EFFECT OF LANDING STRATEGIES ON LOWER LIMB JOINT KINETICS DURING LOADED JUMPS

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The purpose of this study was to analyze the effect of landing strategies on the landing kinetics during loaded jumps. Ten male participants performed counter movement jumps with 50% body weight (BW) additional load using four different landing strategies. Landing strategy referred to peak knee joint flexion during landing. Peak vertical force increased up to 50% with decreasing knee joint flexion during landing. No changes were found regarding peak joint moments and powers. Total lower limb joint work increased up to 83% with increasing knee joint flexion during landing. The results suggest that energy dissipation during loaded landing is shifted from active (muscle-tendon system) to passive (skeletal system) as peak knee flexion decreases during landing, resulting in mechanical stress on different body tissues depending on the landing strategy.

KEYWORDS: overuse injuries, injury prevention, plyometric training

INTRODUCTION: Plyometric training (PT) is frequently used for the improvement of lower limb muscle power and vertical jump performance. PT is characterized by a high intensity eccentric movement followed by a concentric contraction. Typical examples of PT are counter movement jumps or drop jumps. A large scale meta-analysis, 1024 participants, revealed a positive effect on vertical jump height enhancement (+4.7% and +8.7% for squat jumps and counter movement jumps, respectively) from this type of training (Markovic, 2007). PT is also performed with additional load (loaded PT) due to its more advanced training effect (Khlifa et al., 2010). Frequent landing impacts occurring during PT are related to overuse injuries like patellar tendinitis (Lian et al., 2005). Based on the analysis of ground reaction forces, the potentially increased overuse injury risk due to the additional load during loaded landing was suggested to be offset by load-based jump height reductions (Mundy et al., 2018). Recently, we conducted an analysis on the effect of loaded jumps on lower limb joint kinetics during loaded landing, which generally supported this suggestion (paper submitted February 2019). However, we observed not only load-based reductions in jump height but also load-based changes regarding the landing strategy, possibly serving as additional explanation for altered landing kinetics. Therefore, it could be suggested that the use of different landing strategies during loaded jumps alters the loaded landing kinetics. This assumption is supported by previous research, where the lower limb joint kinetics and the joint contribution to energy dissipation were altered during drop-off landings from different heights when using different landing strategies (i.e. soft vs stiff landing) (Zhang et al., 2000). However, to the best of our knowledge the effect of landing strategies on the lower limb joint kinetics during loaded jumps has not been investigated so far. Based on our previous observations, the aim of this study was to analyse the effect of different landing strategies on the landing kinetics during loaded jumps. It was hypothesized that landing kinetics are affected by the landing strategy in load jumps (H1).

METHODS: Ten male sport students (mean ± SD; age: 24 ± 2 yrs; height: 1.80 ± 0.06 m; mass: 80.6 ± 9.7 kg) with vast experience in loaded PT participated in this study. They gave written informed consent for participation approved by the institutional ethics review board. During testing the participants performed five loaded counter movement jumps each with 50% BW of additional load (Olympic barbell with corresponding weights). They were instructed to perform the jump landings in four different landing conditions: super stiff (SST), stiff (ST), soft (SO) and super soft (SSO) landing. Although mechanical stiffness was not calculated, the term stiffness was chosen in accordance with earlier studies published by Devita & Skelly (1992) and Zhang et al. (2000) for differentiation between the landing conditions and referred to the peak knee flexion angle during landing. The order of the four landing conditions was randomly selected. At the beginning of each landing condition the participants were verbally instructed about the movement execution (e.g. “try to land as stiff as possible” (SST) vs “try to land as soft as possible" (SSO)). In each condition, trials one to four were used for familiarization while the fifth trial was used for analysis. Lower body kinematics (Qualisys AB, Göteborg, Sweden: 100 Hz) and ground reaction forces (AMTI, Watertown, MA, USA: 1000 Hz) were measured and subsequently filtered using a 2nd order zero-lag Butterworth filter. Cut-off frequencies were chosen according to an individual residual analysis for each marker and each force component (Winter, 2009). Kinematic and kinetic parameters of the left limb during landing (defined from initial contact to peak knee flexion angle) were calculated for the ankle, knee, and hip joint. Kinematic parameters consisted of: jump height (JH), landing duration (LD) and peak joint flexion angle (PA). To assess the landing kinetics, peak vertical force (PF), peak external flexion moment (PM) and peak eccentric joint power (PP) were calculated. Additionally, total lower limb eccentric joint work (EW = sum of eccentric ankle, knee and hip work) and the percentage contribution (PC) of each of the lower limb joints to EW were determined. To test for the effect of the landing strategy on the variables a one-way ANOVA with repeated measures was used. In case of significant landing strategy effects ($p<0.05$, η^2), pairwise comparisons were conducted using post hoc t-tests with Bonferroni correction ($p<0.008$).

RESULTS:

Table 1: Kinematic and kinetic variables (mean±SD) during loaded (1.5 * BW) jumps using different landing strategies

		SST	ST	SO	SSO	*p*	*η²*
JH [m]		0.16 (0.03)	0.16 (0.02)	0.16 (0.02)	0.16 (0.03)	*0.437*	*0.094*
LD [s]		0.23 (0.14)$^{¥}$	0.26 (0.06)$^{¥}$	0.55 (0.30)	0.66 (0.17)$^{+,\#}$	*0.001*	*0.607*
PA [°]	A	119 (7)	123 (6)	126 (4)	127 (6)	*0.044*	*0.316*
	K	59 (21)$^{\sim,¥}$	76 (18)$^{\sim,¥}$	100 (15)$^{+,\#,¥}$	116 (15)$^{+,\#,\sim}$	*<0.001*	*0.746*
	H	45 (17)$^{\#,\sim,¥}$	66 (28)$^{+,\sim,¥}$	99 (24)$^{+,\#}$	109 (15)$^{+,\#}$	*<0.001*	*0.793*
PF [N/BW]		8.0 (3.4)$^{\sim,¥}$	6.4 (1.8)$^{¥}$	4.6 (1.3)$^{+}$	3.8 (1.3)$^{+,\#}$	*<0.001*	*0.608*
EW [J/kg]		-2.2 (0.4)$^{\sim,¥}$	-2.6 (0.8)$^{\sim,¥}$	-3.7 (0.7)$^{+,\#}$	-4.0 (0.5)$^{+,\#}$	*<0.001*	*0.721*

A, Ankle; K, Knee; H, Hip. + different from SST, # different from ST, ~ different from SO, ¥ different from SSO.

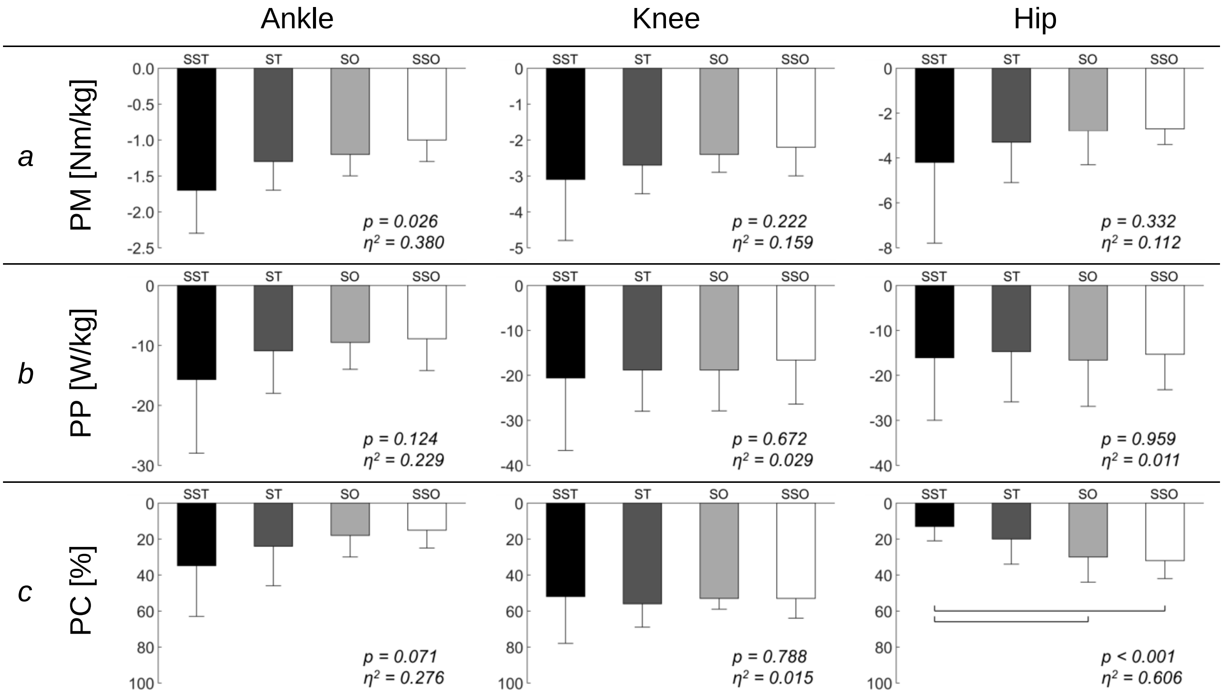

Figure 1: a) Peak flexion moment (PM), b) peak eccentric power (PP) and c) percentage contribution (PC) to total lower limb eccentric joint work (mean±SD) for ankle, knee and hip joint during loaded (1.5 * BW) jumps using different landing strategies. Black brackets indicate significant pairwise differences between the landing strategies.

JH was not affected by the landing strategy. LD and PA of all joints increased with decreasing landing stiffness (Table 1).
PF decreased with decreasing stiffness (Table 1). No landing strategy effects were observed regarding PM (Fig. 1a) and PP (Fig. 1b) except for the ankle PM, which was decreased with decreasing landing stiffness. EW increased with decreasing stiffness (Table 1). PC to EW increased with decreasing stiffness for the hip, while no changes were found regarding the ankle and the knee joint (Fig. 1c). The knee joint was constantly the most dominant contributor to EW (Fig. 1c).

DISCUSSION: This was the first study analysing the effect of different landing strategies on the kinetics during loaded jumps. Due to the substantial and continuous changes of knee peak flexion angle, it can be assumed that the landing strategy instructions have been followed adequately. Jump height and consequently the kinetic energy (which had to be dissipated during landing) were not affected by the landing strategy. Potential bias of jump height on the kinetic results can therefore be excluded.
Substantial increase of peak vertical force was observed with increasing landing stiffness (+50% from SSO to SST). No changes were found regarding peak moment and peak power, except for ankle peak moment. Lower limb eccentric joint work also increased substantially with decreasing stiffness (+83% from SST to SSO), while hip percentage contribution increased. Therefore, H1 is accepted with respect to peak vertical force, lower limb eccentric joint work, ankle peak moment as well as hip percentage contribution, but has to be rejected for peak knee and hip moment, peak power as well as ankle and knee percentage contribution to energy dissipation.
The results regarding peak vertical force are in line with Devita & Skelly (1992) and Zhang et al. (2000), who reported increased values with increased landing stiffness during landing without additional load. Those high impact forces (up to 8 * BW, Table 1) are associated with lower limb overuse injuries (especially skeletal system) and therefore might pose increased injury risk (Lian et al., 2005). Cartilage degeneration and micro bone fractures (leading to a decreased mechanical support of the subchondral bone) have been shown by Serink et al. (1977) due to repetitive mechanical compression of the knee joint in rabbits. The soft landings performed in this study resulted in substantially decreased peak vertical forces. From an overuse injury risk perspective it has been suggested to perform soft landings (Bressel & Cronin, 2005). This, however, cannot always be achieved in a competitive setting, if further actions are required immediately after landing (e.g. rebounds in basketball) because the longer landing duration required for energy dissipation (LD, Table 1) cannot be achieved. However, this recommendation could be easily implemented during loaded plyometric training, because there is usually no need for a consecutive movement after landing.
Peak moment and peak power allow for the assessment of the maximum effort of the joint spanning muscles in energy dissipation. Zhang et al. (2000) reported changes regarding those parameters (at the ankle, knee and hip joint) induced by the use of different landing strategies during drop-off landings without additional load. In their study, peak moment decreased with decreasing landing stiffness for all joints. Peak power was also decreased with decreasing landing stiffness at the ankle joint, remained constant at the knee joint and was decreased at the hip joint. For most of the analysed variables, this indicated that soft landings were favourable from an overuse injury risk perspective (Zhang et al., 2000). Although in the current study similar characteristics regarding peak moment as well as ankle and knee peak power were observed, those results were statistically not significant suggesting the maximum effort of the joint spanning muscles in energy dissipation was not affected by the landing strategy during loaded jumps. This can be explained by the combination of higher vertical forces and simultaneously smaller flexion angles resulting in smaller lever arms of force in the SST and vice versa in the SSO. Regarding peak power the load based increased landing duration might allow for a decreased joint angular velocity and therefore again results in similar characteristics between the different landing strategies.
The differing results between the study presented by Zhang et al. (2000) and the current study are most likely due to the different types of “external loads” used in both studies. In the present

study the jumps where performed with 50% BW additional load, while Zhang et al. (2000) used drop-off landings without additional load. Here, different fall heights served for inducing external load (0.32 m, 0.62 m and 1.03 m). Due to missing interaction effects of jump height and landing strategy, they analysed the effect of strategy on the kinetic variables based on the pooled values across height. Therefore, the mean fall height was 0.66 m, resulting in a mean kinetic energy of 479 J, which had to be dissipated during landing. In the present study the kinetic energy of 188 J on average was much smaller despite the additional load of 50 % BW due to the substantially smaller jump height. This suggests that the effect of the landing strategy becomes more important with increasing demands on the musculoskeletal system (i.e. increased kinetic energy).
Eccentric joint work can be used to assess the overall effort of the lower limb joints in energy dissipation. It was significantly increased with decreasing landing stiffness (+83 %) although kinetic energy did not change due to an unchanged jump height. It can therefore be assumed that energy dissipation is shifted from “active” (joint spanning muscle-tendon system) during soft landings to “passive” (skeletal system) during stiff landings, resulting in mechanical stress on different tissues when using different landing strategies. This also becomes evident when analysing the joint contribution to energy dissipation. The joints spanned by the bigger and more “powerful” muscles contributed more when lower limb joint work increased (Devita & Skelly, 1992; Zhang et al., 2000).

CONCLUSION: Landing with or without additional load results in mechanical stress on the musculoskeletal system. Evidence has been provided that different landing strategies elicited changes regarding the landing kinetics (PF, ankle PM and EW) also during loaded jumps. This suggests that different body tissues are differently exposed to mechanical stress depending on the landing strategy. Based on the study findings, two major recommendations can be provided for loaded PT: i) the use of the most extreme landing strategies (SST and SSO) cannot be recommended due to either substantially higher peak forces (SST) or eccentric joint work (SSO) values, possibly representing an increased overuse injury risk factor; ii) it might be beneficial to vary between landing strategies (ST and SO) to avoid monotonous stress on specific lower limb tissues.

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