RELATIONSHIP OF LEG AND JOINT STIFFNESS DURING BASIC AND SPORTS SPECIFIC TASKS IN HIGH LEVEL ATHLETES

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The purpose of this study was to assess the stiffness relationship between basic jumping tasks and sports specific tasks, and the underlying joint stiffness contributions which contribute to leg stiffness modulation. Forty-seven high level female athletes from varying training backgrounds completed a maximal countermovement jump, drop jump, horizontal jump, 50 m sprint, change of direction cutting task and repetitive hopping. Pearson's correlations or their non-parametric equivalent identified no relationship between basic jumping and sports specific tasks, however the repetitive hopping task exhibited a moderate relationship to each disciplines relevant sports specific task. Furthermore, joint stiffness contributions appeared to be unique to each athletic group. Results of this study appear to suggest sports specific tasks are superior screening tools for athletes.

KEYWORDS: lower-body, neuromechanical properties, jumping

INTRODUCTION: Lower extremity stiffness quantifies the relationship between the compression of the leg spring and the external load to which limbs are subjected. Stiffness allows the joint or limb to resist change under an applied force, enhancing the storage and return of elastic energy via the stretch shortening cycle, necessary for optimal performance (Butler & Crowell, 2003). Research has established stiffness modulation is task dependent and can be augmented through training to improve performance and minimize injury risk (Komi, 2000). Athletic training and conditioning influences the key leg (K_{leg}) and joint (K_{joint}) stiffness modulation strategies required to meet performance demands, including musculoskeletal development, neuromuscular control, co-contraction and regulation of muscle activity (Butler & Crowell, 2003).
Athlete screening and stiffness monitoring is important in high performance sport to provide information on optimizing performance and managing potential injury risk. Higher levels of stiffness have been associated with an increased risk of overuse, bone related injuries, while lower levels appear related to soft tissue injuries (Butler & Crowell, 2003). To date, research has focused on assessing links between injury and lower extremity stiffness in athletic groups using simple jumping tasks such as countermovement (CMJ), repeat jumps or drop jumps (DJ) (Hobara et al., 2010). However, questions remain as to whether these tasks adequately reflect an athlete's typical stiffness properties during training and competition. It is essential when profiling stiffness for performance and injury risk that monitoring programs are implemented. Subsequently, the evaluation of tasks which reflect the relationship of stiffness modulation during sports specific tasks is of critical importance, particularly in female populations who are known to be at high risk of injury incidence and are under-reported in stiffness literature (Butler & Crowell, 2003). The purpose of this study was; 1) to ascertain the relationship between stiffness measures assessed during basic jumping and sports specific tasks, 2) to assess underlying K_{joint} contributions that modulate to K_{leg} in different female sub-populations from varied training backgrounds.

METHODS: Following approval by the University Ethics Committee, 47 female participants (20 nationally identified netballers, 13 high level endurance athletes and 14 age matched controls) were recruited and provided informed consent (Table 1). These populations were targeted due to their differing training and competition demands. Netball athletes represented a high intensity intermittent sport involving maximal jumping efforts, explosive sprints and change of direction, while endurance athletes (1500 m – marathon) represented a sport requiring continuous, efficient running at submaximal intensities. Control group participants did not exceed four hours of weekly physical activity.

Table 1- Participant Descriptive Information. Values: mean (SD).

Group	N	Age (Years)	Mass (kg)	Height (cm)	Average Training Hours ($h \cdot wk^{-1}$)	Training Years
Netball	20	17.4(1.5)	69.2(8.4)	178.1(5.6)	7.9(4.8)	6.4(3.6)
Endurance	13	19.7(4.0)	53.4(2.9)	165.9(4.8)	10.0(3.4)	7.5(2.5)
Control	14	22.1(2.3)	59.6(9.9)	162.9(5.5)	2.1(1.2)	-

To assess the relationship between discrete basic jumping and sports specific tasks with regards to stiffness, participants completed five trials of five unilateral tasks and one trial of the repetitive hopping task (performed on the dominant leg). Tasks classed as basic jumping tasks traditionally utilised to assess stiffness included maximal effort CMJ, DJ from a 40 cm box and maximal horizontal jump (HJ). Sports specific tasks included 50 m sprint, anticipated change of direction cutting task and 27 continuous reactive hops at submaximal intensity (indicated by target heights set at 70% of maximal CMJ height). Participants were instructed to position their hands on their hip in order to minimise the contribution of arm swing to jump height during all jump tasks. 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). Following analysis of the frequency content and residuals of the power spectra in the kinematic data, a low pass Butterworth dual-pass fourth order filter was implemented utilising cut off frequencies of 16 Hz (jump data) and 23 Hz (running tasks) (Winter, 2005). K_{leg} was determined using the McMahon and Cheng (1990, as cited in Butler & Crowell, 2003) formula and K_{joint} (Hip stiffness: K_{hip}, Knees stiffness: K_{knee}, Ankle stiffness: K_{ankle}) calculated using the Steganyshyn and Nigg (1998, as cited in Butler & Crowell, 2003) method. K_{leg} measures were normalized to body mass and standardized to the average horizontal touchdown velocity or jump frequency of all participants using residual calculations derived from population specific linear regression analysis. For a true representation of athlete's K_{leg} and K_{joint}, the highest and lowest scores of the five trials were excluded for analysis with the exception of the repetitive hopping task. The first five and last two trials of the repetitive hopping tasks were excluded from analysis with the mean of the remaining trials utilised in subsequent analysis. Normality was evaluated utilising a critical appraisal approach (Peat & Barton, 2006). Extreme outliers (± 2 SD) were removed from non-normal data; data which violated normality following outlier removal was assessed with non-parametric statistics. Pearson or Spearman rank-order (non-normal data) correlations were utilised to assess the relationship of K_{leg} between each evaluated task and K_{joint} contributions (> 0.7 very strong, 0.5 - 0.69 strong, 0.3 - 0.49 moderate; Peat and Barton, 2006). All statistical analyses were evaluated using the Statistical Package for Social Sciences (SPSS, V19.0, Inc., Chicago, IL, USA) with an alpha level set at $p<0.05$. P values with the range of 0.05-0.09 were defined as providing a clinically meaningful relationship (Peat & Barton, 2006). In order to provide insight into the inferential statistical analysis assessing K_{joint} contributions to K_{leg}, a principal component analysis (PCA) was undertaken to assess major joint contributions to the stiffness variance.

RESULTS AND DISCUSSION: K_{leg} correlations within the netball group displayed clinically meaningful moderate relationships between both sports specific tasks and the drop jump and agility task (Table 2). A strong relationship was evident between the drop jump and repetitive hopping tasks. Although not statistically significant, a moderate relationship was observed between repetitive hopping and both sports specific tasks. As netball athletes are accustomed to performing these movements, it is theorised that the stiffness expressed during these tasks may be related due to neuromuscular adaptations resulting from chronic athletic training. Although not statistically significant, correlation results of endurance athletes displayed a moderate relationship between the CMJ and HJ tasks along with the sprint and repetitive hopping tasks. This reinforces the notion that stiffness modulation is dependent upon the task requirements and the individuals' training background. Although repetitive hopping does not specifically reflect the movement patterns of endurance athletes during competition, it is known to be utilised in the daily training environment as a training tool to develop strength and economic efficiency (Spurrs, Murphy, & Watsford, 2003). Furthermore, repetitive single leg contacts are similar to continuous running at sub-maximal intensities. Unlike the netball group, endurance athletes did not display a relationship between the two sports specific tasks (sprint and change of direction cutting). This result reinforces that stiffness modulation is reliant upon the training background of athletes, as endurance running athletes rarely perform acute change of direction cutting movements. The control group displayed a strong significant relationship between the drop jump and anticipated change of direction cutting tasks. This may occur due to both tasks exhibiting higher impact loads and performance requirements, which this population are likely uncustomed to. The control population lack certain specific adaptations to movement which occur as a result of chronic athletic training. Subsequently it can be suggested they do not utilise any common strategy to optimise stiffness to meet task demands. The results suggest that athletic training inherently influences the stiffness optimisation of athletes to meet task demands. In order to understand why a moderate relationship was observed between sports specific tasks and repetitive hopping, further analysis was undertaken to explore K_{joint} contributions to K_{leg}.

Table 2- Relationships between K_{leg} assessed from basic jumping and sports specific tasks

	CMJ	DJ	HJ	Sprint	Cut
		Netball Athletes			
Drop Jump	0.046	-	-	-	-
Horizontal Jump	0.177	0.048	-	-	-
Sprint	-0.161	0.365	-0.388	-	-
Cut	-0.142	0.422	0.130	0.449	-
Repetitive Hopping	-0.130	0.569[a]	-0.118	0.331	0.353
		Endurance Athletes			
Drop Jump	0.004	-	-	-	-
Horizontal Jump	0.468	0.308	-	-	-
Sprint	-0.082[#]	0.164[#]	0.238[#]	-	-
Cut	0.214	-0.049	-0.067	0.121	-
Repetitive Hopping	-0.261	0.379	0.285[#]	0.491[#]	-0.024
		Control Group			
Drop Jump	0.251	-	-	-	-
Horizontal Jump	0.181	0.049	-	-	-
Sprint	-0.231	-0.207	-0.167	-	-
Cut	0.111	0.633[a]	0.180	0.081	-
Repetitive Hopping	-0.085	0.338	-0.391	-0.308	0.281

[a] Significant correlation ($p<0.05$); [#] Non parametric Spearman's rho test implemented

The correlation results from the control group established the following significant K_{joint} contributions in the evaluated tasks; (CMJ: K_{hip} r=0.709, K_{knee} r=0.590; DJ K_{knee} r=0.769, K_{ankle} r=0.774; HJ: K_{hip} r=0.720; anticipated change of direction cutting: K_{knee} r=0.534) while the sprint and repetitive hopping tasks revealed no significant K_{joint} relationships. The results indicate no clear joint control strategies across the evaluated tasks, suggesting the control group display no common modulation strategy due to a lack of specific neuromuscular adaptations to chronic training. This notion was further supported by PCA results, where control participants appeared to display an individualised K_{joint} modulation strategy during sports specific tasks.

Correlation results and visual inspection of PCA bi-plots (Figure 1) suggested that netball athletes utilised key contributions from K_{knee} and K_{ankle} in order to modulate K_{leg} during basic jumping tasks (CMJ: K_{hip} r=0.460, K_{ankle} r=0.670; DJ: K_{hip} r=0.616, K_{knee} r=0.778, K_{ankle} r=0.738; HJ: K_{ankle} r=0.590) and sports specific tasks (change of direction cutting task: K_{knee} r=0.580; repetitive hopping: K_{knee} r=0.519, K_{ankle} r=0.449). Netball athletes may rely on these specific joint contributions as a stiffer knee and ankle joint is advantageous in running, change of direction and jumping movements (Arampatzis, Brüggemann, & Metzler, 1999). Such results reflect the specific movement demands of their training and competition environment. Further, the correlation and PCA results indicated that the endurance group utilised K_{ankle} contributions during the repetitive hopping task (K_{ankle} r=0.798), however relied upon contributions of K_{hip} across the remaining tasks (CMJ: K_{hip} 0.580, DJ: K_{hip} r=0.709, HJ: K_{hip} r=0.712). A stiffer hip joint plays an important role in generating running velocity for endurance track and field athletes (O'Meara & Moresi, 2012), thus it can be suggested that this population is reliant upon K_{hip} contributions as a result of neuromuscular adaptations to chronic athletic training.

The findings of this study reflect potential training associated variations in K_{leg} relationships between tasks across several groups. The results suggest that basic jumping tasks may not induce sufficient performance demands to elicit K_{leg} responses similar to training and competition of athletes, despite similar K_{joint} contributions. The appropriateness of utilising basic jumping tests as a daily monitoring tool for athletes is therefore questionable since they do not appear to reflect typical stiffness values during training or competition. In contrast, this highlights the potential importance of utilising dynamic sports specific functional tests in athlete screening and monitoring. Although sports specific tasks serve as a direct reflection of training and competition demands, these tests require motion analysis which may be impractical as monitoring tools for athletes and coaches. Results suggest repetitive hopping may be useful as a simple intermediate daily monitoring tool in athletic populations.

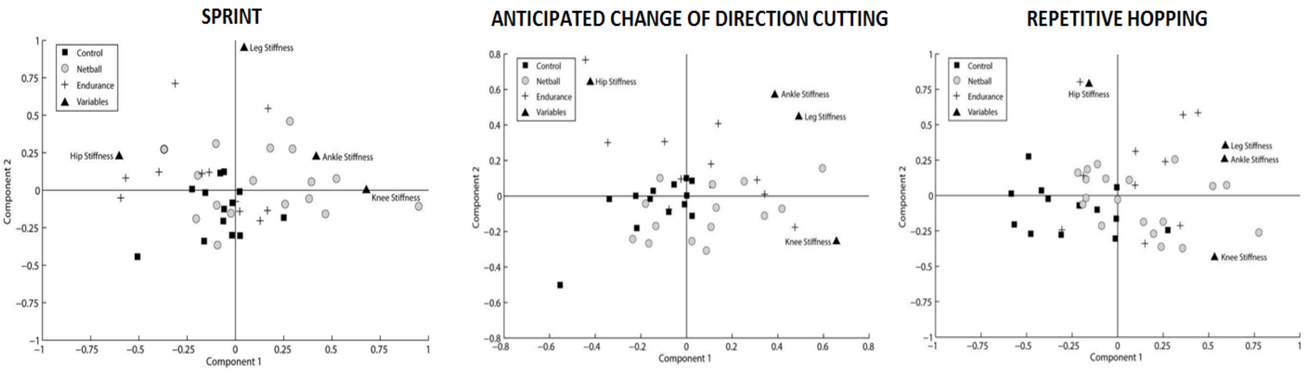

Figure 1: PCA results for sports specific tasks.

CONCLUSION: The results of the present study suggest an athlete's training background appears to influence leg and joint stiffness optimisation during jumping and sports specific tasks. It appears that basic jumping tasks may lack adequate sensitivity and relevance to an athlete's training environment. This highlights the importance for utilising sports specific or functional tasks when assessing stiffness levels of athletes. Accordingly, practitioners monitoring lower limb stiffness for performance or injury risk identification should consider utilising more sports specific or functional tests. Since screening tools requiring motion capture may be impractical for daily monitoring, the moderate relationship observed between repetitive hopping and sports specific tasks suggests that this test may serve as an intermediate monitoring tool.

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