a strength qualities assessment method for the lower body. *Journal of Australian Strength and Conditioning* 2011;1 9(2): 4-10.
8. La Torre A, Castagna C, Gervasoni E, et al. Acute effects of static stretching on squat jump performance at different knee starting angles. *J Strength Cond Res* 2010; 24(3): 687-94.
9. Kawamori N, Rossi SJ, Justice BD, et al. Peak force and rate of force development during isometric and dynamic mid-thigh clean pulls performed at various intensities. *J Strength Cond Res* 2006; 20(3): 483-91.
10. Bobbert MF, Casius LJR, Sijpkens IWT, et al. Humans adjust control to initial squat depth in vertical squat jumping. *J Appl Physiol* 2008; 105(5): 1428-40.
11. Domire Z, Challis J. The influence of squat depth on maximal vertical jump performance. *J Sports Sci* 2007; 25(2): 193-200.
12. Kirby TJ, McBride JM, Haines TL, et al. Relative net vertical impulse determines jumping performance. *J Appl Biomech* 2011; 27(3): 207-14.
13. Cormie P, McBride JM, McCaulley GO. Validation of power measurement techniques in dynamic lower body resistance exercises. *J Appl Biomech* 2007; 23(2): 103-18.
14. Hopkins WG. Measures of reliability in sports medicine and science. *Sports Med* 2000; 30(1): 1-15.

15. Moir G, Button C, Glaister M, et al. Influence of familiarization on the reliability of vertical jump and acceleration sprinting performance in physically active men. *J Strength Cond Res* 2004; 18(2): 276-80.
16. Moir G, Sanders R, Button C, et al. The influence of familiarization on the reliability of force variables measured during unloaded and loaded vertical jumps. *J Strength Cond Res* 2005; 19(1): 140-5.
17. Harriss DJ, Atkinson G. Update-Ethical standards in sport and exercise science research. *Int J Sports Med* 2011; 32(11): 819-21. doi:10.1055/s-0031-1287829
18. Hopkins WG. Estimating sample size for magnitude-based inferences. *Sportscience* 2006; 10: 63-70 (sportsci.org/2006/wghss.htm).
19. Sheppard JM, Doyle TL. Increasing compliance to instructions in the squat jump. *J Strength Cond Res* 2008; 22(2): 648-51.
20. Hopkins W. Calculating the reliability intraclass correlation coefficient and its confidence limits (Excel spreadsheet) newstatsorg/xICCxls. 2009.
21. Chapman DW, Bullock N, Ross A, et al. Detrimental effects of west to east transmeridian flight on jump performance. *Eur J Appl Physiol* 2012; 112(5): 1663-9. doi:10.1007/s00421-011-2134-6
22. Driller M, Argus C, Shing C. The reliability of a 30 second sprint test on the Wattbike cycle ergometer. *Int J Sports Physiol Perf.* In Press.
23. Taylor K-L, Cronin J, Gill ND, et al. Sources of variability in iso-inertial jump assessments. *Int J Sports Physiol Perf* 2010; 5(4): 546-58.
24. Hopkins WG, Hawley JA, Burke LM. Design and analysis of research on sport performance enhancement. *Med Sci Sports Exerc* 1999; 31(3): 472-85.

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A – Study Design
B – Data Collection
C – Statistical Analysis
D – Data Interpretation
E – Manuscript Preparation
F – Literature Search
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