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***Title Page (Showing Author Information)**

TITLE:

Knee joint strength ratios and effects of hip position in Rugby players

RUNNING HEAD:

Hip position and knee joint strength ratios in Rugby

AUTHORS

1. Martine A. Deighan
Faculty of Sport, Health and Social Care
Oxstalls Campus
University of Gloucestershire†
Gloucester GL2 9HW
Tel: 01242 714155
mdeighan@glos.ac.uk

2. Benjamin G. Serpell*
Gloucester Rugby Football Club
Kingsholm Road
Gloucester
GL1 3AX
UNITED KINGDOM

Trauma and Orthopaedic Research Unit,
Canberra Hospital
Woden, ACT
2602
AUSTRALIA

Medical School
The Australian National University
Canberra, ACT
0200
AUSTRALIA

Tel: +61 416 505 714
ben.serpell@gmail.com

3. Mark J. Bitcon
Gloucester Rugby Football Club
Kingsholm Road
Gloucester
GL1 3AX
UNITED KINGDOM
Tel: +44 79 0990 2491
mbfitnesscoach2@hotmail.com

4. Mark De Ste Croix
Faculty of Sport, Health and Social Care
Oxstalls Campus
University of Gloucestershire
Gloucester GL2 9HW
Tel: 01242 714155
mdestecroix@glos.ac.uk

†Laboratory where research was conducted
*Corresponding author

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KEY WORDS: knee, isokinetic, rugby, injury

ABSTRACT

Measures of knee joint function, although useful in predicting injury, can be misleading because hip position in traditional seated isokinetic tests is dissimilar to when injuries occur. This study aimed to determine differences between seated and supine peak torques and strength ratios, and examine the interaction of position with joint velocity. This was a cross-sectional, repeated measures study. Isokinetic knee extensor and flexor concentric and eccentric peak torque was measured seated and supine (10° hip flexion) at 1.04 and 3.14 rad·s^{-1} in 11 Rugby players. Repeated Measures ANOVA and paired t-tests were used to analyses peak torques and strength ratios. Bonferroni posthoc, Limits of Agreement and Pearson's correlation were applied. Seated peak torque was typically greater than supine for muscle actions and velocities. Values ranged from 109 ±18 Nm (mean ±σ) for supine hamstring concentric peak torque at 1.04 rad·s^{-1} to 330 ±71 for seated quadriceps eccentric peak torque at 1.04 rad·s^{-1}. There was a significant position*muscle action interaction; eccentric peak torque was reduced more than concentric in supine. Knee joint strength ratios ranged from 0.47 ±0.06 to 0.86 ±0.23, with a significant difference in means between supine and seated positions for functional ratio at 3.14 rad·s^{-1} observed; seated it was 0.86 ±0.23 and supine it was 0.68 ±0.15 ($p<0.05$). Limits of Agreement for traditional and functional ratios ranged from 1.09 x/÷1.37 to 1.13 x/÷1.51. We conclude hip angle affects isokinetic peak torques and knee joint strength ratios. Therefore, hip angle should be nearer 10° when measuring knee joint function because this is more ecologically valid. Using similar protocols sports practitioners can screen for injury and affect training to minimize injury.

KEY WORDS: knee, isokinetic, rugby, injury

INTRODUCTION

Thigh muscle strength imbalance has been implicated as predictive of some common lower limb musculoskeletal injuries in field and court sports (1, 8, 9, 18, 19, 22, 24-26). Research in this area has examined strength imbalances on isokinetic devices measuring a range of variables including hamstring and quadriceps torques, conventional hamstring-quadriceps ratio (H_{con}:Q_{con}), functional hamstring-quadriceps ratio (H_{ecc}:Q_{con}), bilateral ratios, and stronger-weaker ratios (12, 16). The reliability of these measurements at various velocities has been established and some have been shown to be more reliable than others. For instance, absolute measures have been shown to be more reliable than strength balance ratios (12, 16, 28). For absolute measures, the fewer the repetitions the better the reproducibility (12, 28); concentric actions have been shown to have greater reliability than eccentric actions (12, 28); measurements taken at slower velocities are typically more reliable than measures at high velocity (12, 16, 17); and less variability has been observed with extensor movements compared to flexor movements (12, 28). For strength ratios, H_{ecc}:Q_{con} is reported to be more reliable than others; possibly because H_{ecc}:Q_{con} more accurately reflects the dynamic function of hamstring and quadriceps muscle groups and consequently better describes dynamic muscular stabilization of the knee (16).

There is compelling evidence to suggest a relationship between muscle imbalance and lower limb soft tissue injury (9, 24) and studies have indicated that effective activation of the eccentric component of the hamstrings during active knee extension reduces loading on the anterior cruciate ligament (1, 18). Furthermore, training studies have shown that strength balance ratios can be improved and that improvements may reduce the incidence of lower limb musculoskeletal injury (2, 14). Despite this evidence, doubt over the value of the hamstring-quadriceps strength balance ratios as a screening tool for injury risk remains. This may, in part, be due to a perceived poor relationship between isokinetic strength and muscular power (19, 21), and isokinetic strength and sprinting performance (20). Other limitations may include the movement velocity used in available studies which do not represent the limbs movement velocity during real world movements such as sprinting, or the influence of hip joint position. It may also have not been helped by the inconsistency in studies’ methodology and outcomes (1, 8, 9, 23, 28).

It is hardly surprising therefore that current data exploring the relationship between hamstring-quadriceps balance ratios and injury are conflicting. For example, Orchard et al.(24) reported a significant relationship between H_{con}:Q_{con} ratio and hamstring injury but Bennell et al.(4) found no relationship between the same outcome variables. More recently, Croisier et al.(9) reported a strong correlation between H_{ecc}:Q_{con} ratio, determined from eccentric hamstring torque at a slow velocity (0.53 $rad.s^{-1}$) and concentric quadriceps torque at a fast velocity (4.19 $rad.s^{-1}$), and hamstring injury. These conflicting data may be largely due to Bennell et al.(4) using H_{con}:Q_{con}. Croisier et al.'s (9) work demonstrated that the H_{con}:Q_{con} would not have detected approximately 30% of hamstring injuries in their study.

One major consideration that has been ignored in previous studies of either H_{con}:Q_{con} or H_{ecc}:Q_{con} is the influence of hip joint position (1, 20, 24). Studies which have investigated the relationship between isokinetic test performance and lower limb musculoskeletal injury have typically reported data obtained from participants tested in a seated position. However, rarely are field and court sport athletes active with those kinematics (e.g. the hip flexed at 90º). Most lower limb injuries occur while athletes engage in some running activity; specifically, at foot plant (1, 4, 7, 9, 18, 23). For over-ground running trunk angle is reported to typically be approximately 10° to the vertical with foot plant occurring directly inferior to the torso (see figure 1)(29). Thus, when hip and knee joints are nearer full extension dynamic knee joint stability is most important. Consequently, it could be argued that isokinetic screening where hip angle is more similar to when executing real world sporting tasks, using an eccentric hamstring strength testing protocol, would be more ecologically valid than other traditional methods.

Altering hip angle for lower limb isokinetic screening might have an effect on hamstring and quadriceps torques and subsequent knee joint strength ratios. At the very least the stretch-tension relationship of the hamstrings and quadriceps muscle groups will likely differ (20). Therefore, the relative contribution of the active contractile components of the muscle to overall force production would change. This theory is supported by work which has examined the effect of hip position on knee torque production (3, 6, 15, 20), as well as changes in neuromuscular activation (determined from electromyography) throughout range of motion (17). However, studies which have compared the effect of hip position on isokinetic test performance are limited to only determining whether a significant difference between positions exists (3, 6, 15, 20). No studies have explored the level of agreement between peak torque measures from supine and seated positions using Bland and Altman's Limits of Agreement (3, 5, 6, 15, 20). If H_{ecc}:Q_{con} is to be used as a screening tool for injury risk it is important to determine the level of agreement of values obtained when the hip joint is placed in different positions. If there is good agreement between positions then strength balance ratios would not change and ratios calculated from each position would be equally able to predict musculoskeletal injury. In addition to being limited by statistical constraints, published research which has investigated the effect of hip position on knee joint strength ratios is limited to examining H_{con}:Q_{con} ratio only (15).

Consistent application of a screening method which measures eccentric hamstring strength in a hamstring-quadriceps ratio is necessary because some of the most severe and costly injuries in sport typically occur during active extension of the knee and during the terminal swing phase during running/sprinting (9, 23, 24, 26). Understanding the effect of hip angle on hamstring and quadriceps concentric and eccentric torques and knee joint strength ratios, and applying such knowledge, might enhance current screening methods and subsequently lead to the development of a standard, more ecologically valid, isokinetic protocol. Information obtained from such screening methods may enable sports practitioners to more effectively identify athletes at greater risk of lower limb musculoskeletal injury and allow them to alter training practices to reduce injury risk or to establish progress from rehabilitation. Therefore the aims of this study were to compare isokinetic strength measurements recorded in a near supine position where kinematics were more similar to what would be observed while executing real world sporting tasks (i.e. hip flexion 10° to the vertical) to seated measurements to determine the effect of hip position on H_{con}:Q_{con} and H_{ecc}:$Q_{con.}$

METHODS

Experimental Approach

This was a cross-sectional, repeated measures study. Participants attended the laboratory on three occasions; the first being for familiarization; the other two were test sessions, the order of which was randomized for seated or supine position. There were between 7 and 14 days between sessions.

Subjects

Eleven academy players from an English Premiership Rugby Union Club (characteristics mean ± σ, age 19.3 ± 0.8 y, body mass 92.8 ± 12.6 kg, stature 182.22 ± 8.07 cm) volunteered to participate in this study. All participants completed the testing in the 3 weeks immediately prior to commencement of preseason games. All players were free from injury or illness. Written informed consent was obtained from all participants and a health questionnaire screen took place. The University Research Ethics Committee approved the study.

Procedures

Equipment

Stature and body mass were measured using a stadiometer (Holtain, Crymych, Dyfed, UK) and scales (Cranlea, Birmingham, UK). A warm up prior to testing was performed on a Monark cycle ergometer (Monark 814E, Varberg, Sweden). Isokinetic measurements were made on a Biodex System 3 (Shirley, NY, USA). All statistical analyses were performed using SPSS for Windows (V16.0, SPSS Inc., Chicago, IL, USA

Warm-up and Dynamometer Positioning

For 48hr prior to testing all participants refrained from intense exercise, especially eccentric exercise to reduce the likelihood of delayed onset muscle soreness affecting the results. All participants were asked to remain adequately hydrated prior to testing but refrain from drinking caffeine 12hr before testing. Food was not consumed 2hr prior to testing. All tests involved a standardized procedure, including a 3 min warm-up on a cycle ergometer at a self-regulated moderate intensity.

In the seated test, participants were placed in a seated position with the backrest positioned at 1.4 rad flexion. The axis of rotation of the dynamometer was aligned with the lateral epicondyle of the dominant knee, and the cuff was placed approximately 2 cm superior to the medial malleolus. Straps were tightened around the chest, pelvis and thigh for stabilization. Range of motion was set using the voluntary knee extension position that the participant deemed to be comfortably straight but not hyper extended 0 to 1.31 rad knee flexion. Range of motion was limited in this way to more easily enable the extended or flexed knee to achieve the necessary preload in the eccentric test. The same ROM was used for the other leg. A hard cushion was used so that the length of the acceleration and deceleration phase was shortened. Once positioned, the gravity correction procedure involved the participants relaxing their leg so it could be weighed during passive knee flexion, in accordance with the manufacturer's recommendations

For the other test, participants were placed lying supine with the backrest positioned at 0.2 rad flexion. All other procedures were the same as that described for the seated test. Figure 1 describes the rationale behind the supine angle and shows the two testing positions.

***** Figure 1 near here*****

Isokinetic Protocol

For each velocity and mode of muscle action, participants were permitted four familiarization repetitions of increasing effort with 30 s rest before the test and 90 s between the test and the next set of familiarization repetitions. During the test participants were instructed to push and pull or resist the attachment as hard and as fast as possible. Three continuous maximal efforts at 1.04 rad$\cdot$s^{-1} and 4 at 3.14 rad$\cdot$s^{-1} were performed with concentric tests taking place before eccentric tests. Knee extensors always acted first. Verbal encouragement by the same experimenter but no visual feedback was given. Both knees were tested on the same day but starting leg was randomized. The order of seated and supine testing was also randomized between participants.

Statistical analyses

Hip flexion angle and testing velocity were the independent variables. Peak torques for concentric and eccentric muscle actions for the hamstrings and quadriceps muscle groups and knee joint strength ratios were the dependent variables.

The highest gravity corrected peak torque on the windowed and filtered output was rounded to the nearest 1 Nm and recorded for further analysis. To reduce the effects of acceleration and deceleration of the lever arm on torque output, only peak torque data obtained from a period of constant velocity, (within a 5% range of the pre-set angular velocity) were used for analysis. Descriptive statistics were presented as mean ± σ for all peak torque values and torque ratios. Both H_{con}:Q_{con} and H_{ecc}:Q_{con} were calculated using peak torque data. A Repeated Measures ANOVA was performed on peak torque data. There were four within-subject factors; position (seated or supine), agonist (quadriceps or hamstrings), muscle action (concentric or eccentric) and velocity (1.05 or 3.14 $rad \cdot s^{-1}$). Where significant interaction or main effects were found, paired t-tests with Bonferroni adjustment were used to assess for differences between pairs. The same analysis was performed on H_{con}:Q_{con} and H_{ecc}:Q_{con} but with position and velocity as within-subject factors. Pearson correlations were calculated between seated and supine variables. Ninety-five percent ratio Limits of Agreement (LOA)(5) based on log transformed data and antilogged to give a dimensionless ratio, which represents random error, were calculated to determine the extent of agreement between seated and supine variables. Limits of Agreements were only calculated where there was no significant difference between seated and supine variables. Alpha level was set at $p<0.05$.

RESULTS

Mean values of peak torque, Pearson correlations, and 95% ratio LOA are displayed in Table 1.

*****table 1 near hear*****

The Repeated Measures ANOVA demonstrated significant main effects of position Significant main effects of position (seated greater than supine, $p=0.014$), agonist (extensor greater than flexor, $p<0.001$), muscle action (eccentric greater than concentric, $p=0.002$) and velocity (slower greater than fast, $p<0.001$) were also identified. A significant position*muscle action interaction ($p<0.05$) for peak torque (see Figure 2).

*****Figure 2 near here*****

The interaction was due to eccentric peak torque being reduced more in the supine position compared to concentric peak torque. Paired t-tests revealed a significantly lower extensor concentric peak torque at 3.14 rad·s^{-1}, extensor eccentric peak torque at 1.05 rad·s^{-1} and flexor eccentric peak torque at 3.14 rad·s^{-1} in the supine position (Table 1). Pearson correlations between seated and supine peak torques varied from low to high. Where no significant difference between seated and supine peak torque existed, 95% ratio LOAs were calculated and varied from x/÷1.38 to 1.53. That is, seated and supine peak torque measurements will differ due to random error by between 38% and 53% on either side of the systematic bias which ranged from 6% to 21%.

Mean values of H_{con}:Q_{con} and H_{ecc}:Q_{con}, Pearson Correlations and 95% ratio LOAs are shown in Table 2.

*****table 2 near here*****

No other significant interactions were observed but the Repeated Measures ANOVA (Table 3) revealed a significant main effect of velocity ($p<0.05$) on H_{con}:Q_{con} and H_{ecc}:Q_{con} due to a higher ratio at the faster velocity. There was also a significant ($p<0.05$) main effect of position but for H_{ecc}:Q_{con} only. Paired t-tests revealed the seated H_{ecc}:Q_{con} was significantly greater than the supine equivalent at the faster velocity only (Table 2). However, it was in this ratio that there was a significant Pearson correlation ($p<0.05$) between seated and supine. All other correlations were low. Larger differences between seated and supine were observed in the H_{ecc}:Q_{con} compared to the H_{con}:Q_{con} with the mean seated H:Q being greater than supine. Where there was no significant difference between seated and supine H:Q, 95% ratio LOAs were calculated and varied from x/÷1.37 to 1.51 on either side of the systematic bias which ranged from 9 to 14% (table 2).

*****table 3 near here*****

DISCUSSION

The first aim of this study was to compare knee flexion and extension isokinetic peak torque measured in a supine compared with a seated position. A significant position*muscle action interaction effect was found with greater concentric torque recorded in a seated position compared with eccentric torque in a supine position. Subsequently the significant main effects for position (seated torque greater than supine) and muscle action (eccentric greater than concentric) are in agreement with the existing literature (3, 6, 15, 20). We found that for 3 of the 8 peak torque variables mean peak torque was significantly greater in the seated position compared to the supine position; for the other 5 measures agreement was poor, i.e. the random error limits were between 37 and 53% and there was a large systematic bias ranging between 6 and 21% (Table 1). Furthermore, in most instances correlations were only weak to moderate. Therefore, it can be argued that results obtained in a seated position would typically be significantly different and unrelated to testing in the near supine position.

Both concentric and eccentric peak torque was negatively affected by testing in the supine position. However, the magnitude of that effect was greater for eccentric actions (Figure 2). This is not surprising since supine peak torques were dissimilar and unrelated to seated peak torques as indicated by some significant differences, and poor agreements and correlations.

This study, similarly to others (3, 6, 15, 20), has shown that hip angle influences both concentric and eccentric peak torque. Based on results from this study and others (3, 6, 15, 17, 20) it can be hypothesized that hip angle influences the stretch tension relationship of the muscle, the relative contribution of active contractile components of the muscle, and/or neuromuscular control; which ultimately effects a number of isokinetic peak torque indices. For example, it could be argued that when extending the knee with a greater hip-thigh angle neural activation of the hamstrings differs to when seated due to less tension applied by the series elastic and parallel elastic components of posterior chain muscles. Further research to support this argument is necessary. Repeating this study with a larger sample while concurrently measuring muscle activity using electromyography would be a reasonable approach.

In agreement with other studies we have found a significant main effect for velocity on both concentric and eccentric torque production, with greater torque found at the slower velocity (12, 15). However, it is important for knee stability that during faster velocity movements that the eccentric hamstring torque is relatively unaffected by velocity to increase the H_{ecc}:Q_{con} to produce less strain on the ACL. Irrespective of hip positioning we have found that concentric quadriceps decreases by around 20% with increasing velocity but comparable eccentric hamstring torque only decreased by 3%.

The second aim of this study was to determine if there was an influence of hip angle on knee joint strength ratios. This is important to determine if strength ratios are to be used as a screening tool to explore the possible risk of an individual to injury. As the hip is rarely fixed at 90° during most functional movements then assessment of the ratio in a seated position provides little ecological validity. Determination of strength ratios in a prone or supine position where the hip is fixed at a position that more closely reflects running (10° of hip flexion) is more valid, especially as it replicates more closely the length-stretch relationship. It is important when testing in a supine position to correct for gravity, as we have done in this study, as the gravitational influence on torque production will be different from upright running. Unlike previous work, a main effect for H_{con}:Q_{con} was not found in the current study (15). However, a main effect of position on H_{ecc}:Q_{con} was observed. To the knowledge of the researchers of the present study this is the first which has examined the effect of hip angle on H_{ecc}:Q_{con}. The non-significant effect of position on H_{con}:Q_{con} is not surprising since its calculation requires division of one concentric peak torque by another (14). Assuming hamstring and quadriceps concentric peak torques in the 2 positions were different by the same amount, the same ratio was expected for H_{con}:Q_{con}; whereas H_{ecc}:Q_{con} calculation requires division of an eccentric action by a concentric action (14) and since eccentric actions were more negatively affected by position a smaller H_{ecc}:Q_{con} from testing in the supine position was expected because the numerator in the equation was disproportionately smaller.

Unlike the main effect of position where an effect was observed for H_{ecc}:Q_{con} only, a main effect of velocity was observed for H_{ecc}:Q_{con} and H_{con}:Q_{con}. This can be explained by the main effect of velocity on the absolute values from which the ratios are calculated. However, these results must be read with caution since torque reliability at higher velocities becomes questionable (9, 12, 28).

As noted previously, isokinetic measurement of knee joint strength balance can be used as a screening tool to predict lower limb musculoskeletal injury (1, 8, 9, 18, 22, 24-26). However, evidence to support the relationship between muscular imbalances and lower limb musculoskeletal injury is inconsistent (1, 4, 9, 13, 24). Thus, the development of a standard, ecologically valid testing protocol is necessary (9, 23-26). Using an eccentric protocol, Croisier et al.(9) revealed a strong relationship between strength imbalance and hamstring strain. However, their mixed H_{ecc}:Q_{con} still did not detect approximately 5% of injuries, and despite having a large sample their alpha level was set at $p<0.05$. Therefore, their protocol, while promising, may have 'missed' a considerable number of injuries. This may be explained by the fact that the protocol used by Croisier et al. (9) tested participants in a seated position, given the present study has shown that hip flexion angle affects isokinetic test performance considerably. This begs the question - since hip angle affects concentric and eccentric peak torque, and this has a carryover effect to H_{ecc}:Q_{con}, would a H_{ecc}:Q_{con} calculated from peak torques measured with a hip angle which more closely reflects that which is observed while executing real world sporting tasks better predict musculoskeletal injury?

PRACTICAL APPLICATIONS

Compelling evidence showing a relationship between knee joint strength ratios, determined by use of isokinetic dynamometers, and lower limb musculoskeletal injury exists. Furthermore, training studies have shown that knee joint strength ratios can be improved and, consequently, injury risk may be reduced. Despite this evidence some reluctance by sports practitioners to test knee joint strength ratios on isokinetic dynamometers remains. This may be due to perceptions of a lack of relationship between isokinetic test performance and other physical performance qualities. It may also be related to inconsistencies in testing protocols and outcomes. Thus, we argued that the development of a standard ecologically valid testing protocol be developed. Evidence leans toward testing protocols which measure hamstring strength eccentrically being better able to predict injury. However, in studies which have presented this evidence a considerable number of injuries were still not predicted. We highlighted that an oversight of much of the research to date is the effect of hip position on isokinetic test performance. In fact it has been argued in this paper that the ecological validity of isokinetic testing protocols for knee joint strength ratios is typically questionable because they typically test athletes in seated positions (i.e. hip angle of 90°). Most functional tasks in field and court sports, rugby included, are executed with far less hip flexion (i.e. hip angle of approximately 10°). This study showed that hip position has a significant effect on isokinetic peak torque and agreement between seated and supine measurements was poor. Furthermore, the effect of hip position on peak torques carried over to affect functional knee joint strength ratio. Thus, an isokinetic testing protocol which considers eccentric hamstring strength where measurements are recorded with a hip flexion angle nearer 10° is likely to be most ecologically valid. Using such a protocol strength imbalances can be determined and lower limb musculoskeletal injury may be predicted. By adopting screening methods such as this, sports practitioners can affect training to reduce injury risk and therefore enhance performance.

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FIGURE LEGEND

Figure 1: (a) The approximate lower body joint angles while running in rugby union (10,11,27,29) providing some justification for the selected hip joint angle adopted for the supine test; (b) The two testing positions

Figure 2: The interaction ($p=0.004$) between position and muscle action type on peak torque.

Table 1: Descriptive statistics (mean ± s) for isokinetic peak torque (Nm) in the seated and supine positions.

Table 2: Descriptive statistics (mean ± s) and 95% ratio Limits of Agreement (LOA) for traditional H:Q ratio (H_{con}:Q_{con}) and functional H:Q ratio (H_{ecc}:Q_{con}).

Table 3: Significance of main effects on H:Q ratio of position and velocity, and position*velocity interaction.

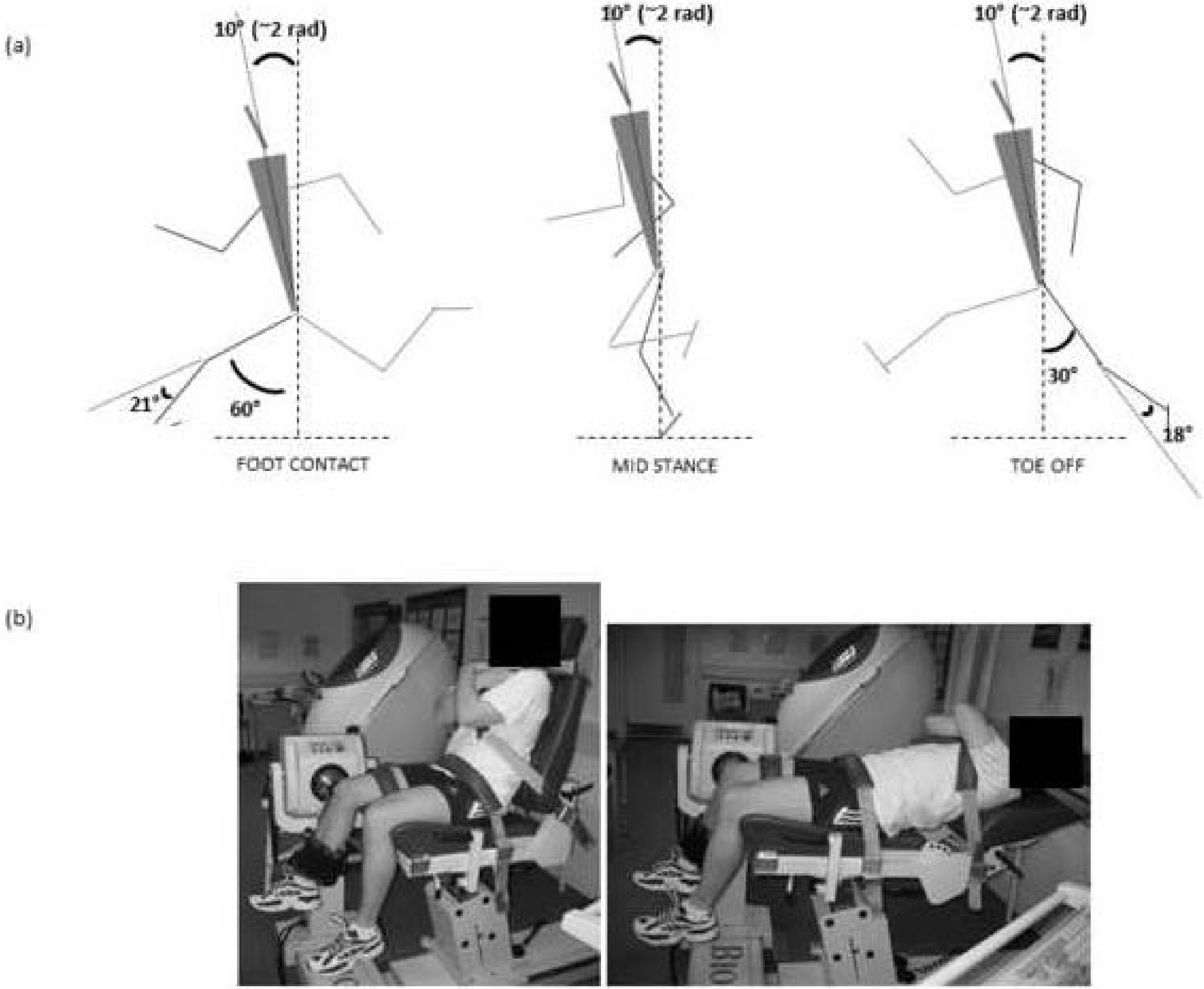

Figure 1: (a) The approximate lower body joint angles while running in rugby union (9,10,26,28) providing some justification for the selected hip joint angle adopted for the supine test; (b) The two testing positions

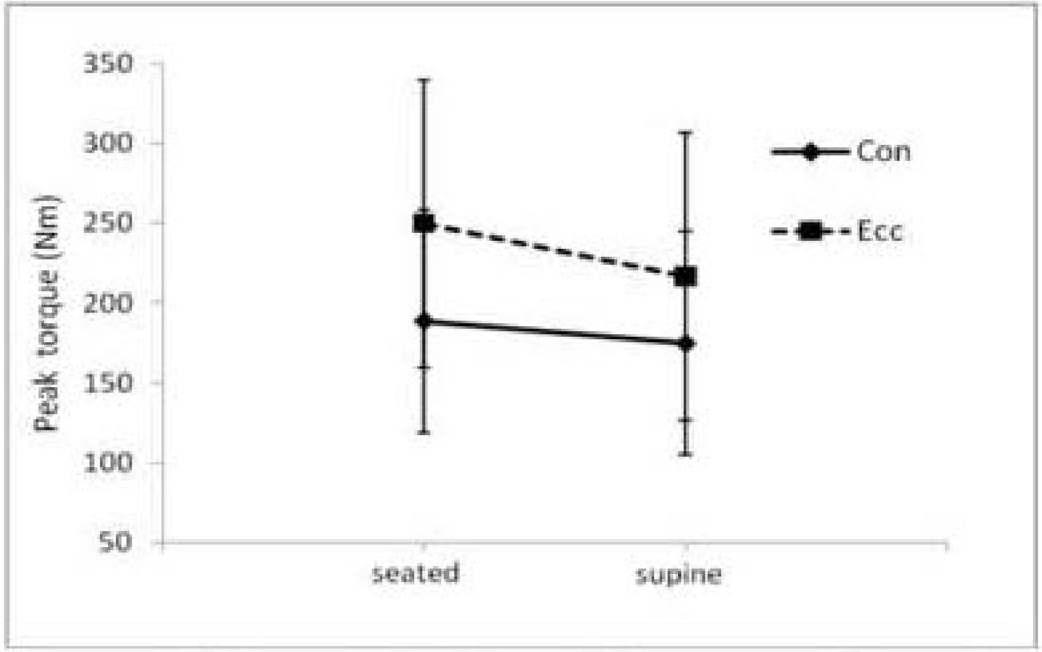

Figure 2: The interaction (p=0.004) between position and muscle action type on peak torque.

Table

Table 1: Descriptive statistics (mean ± s) for isokinetic peak torque (Nm) in the seated and supine positions.

	Quadriceps				Hamstrings			
	Con		Ecc		Con		Ecc	
	1.05 rad·s^{-1}	3.14 rad·s^{-1}	1.05 rad·s^{-1}	3.14 rad·s^{-1}	1.05 rad·s^{-1}	3.14 rad·s^{-1}	1.05 rad·s^{-1}	3.14 rad·s^{-1}
Seated	272 ± 49	*219 ± 27	*330 ± 71	305 ± 56	144 ± 26	121 ± 16	179 ± 45	*186 ± 60
Supine	260 ± 33	211± 37	307 ± 70	277 ± 78	123 ± 19	109 ± 18	147 ± 20	138 ± 30
Pearson Correlation	0.44	**0.57	0.23	0.03	0.44	**0.57	***0.70	***0.83
95% ratio LOA	1.06 x/÷ 1.38	n/a	n/a	1.12 x/÷ 1.37	1.19 x/÷ 1.53	1.15 x/÷ 1.38	1.21 x/÷ 1.54	n/a

*Significantly higher peak torque in seated compared to supine condition (p<0.00625) based on Bonferroni adjustment of p
**p<0.05
***p<0.01

Table 2: Descriptive statistics (mean ± s) and 95% ratio Limits of Agreement (LOA) for traditional H:Q ratio (H_{con}:Q_{con}) and functional H:Q ratio (H_{ecc}:Q_{con}).

	Traditional H:Q Ratio (H_{con}:Q_{con})		Functional H:Q Ratio (H_{ecc}:Q_{con})	
	1.05 rad·s^{-1}	3.14 rad·s^{-1}	1.05 rad·s^{-1}	3.14 rad·s^{-1}
Seated	0.53 (0.07)	†0.56 (0.07)	0.66 (0.09)	*†‡ 0.86 (0.23)
Supine	0.47 (0.06)	†0.51 (0.09)	0.58 (0.07)	†‡ 0.68 (0.15)
Pearson Correlation	-0.11	0.10	-0.03	**0.78
95% ratio LOA	1.13 x/÷ 1.51	1.09 x/÷ 1.37	1.14 x/÷ 1.41	n/a

*Significantly greater in seated compared to supine ($p<0.0125$) based on Bonferroni adjustment of p

**$p<0.01$

† Significant main effect for velocity

‡ Significant main effect for position

Table 3: Significance of main effects on H:Q ratio of position and velocity, and position*velocity interaction.

	position	velocity	position*velocity
Traditional H:Q ratio	0.090	0.046	0.549
Functional H:Q ratio	0.003	0.018	0.316