INFLUENCE OF A SEASON OF ATHLETIC TRAINING ON LEG AND JOINT STIFFNESS IN HIGH LEVEL NETBALLERS

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The purpose of this study was to ascertain the impact of a season of training on lower limb stiffness, joint stiffness and the contributing mechanisms during basic jumping and sports specific tasks. Eleven high level female netballers completed a maximal countermovement jump (basic), 50 m sprint and change of direction cutting task (sports specific) prior to and following a competition/training season. Student paired t-tests or their non-parametric equivalent identified no pre-post season stiffness changes, however stiffness mechanism changes during sports specific tasks did occur.

KEYWORDS: leg stiffness, athletes, netball, training

INTRODUCTION: The sport of netball is a high intensity intermittent activity, which requires athletes to perform varying vertical and horizontal movement patterns, such as maximal jumps, repeated sprints, and cutting tasks. Exposure to repeated high impact forces places these athletes at approximately 3.3 times more risk of lower limb injury than other court based sports (McKay, Payne, Goldie, Oakes, & Stanley, 1996). Few studies have evaluated injury incidence risk factors in netballers, although, age, prior injury, playing position, or muscle strength and stiffness properties may be related.
Lower body stiffness measures quantify the relationship between leg flexion and the external load to which limbs are subjected. Specifically, leg stiffness (Kleg) assesses the muscle's ability to resist change under an applied load, providing optimal storage and return of elastic energy via the stretch shortening cycle (SSC) (Butler & Crowell, 2003). Joint stiffness evaluates limb stiffness at an individual joint level, assessing the ratio of joint moment to joint displacement. Optimizing Kleg and joint stiffness, rapid transmission of impact forces and adequate storage and return of elastic energy are each necessary to improve athletic performance, reduce injury incidence and manage the mechanical interaction of the musculoskeletal system and its surrounding environment (Butler & Crowell, 2003). Kleg is task dependent and can be modulated by training due to musculoskeletal, neural control, muscle activity and kinematic adaptations (Komi, 2000; Millett, Moresi, Watsford, Taylor, & Greene, 2013). Further, stiffness has known links to both performance and injury risk, whereby relatively higher levels of stiffness are associated with high impact injuries such as stress fractures, while lower levels of stiffness have been linked to soft tissue injuries (Butler & Crowell, 2003). Few studies, however, have investigated the longitudinal impact of elite athletic training on lower limb stiffness, its associated controlling mechanisms and the subsequent effect on injury incidence, particularly in female athletes during tasks relevant to an athlete's habitual training background. The purpose of this study was to ascertain the impact of a season of training on lower limb stiffness, joint stiffness and the contributing mechanisms during a basic jumping task and sports specific tasks.

METHODS: Eleven national to international level female adult netballers (Mean [SD] Age: 16.91[0.79], Height: 177.86 [6.65], Weight Pre: 68.71 [7.81], Weight Post: 69.84 [7.19]) were recruited and provided informed consent to participate. This study was approved by the University Ethics Committee prior to the commencement of data collection. To assess the longitudinal impact of training on stiffness, participants were tested prior to the start of training for the competition season and at the conclusion of the season (approximately 5 months apart). Participants completed five trials of three unilateral tasks (performed on the dominant leg) which were relevant to their training and competition background. Tasks consisted of a basic maximal countermovement jump (traditional stiffness measure, CMJ), and two functional, sports specific tasks (50 m sprint and an anticipated change of direction cutting task). Data was captured using a 10 camera motion analysis system (Vicon MX; Oxford Metrics Ltd., Oxford, United Kingdom; 500 Hz) and force plate (Kistler, 9281CA, Switzerland; 1000 Hz). Cut off frequencies of 16 Hz (jump data) and 23 Hz (running tasks) were implemented using a low pass Butterworth dual-pass fourth order filter following analysis of the frequency content and residuals of the power spectra in kinematic data (Winter, 2009). Kleg was determined using the McMahon and Cheng (1990, as cited in Butler & Crowell, 2003) formula and joint stiffness (HipS, KneeS, AnkleS) calculated using the Steganyshyn and Nigg (1998, as cited in Butler & Crowell, 2003) method. Contributing mechanisms including joint displacement (HipD, KneeD, AnkleD), peak joint moment (HipPM, KneePM, AnklePM) and touchdown angles (HipTD, KneeTD, AnkleTD) of hip, knee and ankle were assessed. Peak vertical ground reaction force (PVF), centre of mass displacement (COM) and performance measures (contact time [CT], jump height [JH] and running velocity [RV]) were determined. Kleg measures were normalized to body weight and standardized to pre-season touchdown velocities of 6.03 m/s (Sprint) and 4.52 m/s (Cutting) using residual calculations derived from linear regression analysis. For a true representation of athlete's leg spring and contributing mechanisms to be assessed, the highest and lowest scores of the five trials were excluded for analysis. Data which met normality criteria outlined by Peat and Barton (2006) was evaluated using paired t-tests. Non-normal data was assessed using Wilcoxon Signed Rank tests. All statistical analysis was evaluated using the Statistical Package for Social Sciences (SPSS, V19.0, Inc., Chicago, IL, USA) with an alpha level set at $p<0.05$. Following initial assessment, data was subsequently split into injured (lower body, ≥1 missed game) and uninjured populations to assess the effect of injury status on the results. Two athletes displayed high initial stiffness scores during sprint tasks due to their Track and Field backgrounds (Figure 1). One athlete was excluded from the overall group analysis with both athletes excluded from the injured/non-injured analysis.

RESULTS AND DISCUSSION: There were no differences between pre and post season Kleg or joint stiffness across all tasks, however, significant differences were observed in the contributing mechanisms which regulate stiffness (Table 1). CMJ results displayed a decrease in PVF and KneePM at the end of the season while AnkleS trended towards a significant increase. Evaluation of the sports specific tasks revealed significant decreases in CT, HipTD and KneeTD, an increase in RV during sprinting, with AnkleS trending towards a decrease. During the change of direction cutting task, COM, CT, HipTD, KneeTD and AnkleTD displayed significant decreases, while HipS displayed a significant increase. Despite no overall differences in Kleg, the sports specific tasks revealed several differences in the mechanisms that contribute to stiffness, which the CMJ was unable to identify. CMJ results displayed a decrease in PVF indicative of a performance deficit. In contrast, the sports specific tasks showed improvements in performance variables and clear changes in the contributing mechanisms. Despite no clear overall changes in stiffness, the results of the sports specific tasks suggest these tasks may be more sensitive to training-induced stiffness mechanism changes than the CMJ. Mechanism changes were particularly evident in the ways athletes approached ground contact, suggesting that kinematic changes occurred following training. Appropriate screening tools to assess performance and subsequent injury risk are vital in high performance athlete screening and monitoring. Previous results suggest that basic jumping tasks, such as the CMJ, are not related to sports specific stiffness measures (Millett et al., 2013) which appears supported by the present results. Although there were no clear overall differences in Kleg post training, the results may be confounded by a high incidence of injury (over 50%) within the participants. Subsequent analysis was undertaken to explore the impact of injury incidence on the results.

Although the uninjured population consisted of a small sample size, the results appear to support the notion that sports specific tasks are superior screening tools and that stiffness may increase as a result of training stimulus. Uninjured CMJ data established no differences in Kleg, however, Kleg tended to change for the 50 m sprint and the cutting task displayed a significant increase. Along with performance increases, several mechanism changes were also observed in sports specific tasks (Table 2). An increase in Kleg during sports specific tasks at the conclusion of the training season, coupled with a reduction in CT, suggests improved movement efficiency from a greater reliance on the SSC for the uninjured players. Sports specific task results suggest that stiffness increases as a result of increased training and performance demands, as evident by the improvements in cutting and sprint task running velocities.

Table 1- Pre-Post Season Changes In Netball Athletes

	CMJ (n=10)		Sprint (n=10)		Cutting Task (n=11)	
	Pre Season	Post Season	Pre Season	Post Season	Pre Season	Post Season
Kleg (N/m/kg)	38.79(13.25)	40.55 (12.54)	116.01(15.61)	124.87(15.95)	90.52(34.89)	91.79 (28.63)
PVF (N)	2.22 (0.24)	1.88 (0.18)*	2.76 (0.21)	2.88 (0.23)	2.46 (0.31)	2.48 (0.29)
COM (m)	0.22 (0.06)	0.22 (0.05)	0.03 (0.01)	0.03 (0.01)	0.06 (0.02)	0.05 (0.01)*
CT (s)	0.80 (0.14)	0.79 (0.12)	0.17 (0.01)	0.15 (0.01)*	0.22 (0.04)	0.20 (0.03)*
JH (m)	0.135 (0.033)	0.131 (0.042)	-	-	-	-
RV (m/sec)	-	-	6.03 (0.42)	6.36 (0.28)*	4.52 (0.57)	5.10 (0.59)*
HS (N/deg/kg)	0.062 (0.014)	0.060 (0.012	0.042 (0.177)	0.119 (0.445)	0.317(0.358)	0.299 (0.257)
HipPM (Nm/kg)	2.73 (0.40)	2.60 (0.42)	3.22 (1.70)	3.13 (3.49)	5.65 (2.36)	5.69 (1.98)
HipD (Deg)	47.29 (15.37)	49.38 (11.45)	13.28 (2.53)	11.68 (4.89)	12.88 (5.20)	11.32 (4.02)
HipTD (Deg)	-	-	47.12 (8.24)	37.05 (8.99)*	46.77(10.81)	37.50 (7.75)*
KneeS(N/m/kg)	0.021 (0.008)	0.016 (0.007)	0.303 (0.124)	0.288 (0.215)	0.182(0.089)	0.161 (0.064)
KneePM(Nm/kg)	1.54 (0.57)	1.21 (0.45)*	2.57 (0.44)	2.31 (0.76)	3.47 (0.62)	3.12 (0.81)
KneeD (Deg)	57.68 (12.73)	58.74 (7.64)	14.99 (3.79)	16.30 (7.33)	30.24 (7.08)	29.95 (6.55)
KneeTD (Deg)	-	-	34.06 (5.44)	26.75 (7.43)#	27.47 (4.95)	19.22 (5.11)*
AnkleS(N/deg/kg)	0.061 (0.012)	0.076(0.026)’	0.173 (0.038)	0.141(0.024)#	0.093(0.025)	0.088 (0.020)
AnklePM(Nm/kg)	1.88 (0.34)	1.93 (0.41)	3.10 (0.57)	2.81 (0.51)	2.82 (0.41)	2.59 (0.64)
AnkleD (Deg)	23.09 (4.28)	21.91 (4.45)	19.14 (5.48)	21.28 (4.15)	32.25 (8.07)	32.69 (8.79)
AnkleTD (Deg)	-	-	3.87 (9.81)	1.18 (5.22)	-5.51 (9.99)	-10.37(10.26)*

* Significant difference *p*<0.05, # trends towards significant difference *p*= 0.05-0.09

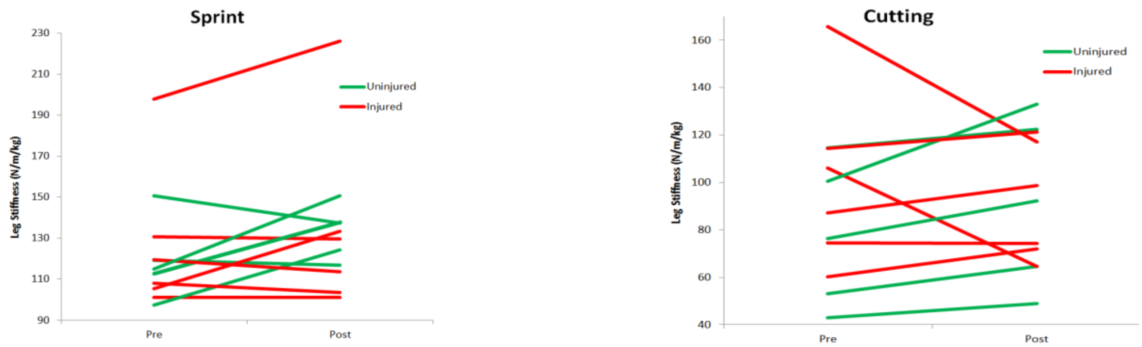

Figure 1- Individual pre-post season sports specific stiffness differences in uninjured and injured netballers.

Table 2- Pre-Post Season Changes In Uninjured Netball Athletes

	CMJ (n=5)		Sprint (n=4)		Cutting Task (n=5)	
	Pre Season	Post Season	Pre Season	Post Season	Pre Season	Post Season
Kleg (N/m/kg)	43.82 (9.09)	47.19 (8.28)	111.12(9.47)	132.47(14.94)#	77.52(30.37)	92.25(36.04)*
PVF (N)	2.08 (0.20)	1.98 (0.13)	2.69 (0.12)	2.93 (0.21)	2.33 (0.31)	2.49 (0.33)*
COM (m)	0.21 (0.03)	0.21 (0.03)	0.03 (0.01)	0.03 (0.01)	0.06 (0.02)	0.04 (0.02)#
CT (s)	0.75 (0.08)	0.75 (0.09)	0.16 (0.00)	0.15 (0.01)#	0.23 (0.05)	0.20 (0.04)*
JH (m)	0.144(0.026)	0.132 (0.027)	-	-	-	-
RV (m/sec)	-	-	6.17 (0.18)	6.38 (0.16)	4.56 (0.64)	5.25 (0.81)*
HipS(N/deg/kg)	0.066(0.009)	0.060(0.009)	0.073(0.120)	0.079 (0.411)	0.242(0.391)	0.232 (0.161)
HipPM (Nm/kg)	2.86 (0.47)	2.42 (0.39)	4.30 (1.89)	2.29 (4.12)	4.80 (2.67)	4.74 (2.10)
HipD (Deg)	44.34 (7.27)	46.55 (3.20)	13.83 (1.14)	12.94 (5.03)	12.19 (5.07)	10.56 (4.36)
HipTD (Deg)	-	-	51.78 (7.01)	38.72 (12.38)	54.31 (8.47)	41.07 (8.16)#
KneeS(N/m/kg)	0.025(0.008)	0.017(0.009)#	0.264(0.088)	0.347 (0.246)	0.164(0.047)	0.161 (0.040)
KneePM(Nm/kg)	1.84 (0.60)	1.29 (0.56) *	2.43 (0.65)	2.32 (0.56)	3.20 (0.34)	3.21 (0.19)
KneeD (Deg)	59.62 (6.28)	60.80 (5.27)	16.28 (3.07)	12.70 (7.29)	30.98 (7.47)	28.62 (7.68)*
KneeTD (Deg)	-	-	34.92 (8.34)	31.26 (7.77)	30.48 (3.69)	19.98 (5.74)*
AnkleS(N/deg/kg)	0.061(0.016)	0.071(0.021)	0.154(0.054)	0.126 (0.023)	0.085(0.025)	0.085 (0.019)
AnklePM(Nm/kg)	2.09 (0.29)	2.05 (0.49)	2.88 (0.84)	2.52 (0.56)	2.73 (0.33)	2.39 (0.56)
AnkleD (Deg)	24.61 (3.50)	23.45 (2.72)	20.75 (8.34)	22.51 (5.95)	34.93 (8.72)	34.57 (10.18)
AnkleTD (Deg)	-	-	1.91 (12.65)	0.29 (4.57)	-9.79 (4.28)	-15.21 (5.40)

No significant changes were found for Kleg in the injured group across all three tasks following the competition season (Table 3). In contrast to the CMJ, the sports specific tasks displayed several mechanism changes (Table 3), further supporting the notion that sports specific tasks are superior screening tools. Despite small participant numbers it appears that injured athletes’ Kleg did not change pre to post season. However, it remains unclear if the lack of Kleg change is related to increased injury risk or the rehabilitation from injuries themselves. Preliminary results from this study appear to support previous research in regards to lower limb stiffness and injury risk (Butler & Crowell, 2003; Watsford et al., 2010). Athletes with relatively low stiffness reported soft-tissue injuries and injured athletes displaying high stiffness encountered overuse, stress-related injuries. Direct linkage to injury causation, relative stiffness and training stimulus requires further investigation. An optimal stiffness range may be necessary for optimal performance and injury risk minimization during the competition season to cope with regular high impact loading and increased training load. However, the upper and lower stiffness limits for athletes require further investigation. Further research should undertake regular monitoring on a larger sample size through a competition season to gain a true understanding of the relationship between stiffness, contributing mechanisms, training and injury incidence.

Table 3- Pre-Post Season Changes In Injured Netball Athletes

	CMJ (n=5)		**Sprint (n=5)**		**Cutting Task (n=6)**	
	Pre Season	Post Season	Pre Season	Post Season	Pre Season	Post Season
Kleg (N/m/kg)	33.76 (15.78)	33.91 (13.24)	112.99(12.05)	116.29(14.72)	101.36(37.24)	91.40 (24.48)
PVF (N)	2.35 (0.21)	1.79 (0.18)*	2.74 (0.22)	2.78 (0.20)	2.57 (0.30)	2.46 (0.28)*
COM (m)	0.23 (0.09)	0.23 (0.07)	0.03 (0.01)	0.03 (0.00)	0.05 (0.01)	0.05 (0.01)
CT (s)	0.85 (0.17)	0.83 (0.14)	0.17 (0.02)	0.16 (0.01)#	0.21 (0.03)	0.20 (0.02)
JH (m)	0.126 (0.037)	0.130 (0.052)	-	-	-	-
RV (m/sec)	-	-	5.96 (0.58)	6.29 (0.37)	4.48 (0.56)	4.97 (0.36)
HipS(N/deg/kg)	0.059 (0.018)	0.060 (0.016)	0.003 (0.255)	0.147 (0.596)	0.380 (0.351)	0.356 (0.322)
HipPM (Nm/kg)	2.60 (0.30)	2.79 (0.39)	2.39 (1.11)	3.56 (3.65)	6.37 (2.02)	6.48 (1.63)
HipD (Deg)	50.23 (21.38)	52.22 (16.28)	12.24 (3.56)	8.52 (1.92)*	13.46 (5.71)	11.96 (4.01)
HipTD (Deg)	-	-	44.04 (8.76)	35.72 (7.44)#	40.49 (8.51)	34.54 (6.61)#
KneeS(N/m/kg)	0.016 (0.006)	0.015 (0.007)	0.346 (0.170)	0.262 (0.227)	0.198 (0.116)	0.161 (0.083)
KneePM(Nm/kg)	1.24 (0.37)	1.13 (0.36)	2.66 (0.19)	2.51 (0.98)	3.69 (0.73)	3.04 (1.12)
KneeD (Deg)	55.74 (17.78)	56.67 (9.64)	14.02 (4.99)	20.00 (7.39)*	29.62 (7.39)	31.06 (5.97)
KneeTD (Deg)	-	-	34.40 (0.90)	24.84 (4.33)*	24.96 (4.63)	18.59 (4.99)*
AnkleS(N/deg/kg)	0.060 (0.009)	0.082 (0.031)	0.187 (0.008)	0.161(0.007)*	0.100 (0.025)	0.090 (0.023)
AnklePM (Nm/kg)	1.67 (0.24)	1.80 (0.33)	3.26 (0.20)	3.09 (0.41)	2.90 (0.48)	2.75 (0.71)
AnkleD (Deg)	21.57 (4.84)	20.36 (5.60)	17.82 (2.04	19.84 (2.36)#	30.01 (7.49)	31.13 (8.07)
AnkleTD (Deg)	-	-	7.05 (8.38)	3.33 (5.99)	-1.94 (12.31)	-6.33 (12.00)

CONCLUSION: The results of the present study established that during sports specific tasks there were mechanism differences pre-post season which basic jumping tasks were unable to identify. Results of the sports specific tasks suggest Kleg, performance improvements and mechanism changes occur following an expensive period of high load training stimulus. The results support the notion that coaches, athletes, and biomechanists should screen athletes using sports specific tasks when assessing performance changes and injury risk.

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