EFFECTS OF FATIGUE ON PATELLAR TENDON LOADING DURING THE LANDING PHASES OF A STOP-JUMP MOVEMENT

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Therefore, the purpose of this study was to establish whether there were any significant differences in the patellar tendon forces generated by athletes during the landing phases of a stop-jump (SJ) movement before and after fatigue induced by repetitive SSC exercises. Eighteen soccer and basketball players performed a SJ movement before and after a fatigue protocol. During each SJ trial, three-dimensional kinematic, kinetic and electromyographic data for each subject's lower limbs were recorded. When fatigued, athletes significantly ($p < 0.05$) reduced their patellar tendon forces during the SJ movement by reducing knee and hip flexion. Whether "stiff limb" landings reduces the risk of developing patellar tendinopathy by decreasing patellar tendon loading during jumping requires further investigation.

KEY WORDS: Landing, Fatigue, Patellar Tendon.

INTRODUCTION:

Patellar tendinopathy is a functional overload syndrome common in individuals who submit their extensor mechanism to intense and repetitive loading, such as is experienced during repetitive vertical jumping characteristic of sports such as volleyball, basketball and soccer (Witvrouw et al., 2001; Lian et al., 2005). These repetitive SJ movements are frequently characterized by a stretch-shortening cycle (SSC) muscle action. In movements involving SSC, large loads are placed on the knee extensor mechanism during both the concentric and eccentric phase of the SSC, continually loading the patellar tendon (Fredberg and Bolvig, 1999). In jumping, the patellar tendon has been found to sustain forces of up to 8,000 N compared to only 500 N typically generated during walking (Johnson et al., 1996). It is these high loads placed on the extensor mechanism during repetitive jumping and landing that is thought to be involved in the aetiology of patellar tendinopathy (Lian et al., 2005).

Although patellar tendinopathy is usually only self-limiting, it can impair an athlete's performance by reducing training and competition levels for long time periods, severely restricting or even ending an athlete's career (Lian et al., 2005). Despite substantial pathological and histological evidence pertaining to patellar tendinopathy in the literature, there is only limited research on the specific intrinsic and/or extrinsic factors that increase the risk of patellar tendinopathy. One such extrinsic factor that may be related to patellar tendinopathy is that of fatigue. Fatigue is known to decrease muscle performance in landing tasks as fatigued muscles are less able to absorb the repetitive loads sustained during SSC movements (Nicol et al., 1996). This reduced ability of the lower limb muscles to absorb load may increase the load transferred to the patellar tendon during a SJ movement, contributing to the development of patellar tendinopathy.

In order to decrease the incidence and severity of patellar tendinopathy within sporting communities, knowledge of risk factors that contribute to injury incidence and severity require urgent investigation so that we can develop effective prevention and/or treatment regimes. However, no research has systematically investigated the factors affecting patellar tendon loading during a SJ movement or how these factors are affected by fatigue. Therefore, the purpose of this study was to establish whether there were any significant differences in the patellar tendon forces generated by athletes during a SJ movement before and after fatigue induced by repetitive SSC exercises.

METHODS:

Data Collection: Eighteen skilled male basketball, soccer and volleyball players (mean age = 23.5 ± 3.6 yr; height = 183.5 ± 7.4 cm; mass = 80.4 ± 10.0 kg) volunteered to attend two testing sessions over 2 weeks to complete the study requirements. All subjects had their tendon morphology confirmed by ultrasound prior to participating in the study. During the first testing session subjects were familiarized with the fatigue protocol, which required a series of SSC exercise sets to be performed on a custom-designed sledge apparatus, which consisted of a 23 kg seat that glided along a low friction aluminum track, inclined at 23.6° from the horizontal (Aura and Komi, 1986). After warm-up and familiarization, the subjects performed three maximum SSC exercises with 2 minutes rest between each set. Subjects then repeatedly performed sets of 30 submaximal SSC exercises (rebounding to 70% of their maximum SSC exercise height), followed by 30 seconds rest, until they could no longer reach the target submaximal rebound height for three successive trials. The fatigue protocol has been previously shown to be both reliable and valid in terms of inducing lower limb muscle fatigue during landing (Edwards and Steele, 2006).

Figure 1: A subject performing the fatigue protocol in the sledge apparatus.

One week following the familiarization session, the subjects returned to the laboratory and performed the SJ movement under two conditions, non-fatigued and fatigued. Each SJ trial required the subject to accelerate forwards for four steps, to stop and land with each foot on a separate force platform, to jump vertically upwards to hit a ball suspended from the ceiling and to again land with each foot on a separate force platform. After performing 10 SJ non-fatigue trials, the subjects performed three isometric maximum voluntary contractions (IMVC; 105º knee angle), with 1 min rest between each IMVC. Each subject then performed up to three maximum exercises on the sledge apparatus to determine their maximum SSC exercise height and then completed the fatigue protocol described previously. Immediately after completing this fatigue protocol, the subjects then performed an additional 10 SJ fatigue trials in rapid succession, followed by another three IMVC. Pre- and post-fatigue blood lactate samples were taken to confirm each subject's fatigue level.

During performance of the SJ movement, each subject's three-dimensional lower limb motion was recorded (100 Hz) using the Opto*Trak* 3020 motion analysis system (Northern Digital, Waterloo, Canada) and the ground reaction forces generated at landing for each trial were recorded (1,000 Hz) using two multichannel force platforms (Kistler, Winterthur, Switzerland) embedded in the floor. Electromyographic activity was recorded (1,000 Hz) bilaterally for vastus lateralis (VL), rectus femoris (RF), vastus medialis (VM), biceps femoris (BF), semitendinosus (ST), tibialis anterior (TA) and medial gastrocnemius (MG) using two Telemyo systems (Noraxon, Arizona, USA). The kinetic, kinematic and electromyographic data were time synchronized and collected using First Principles (Version 1.00.2, Northern Digital, Waterloo, Canada) software.

Data Analysis: Analysis of the kinematic and kinetic data was performed using Visual 3D (Version 3, C-Motion, Maryland, USA) software. The raw kinematic coordinates, ground reaction forces, free moments and center of pressure data were filtered using a fourth-order zero-phase-shift Butterworth digital low pass filter (f_c = 18 Hz) before calculating individual knee joint moments and patellar tendon forces. Although data for each lower limb were collected, this study was restricted to data calculated for each subject's dominant limb, which was defined as the lower limb the subject used to kick a ball. To interpret the kinematic and kinetic data, the SJ movement was divided into five phases including preparation, 1st landing, take-off, flight and 2nd landing. The transition between each of the five phases was confirmed using the ground reaction force-time curves. The primary outcome variable selected for analysis in the present study was the peak patellar tendon force generated during the two landing phases of the task with secondary variables including lower limb alignment and motion during landing to assist in explaining any changes in patellar tendon loading. After confirming normality and equal variance, the data were analyzed using a series of paired *t*-tests to determine whether there was any significant differences ($p < 0.05$) pre- and post-fatigue in patellar tendon loading or the biomechanical variables characterizing landing technique during the SJ movement.

RESULTS:

An average of 14.4 (± 9.2) sets of the 30 submaximal exercises were completed by subjects until they could no longer achieve 70% of their maximal jump height on the sledge. Fatigue was confirmed by a significant ($t = -9.097$; $p < 0.001$) increase in blood lactate levels from 3.3 ± 0.6 $mmol.L^{-1}$ when non-fatigued to 7.9 ± 1.8 $mmol.L^{-1}$.

When fatigued, the subjects generated significantly lower peak patellar tendon forces during the 1st and 2nd landing phases of the SJ movement (see Figure 2). This reduction in force when fatigued was accompanied by less knee and hip flexion compared to when non-fatigued. Those secondary variables found to differ significantly between the pre- and post-fatigue conditions are listed in Table 1.

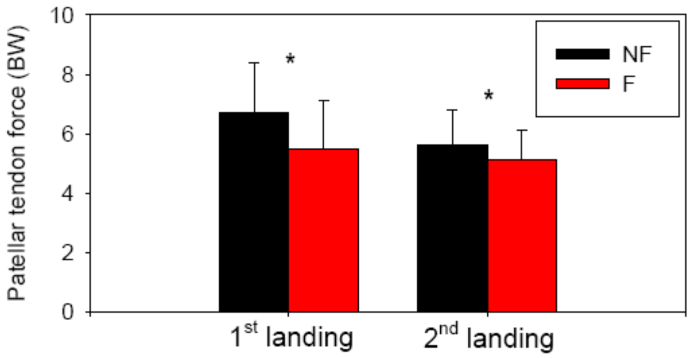

Figure 2 Peak patellar tendon forces during landing phases of SJ movement (*$p < 0.05$).

Table 1 Means (± standard deviations) for the knee and hip alignment variables displayed by the subjects ($n = 18$) during the landing phases of the SJ movement that were found to be significantly different non-fatigued- and fatigued conditions.

Variable	Non-fatigued	Fatigued	*p*-value
1st landing			
Knee flexion θ at peak $F_{Vertical}$	51 ± 9	46 ± 10	0.016
Hip flexion θ at peak $F_{Vertical}$	65 ± 6	62 ± 6	0.006
Knee flexion θ at peak F_{PT}	49 ± 12	39 ± 10	0.000
Hip flexion θ at peak F_{PT}	51 ± 15	43 ± 11	0.005
2nd landing			
Hip flexion θ at initial contact	16 ± 7	14 ± 8	0.028
Hip abduction θ at initial contact	-7 ± 2	-6 ± 3	0.040
Knee flexion θ at peak $F_{Vertical}$	47 ± 7	45 ± 8	0.045
Hip flexion θ at peak $F_{Vertical}$	23 ± 7	20 ± 9	0.005
Hip flexion θ at peak F_{PT}	31 ± 11	27 ± 13	0.005

DISCUSSION:

Previous studies investigating the SJ movement have reported knee (Chappell et al., 2005; Yu et al., 2006) and hip joint angles (Yu et al., 2006) consistent with those displayed by the subjects when non-fatigued in the present study. Interestingly, when fatigued the subjects displayed significantly decreased patellar tendon forces together with altered segmental alignment and motion during the SJ movement compared to when they were non-fatigued. It has been previously suggested that when players land with their knees more flexed, patellar tendon tension is increased, contributing to the development of patellar tendinopathy (Richards et al., 1996). In fact, it has been previously noted that fatigued athletes displayed less knee flexion (Nicol et al., 1996; Chappell et al., 2005) to prevent further muscle damage (Nicol et al., 1996). The results of the present study support this notion whereby as subjects decreased their patellar tendon forces during the SJ movement when fatigued, they simultaneously displayed less knee flexion. In addition to decreased knee flexion when fatigued, subjects also displayed less hip flexion during the SJ movement when fatigued relative to in the non-fatigued condition. It would therefore appear that a "stiffer" landing strategy was being used by these skilled athletes to reduce patellar tendon loading when fatigued; possibly to accommodate for the inability of their fatigued muscles to efficiently absorb the forces generated at landing.

CONCLUSION:

It was concluded that when fatigued, athletes significantly reduced their patellar tendon forces during the SJ movement by reducing knee and hip flexion and displaying a "stiffer" landing. However, whether "stiff limb" landings could be used as a strategy to reduce the risk of developing patellar tendinopathy by decreasing patellar tendon loading during jumping movements requires further investigation.

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