ORIGINAL ARTICLE

Task-specific initial impact phase adjustments in lateral jumps and lateral landings

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Abstract Load-dependant adjustments in lateral jumps are thought to rely on foot placement and on upper leg's kinematic and neuromuscular adaptations. The aim of this study was to elucidate task-specific adjustments during the initial impact phase under varying stretch-loads by the comparison of lateral jumps and lateral landings. Ten subjects performed lateral jumps and landings from four distances. Electromyographic (EMG) data of five lower extremity muscles were measured, whilst lower extremity kinematics and kinetics were analysed by 3D motion analysis. Lateral jumps were characterized by increased impact forces, higher lower extremity joint moments with exception of the initial knee abduction moment, greater sagittal knee and hip joint displacements, and a further exorotated foot placement. In lateral landings frontal ankle and hip joint displacements were greater. Thigh muscle and m. tibialis anterior (TA) pre-activity as well as initial post-impact EMG were higher in lateral jumps than in lateral landings, whilst during the reflex-induced phase thigh and shank muscle EMG, except for TA, were enhanced in lateral jumps. From these findings it can be concluded that task specificity in lateral jumps in contrast to lateral landings impedes a stretch-load adequate modulation of initial impact forces which particularly affects ankle joint loading. Foot placement seems to play a decisive role for limiting lateral ankle and medial knee joint loading.

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Therefore, in sports containing high-impact frontal plane movements a special emphasis in training routines should be paid to foot placement strategy in those movements. Such training interventions might contribute to injury prevention in lateral movements.

Introduction

Controlling landings is an essential requirement to avoid serious injuries of the lower extremity ligaments and of the muscle–tendon complex (Fong et al. 2009; Jones et al. 2000; Olsen et al. 2004). Lateral landings conducted during a frontal plane movement are even more difficult to control than sagittal landing tasks as for example during vertical jumps. Those difficulties are caused by the lower extremity joints' anatomy (Hertel 2002; Mclean 2010; Recondo et al. 2000). The muscles crossing these joints are mainly anterior-posterior located, and control primarily flexion–extensions rather than abduction–adductions or inversion–eversions. Studies focusing on neuromuscular and mechanical control in vertical landings and jumps are manifold (Brown et al. 2009; Horita et al. 2002; McNitt-Gray 1993; Santello 2005; Sousa et al. 2007). But so far central kinematic and neuromuscular control mechanisms of lateral landing tasks are not well investigated, although those motions are crucial components of many frontal plane movements. Those movements occur with a high frequency in ball games, for instance during direction changing manoeuvers or feints.

In order to control lateral landings, the central nervous system must provide effective strategies involving the

adaptation of both neuromuscular and kinematic parameters to adequately attenuate impact forces and to control joint loading. Those strategies need to be adjusted to landing task-specific requirements and to the resultant lower extremity loading to minimize injury risk. Thus, the task-specific requirement in a lateral jump to perform a push-off immediately after the landing phase requires different biomechanical adjustments during the initial impact phase than a singular lateral landing which lacks a subsequent push-off.

Neuromuscular control during the initial impact phase of lateral landings and lateral jumps needs to be adjusted to task-specific impact loading. Those adjustments involve task- and associated load-specific adaptations of muscle activity prior and initially after impact. Before ground contact muscle pre-activity is adjusted to the anticipated impact loading to enable the muscle–tendon complex to resist immediately after touch-down impact loading, and thus to enable a controlled and safe landing (Avela et al. 1996; Santello 2005). Studies investigating vertical jump and landing tasks for instance showed that pre-activity is modulated according to impact load induced by different drop heights (Mrdakovic et al. 2008; Santello and McDonagh 1998). Initial post-impact muscle activity is characterised by stretch reflex activity which contributes to muscle–tendon stiffness during the initial impact phase and to force enhancement (Duncan and McDonagh 2000; Hoffer and Andreassen 1981; Komi and Gollhofer 1997; Ludvig et al. 2007; Nicol and Komi 1998; Sinkjaer et al. 1988).

Task- and load-specific adjustments of muscle activity prior and after impact are essential to control joint rotations (Santello 2005). Thus, increasing impact forces require higher lower extremity joint flexions to allow a better shock absorption, as it has for instance been demonstrated for the knee joint in vertical landings from different heights (Yeow et al. 2009, 2010).

A previous study investigating load adjustment strategies in lateral jumps to varying jumping distances could demonstrate that load compensation relies on greater sagittal knee and hip joint displacements. Those displacements required load-dependant thigh muscle activity adjustments during pre-activity and the stretch reflex-induced phase (Fleischmann et al. 2010). An increased transversal foot exorotation under higher stretch-loading in lateral jumps seems to be a central strategy to shift load compensation from the fontal to the sagittal plane.

The purpose of this study was to investigate task-specific neuromuscular and kinematic adjustments during the initial impact phase of lateral jumps and lateral landings under stretch-load variation.

We hypothesised that the task-specific requirement in lateral jumps to perform a push-off immediately after the landing phase would cause higher initial impact forces than in lateral landings. Higher impact forces in lateral jumps would induce higher initial lower extremity joint moments in this task. In order to compensate this increased initial loading in lateral jumps, we therefore further hypothesised, based on previously described load adjustment mechanisms in lateral jumps, higher knee and hip joint flexions, increased thigh muscle activity prior and after impact, and a further exorotated foot placement in lateral jumps.

Methods

Subjects

Ten male sports students (height: 182 ± 3.1 cm, weight: 75.8 ± 7.6 kg, age: 24 ± 2 years) who were accustomed to conduct frontal plane movements participated in the study. They were free of injury and gave their written consent to participate after having been informed about procedures, purpose and possible risks associated with the experimental setup. The experiments were run in accordance with the declaration of Helsinki.

Procedures

Ten lateral jumps and ten lateral landings were performed barefooted and in randomized order onto a force plate from four distances. Before measurements started subjects could practise each movement from the respective jumping distance until feeling comfortable with the task. Subjects were instructed to omit trunk rotations, and to keep the jumping and landing techniques consistent throughout the measurements. During both tasks, take-off from the start position was conducted with the right leg, whilst landing on the force plate was executed on the left leg. During the lateral jump task, subjects had to jump from the respective jumping distance onto the force plate and back to the start position whilst keeping the force plate contact as short as possible (Fig. 1).

Fig. 1 Schematic illustration of the lateral jump movement

The landing movement task involved jumping onto the force plate from the same four distances as in the jumping task. After the unilateral landing on the force plate, subjects had to remain in the final landing position for 2–3 s before placing the contra lateral leg down.

The four jumping distances were used to vary lateral stretch-load to investigate if the expected landing task-specific adjustments during the initial impact phase differ under small and high stretch-loads. Jumping distances were determined upon the individual maximum lateral jumping ability, to which is referred to as extreme distance (EXD). The remaining three distances were set at 85% [long distance (LOD)], 70% [medium distance (MED)] and at 55% [short distance (SHD)] of EXD.

Data collection

Kinematics and kinetics

Ground reaction forces were measured using a force plate (Advanced Mechanical Technology Inc, Watertown, MA) with a sampling frequency of 1,000 Hz. A twelve camera (200 Hz) 3D motion analysis system (VICON Motion Systems Ltd. Oxford, UK) was used to determine segment kinematics.

Before measurements, subjects were instrumented with 17 retro reflective markers (diameter: 14 mm). Those were placed onto anatomical landmarks of the pelvis and the lower left extremity based on a model by Kadaba et al. (1990). Markers were placed on the anterior superior iliac spines, the posterior iliac spines, the great trochanter, the medial and lateral epicondyles, two on the tibia, the medial and lateral malleolus, the heel, the medial and lateral aspect of the calcaneus, and on the 1st, 2nd and 5th metatarsals.

EMG

Based on the findings of stretch-load dependant movement regulation in lateral jumps (Fleischmann et al. 2010) which showed that the observed hamstring, quadriceps and triceps surae muscles had rather comparable activation characteristics during the initial impact phase, we focused in this study on one representative muscle of each group.

Thus, EMG activity of m. biceps femoris (BF), m. vastus lateralis (VL), m. soleus (SOL), m. peroneus longus (PL) and m. tibialis anterior (TA) of the left leg were recorded using Ag/AgCl bipolar surface electrodes (Blue Sensor, Ambu, Balerup, Denmark). The reference electrode was placed on the medial anterior aspect of the tibia. Skin preparation and electrode placement followed SENIAM recommendations (Hermens et al. 2000).

Data analysis

Kinematic and kinetic analysis

Kinematic data was processed by VICON motion analysis software (Nexus 1.3, VICON Motion Systems Ltd., Oxford, UK) using a Woltring filter (mean square error = 10) to smooth kinematic data. Joint kinematics were calculated based on Cartesian joint coordinate systems, whereas the definition of the respective joint coordinate systems and subsequent kinematic calculations followed for the hip joint recommendations of Davis et al. (1991), and for the knee and ankle joint those of Grood and Suntay (1983) and Wu et al. (2002).

In order to analyse the initial impact phase of lateral jumps and lateral landings mean medio-lateral and vertical initial impact forces were calculated between 0 and 150 ms in accordance to the previously reported interval used to investigate the initial impact phase of lateral jumps (Fleischmann et al. 2010). To determine lower extremity joint loading maximum sagittal and frontal plane joint moments were determined during the initial impact phase. Sagittal and frontal plane initial impact phase displacements of the ankle, knee and hip joint were calculated between touch-down and 150 ms. Possible task-dependant differences in foot placement were quantified by the foot progression angle (FPA) at touch-down. The FPA defines the transversal deflection of foot's coordinate system from the global coordinate system. A negative FPA has been defined as exorotation and the positive angle as endorotation.

EMG analysis

Signals were sampled at 1,000 Hz and processed by a LabVIEW-based (National Instruments, Austin, USA) software tool (IMAGO, University of Freiburg, Freiburg, Germany). EMG data was triggered on force plate data, filtered (10–500 Hz bandwidth 2nd order Butterworth filter) and full-wave rectified. Ten trails of each movement were averaged.

In order to determine possible task-dependant influences on muscle activity before impact, the mean pre-activity amplitude was calculated for the interval 30 ms before touch-down till impact. In accordance to the kinetic and kinematic analysis post-impact initial impact phase EMG was analysed between 0 and 150 ms (Fig. 2). To determine task-specific influences on muscle activity immediately after touch-down, the mean EMG amplitude was calculated between 0 and 30 ms (initial post-impact amplitude). Within the subsequent interval between 30 and 150 ms reflex activity had been observed in lateral jumps (Fleischmann et al. 2010), hence the mean amplitude for the 30–150 ms interval (reflex phase amplitude) was
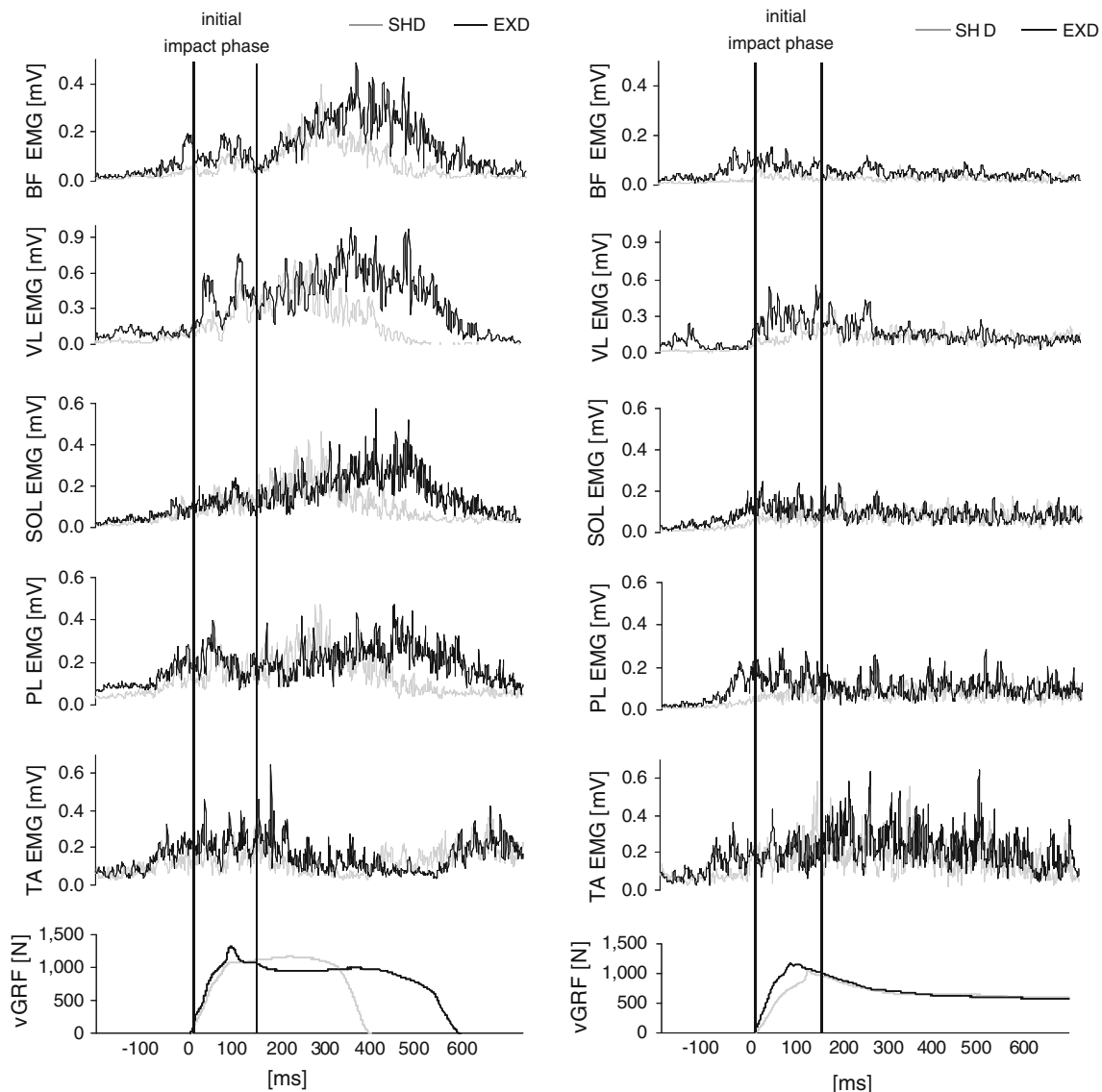
Fig. 2 Averaged and rectified EMG and vertical ground reaction forces (vGRF) of one subject during short distance (SHD *grey*) and extreme distance (EXD *black*) lateral jumps (*left panel*) and lateral landings (*right panel*). *Vertical solid lines* mark the initial impact phase 0–150 ms. *BF* m. biceps femoris, *VL* m. vastus lateralis, *SOL* m. soleus, *PL* m. peroneus longus and *TA* m. tibialis anterior

determined. EMG data was normalized on SHD pre-activity mean amplitude in lateral jumps.

Statistical analysis

A two-factor analysis of variance for repeated measurements was calculated to determine possible main differences on the dependant variables between lateral jumps and lateral landings under the four stretch-load conditions. An alpha level of 0.05 was selected to identify statistical significance.

If a main effect on a dependant variable between the two movements could be observed, differences between the initial impact phase of lateral jumps and lateral landings were analysed by paired samples *t* tests for each stretch-load condition (SHD, MED, LOD and EXD), after data normal distribution was tested with the Kolmogorov–Smirnov test. Due to the low number of degrees of freedom and the inter-individual dependant variables values' variance, the reported alpha level has been used for those tests to exploratively describe the influence of the four stretch-load conditions on the two observed movements.

Statistical calculations were performed with SPSS 15.0 (SPSS Inc., Chicago, USA). Results are presented as group mean values ± standard deviation. Due to better readability the results of the paired samples *t* tests, but not the main effect analysed with the two-factor analysis of variance are incorporated in the graphics. Those values are presented in the text.

Results

Kinetics

In lateral jumps mean medio-lateral and vertical initial impact forces were significantly higher ($P < 0.001$) than in lateral landings. The task comparison for each stretch-load condition indicated that mean medio-lateral impact forces in lateral jumps were in all four stretch-load conditions higher than in lateral landings. In contrast, mean initial vertical impact forces increased in lateral jumps in comparison to lateral landings in SHD ($P < 0.001$) and in MED ($P < 0.001$), but not in LOD and EXD stretch-load conditions (Fig. 3).

As illustrated in Fig. 4, joint moments during the initial impact phase were higher in lateral jumps than in lateral landings. Thus, in the sagittal plane ankle ($P = 0.006$), knee ($P = 0.021$) and hip ($P < 0.001$) joint moments were enhanced in lateral jumps compared to lateral landings. In the frontal plane lateral jump ankle inversion ($P = 0.004$) and hip adduction ($P = 0.039$) moments were higher than those of lateral landings, but no difference between the two tasks was found for the initial knee abduction moment.

Kinematics

Foot placement in lateral jumps occurred at touch-down with a greater exorotation ($P = 0.007$) than in lateral landings. As illustrated in Fig. 5, differences in this parameter enhanced with stretch-load, hence exorotation in lateral jumps was higher than in lateral landings in MED ($P = 0.046$), LOD ($P = 0.023$) and EXD ($P = 0.002$).

The analysis of sagittal joint displacements showed no differences in ankle dorsiflexion displacement between the two movements, whereas knee ($P = 0.039$) and hip ($P = 0.045$) joint flexion displacements were higher in lateral jumps than in lateral landings (Fig. 6a). In the
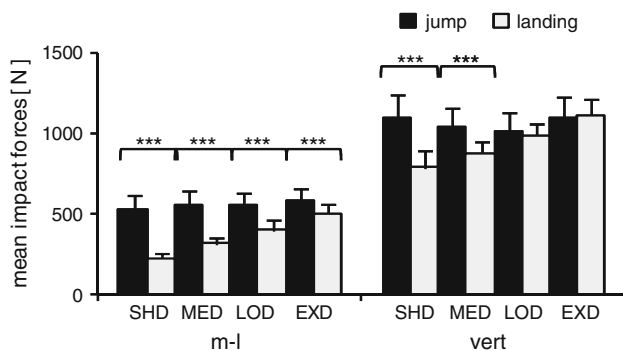
frontal plane, ankle inversion ($P < 0.001$) and hip abduction ($P < 0.001$) displacements were greater in lateral landings than in lateral jumps. Contrary, knee adduction displacement was higher ($P < 0.041$) during the initial impact phase of lateral jumps than during lateral landings (Fig. 6b).

EMG

Pre-impact muscle activity was task- and muscle-specifically modulated. During lateral jumps, thigh muscles' pre-activity mean amplitudes were significantly enhanced in BF ($P = 0.018$) and in VL ($P = 0.003$) compared to pre-activity mean amplitudes of lateral landings (Fig. 7a). No significant differences in pre-activity mean amplitudes between the two tasks were found for the lower leg muscles SOL and PL, whereas TA pre-activity mean amplitudes were significantly higher ($P = 0.002$) in lateral jumps.

The observed pre-activity mean amplitude patterns resemble those patterns of initial post-impact activity between touch-down and 30 ms of ground contact. Thus, during lateral jumps thigh muscles' initial post-impact mean amplitudes were significantly higher in BF ($P = 0.002$) and in VL ($P < 0.001$) compared to the initial post-impact mean amplitudes of lateral landings (Fig. 7b). In the shank muscles SOL and PL no differences between the two investigated lateral tasks could be observed during this interval, whereas in lateral jumps TA initial post-impact mean amplitudes were significantly enhanced ($P < 0.001$) in comparison to lateral landings.

During the subsequent reflex-induced phase the mean reflex phase amplitudes of the thigh (BF $P < 0.001$, VL $P < 0.001$) and the shank (SOL $P < 0.001$, PL $P < 0.001$) muscles were significantly higher in lateral jumps than in lateral landings. TA activity did not show any significant differences between the two tasks during the reflex-induced phase (Fig. 7c).
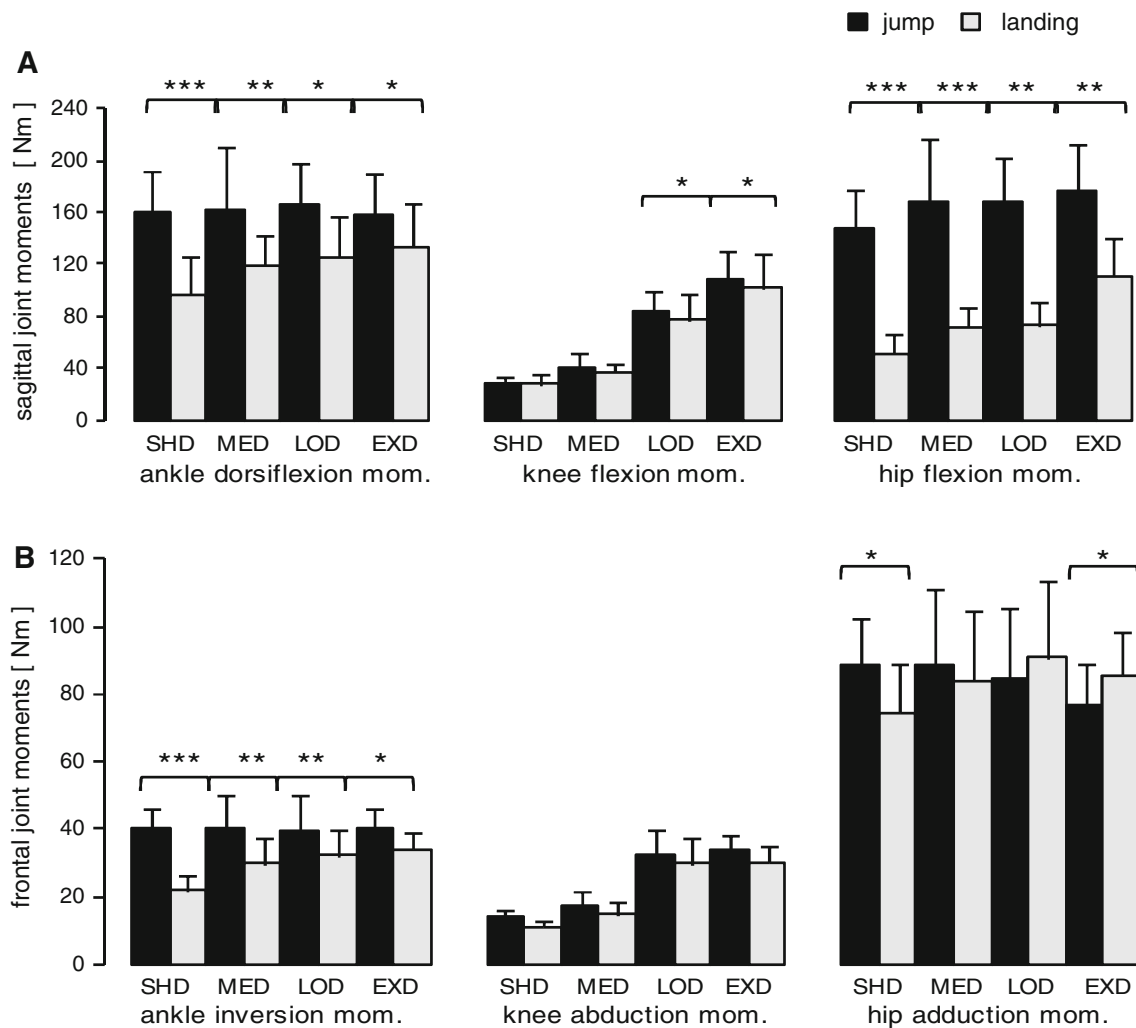
Discussion

This study utilized the comparison of singular lateral landings with the landing phase of lateral jumps under varying stretch-loads to investigate kinematic and neuromuscular adjustments to task-specific loading during the initial impact phase.

The main findings of the study were that in lateral jumps initial impact forces, in particular the medio-lateral ones, were higher than in lateral landings. Also lower extremity joint moments, with exception of the initial knee adduction moments, were in lateral jumps higher than in lateral landings. Lateral jumps required greater sagittal knee and hip joint flexions and a greater exorotated foot placement

Fig. 3 Mean medio-lateral (*m-l*) and vertical (*vert*) initial impact forces during lateral landings and lateral jumps in dependency of stretch-load. *SHD* short distance, *MED* medium distance, *LOD* long distance and *EXD* extreme distance. ***$P < 0.001$

Fig. 4 Lower extremity maximum joint moments during lateral landings and lateral jumps in dependency of stretch-load. **a** Sagittal joint moments. **b** Frontal joint moments. *SHD* short distance, *MED* medium distance, *LOD* long distance, *EXD* extreme distance and *mom* moment. $*P < 0.05$; $**P < 0.01$ and $***P < 0.001$
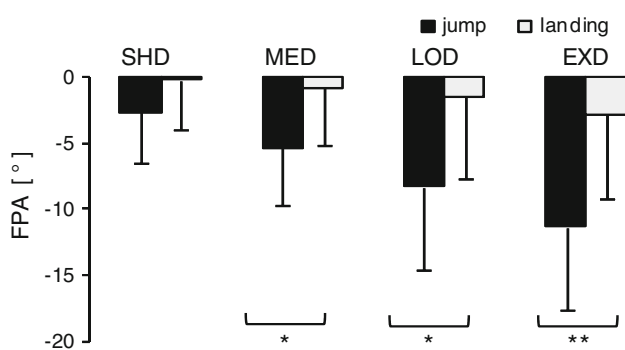
Fig. 5 Foot progression angle (FPA) at touch-down during lateral landings and lateral jumps in dependency of stretch-load. *SHD* short distance, *MED* medium distance, *LOD* long distance and *EXD* extreme distance. $*P < 0.05$ and $**P < 0.01$

compared to lateral landing tasks. Contrary, lateral landings showed greater frontal ankle and hip joint displacements, whereas frontal knee displacements were enhanced

in lateral jumps. Lateral jumps revealed increased thigh muscle activity before and immediately after touch-down, whilst during the stretch reflex-induced phase muscle activity of thigh and shank muscles, except for TA, were enhanced in lateral jumps.

Task-specific influences on ground reaction forces and joint moments

The necessity of short ground contact times requires a push-off phase which immediately succeeds a task-adequate short landing phase in a reactive lateral jump. This task-specificity accounts for a time constraint to attenuate impact forces and the associated landing impulse in lateral jumps. In lateral landings on the contrary, which do not require a push-off, impact forces and landing impulse can be compensated over a greater time span. Therefore, in lateral landings lower initial impact forces
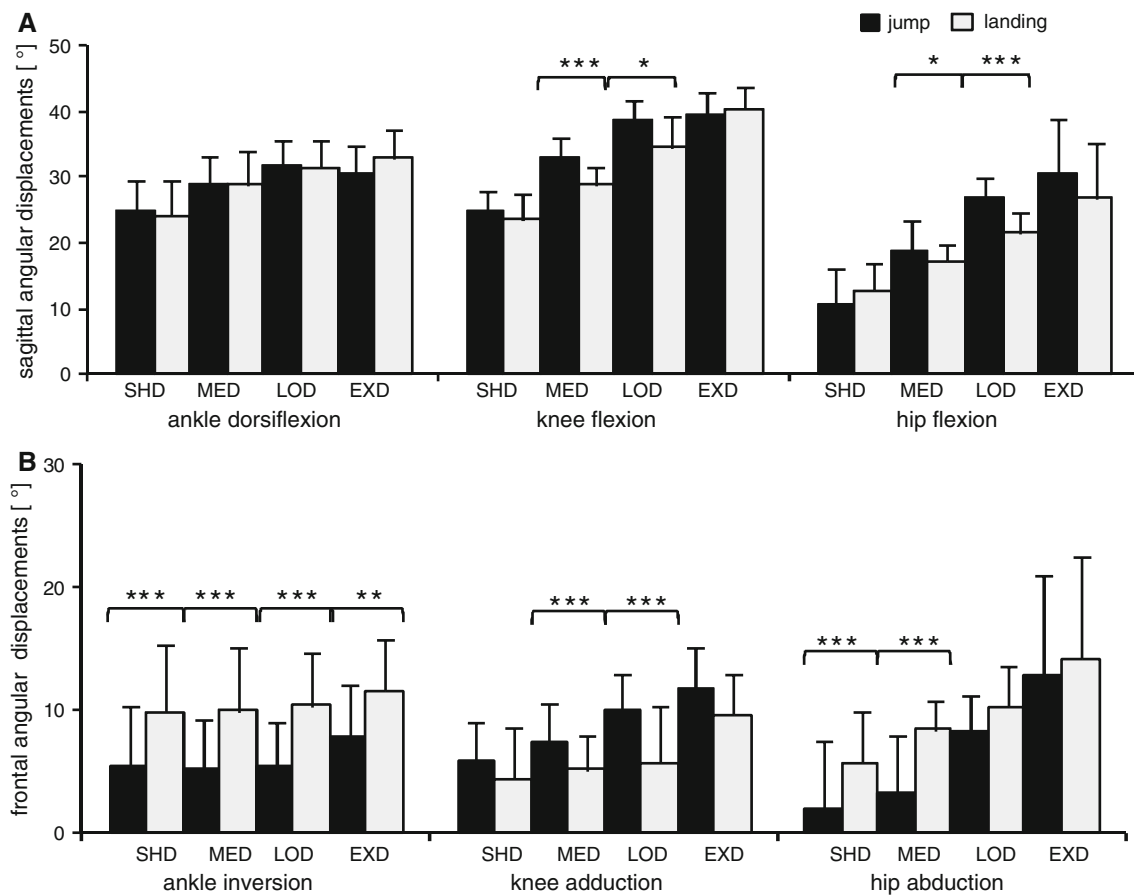
Fig. 6 Lower extremity angular displacements during lateral landings and lateral jumps in dependency of stretch-load. **a** Sagittal joint displacements. **b** Frontal joint displacements. *SHD* short distance, *MED* medium distance, *LOD* long distance and *EXD* extreme distance. *$P < 0.05$, **$P < 0.01$ and ***$P < 0.001$

can be generated and modulated according to stretch-loading which does not seem to be possible in lateral jumps. Hence, in lateral jumps, the necessity of a short landing phase and a fast transition to the push-off phase seems to account for rather constant and high mean initial vertical and medio-lateral impact forces during all stretch-load conditions. Thus, the motor system does not seem to be able to adjust initial impact forces during the observed interval adequately to stretch-loading in lateral jumps. As a consequence lower extremity loading during the initial impact phase is already high in low stretch-load conditions in lateral jumps. Joint moment analysis indicates that high-impact forces in lateral jumps even in low stretch-load conditions affect in particular the distal ankle joint. Thus, sagittal and frontal ankle joint moments exhibit the same task-specific pattern under stretch-load variation as initial impact forces. Consequently, in lateral jumps ankle joint moments reveal constantly high values during all stretch-load conditions, whereas in lateral landings those are modulated according to stretch-load.

Hence, lateral jumps require a different load compensation strategy than lateral landings to compensate higher lower extremity loading. In particular the high ankle joint loading in lateral jumps even in short jumping distances needs to be task-adequately controlled.

Task-specific foot placement and its influence on frontal joint loading

In lateral jumps foot placement occurs in with a greater exorotation which can be interpreted as a strategy to limit frontal joint loading, and in particular the high lateral ankle joint loading. A greater exorotated foot placement favours that loading can be shifted from the frontal to the sagittal plane as it has previously been shown in lateral jumps under increasing stretch-load conditions (Fleischmann et al. 2010). In the sagittal plane capabilities to attenuate impact forces by higher joint displacements and muscle activity in the anterior-posterior located thigh muscles are greater than in the frontal plane, as frontal plane joint displacements underlie greater limitations due to joints' anatomy (Hertel 2002; Recondo et al. 2000). Hence, excessive lower extremity joint displacements in that plane are associated with an increased injury risk (Ford et al.
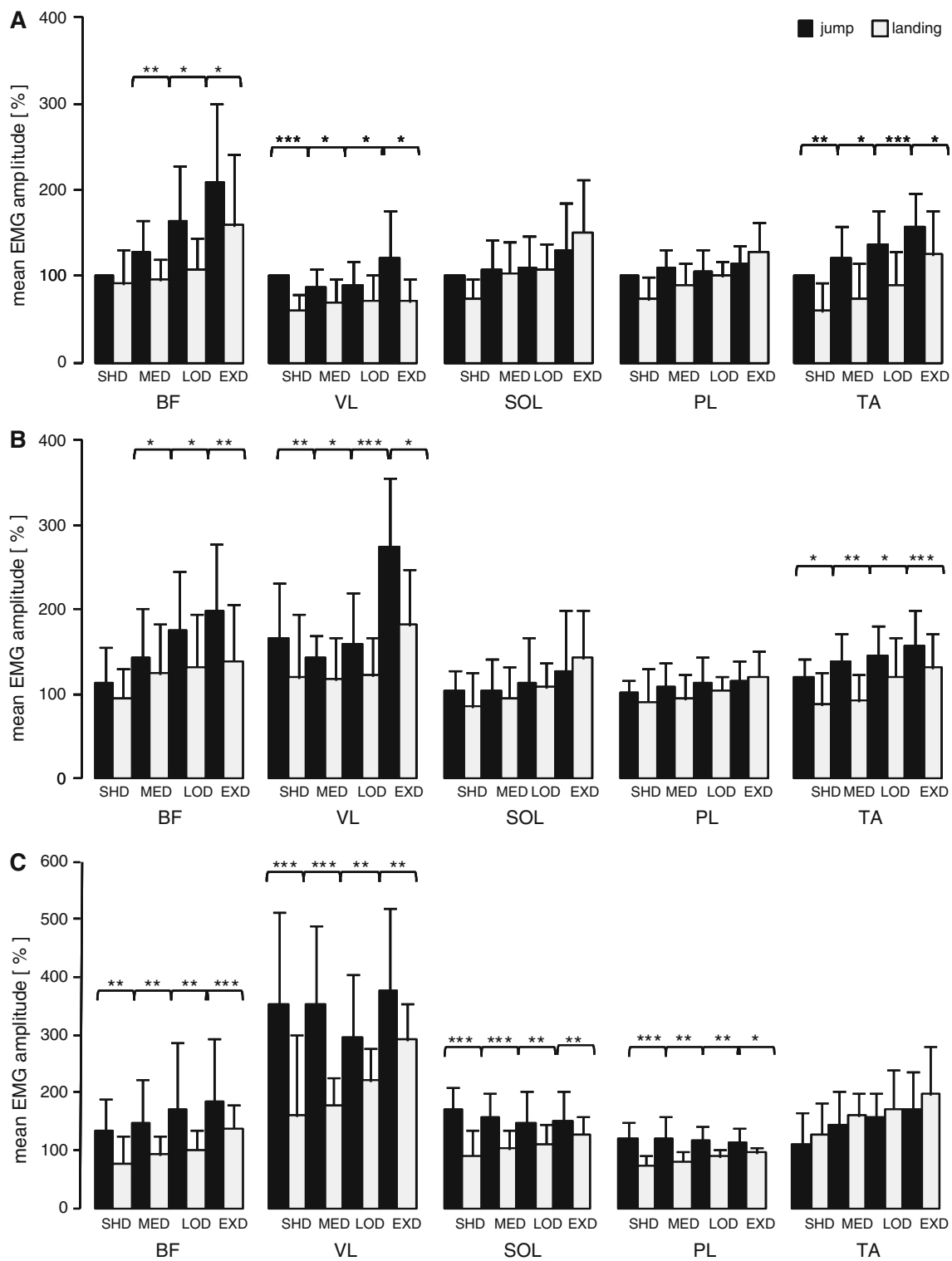
Fig. 7 Mean EMG amplitudes during lateral landings and lateral jumps in dependancy of stretch-load. EMG data is normalized on SHD lateral jump pre-activity mean amplitudes. **a** Mean pre-activity amplitudes. **b** Mean initial post-impact amplitudes. **c** Mean reflex phase amplitudes. *SHD* short distance, *MED* medium distance, *LOD* long distance, *EXD* extreme distance, *BF* m. biceps femoris, *VL* m. vastus lateralis, *SOL* m. soleus, *PL* m. peroneus longus and *TA* m. tibialis anterior. *$P < 0.05$, **$P < 0.01$ and ***$P < 0.001$

2006; Hewett et al. 2005). Consequently high frontal joint displacements are less benefited to compensate loading in reactive high-loading lateral movement tasks.

The higher exorotation of the FPA in lateral jumps compared to the lateral landing tasks seems to be a strategy to limit inversion–eversion displacements as it has previously been demonstrated in gait analysis (Ho et al. 2000). Reducing frontal plane ankle joint displacements in dynamic lateral jumps characterised by high inversion moments is crucial for the lateral ankle joint stability.

Aside influencing frontal ankle joint displacements the lateral task comparison suggests that the FPA also affects frontal knee joint mechanics during the initial impact phase of lateral movements. As knee joint moment analysis revealed initial knee abduction moments do not differ between the two tasks, although initial impact forces are enhanced in lateral jumps. Further analysis revealed that a higher foot exorotation which causes an increased exorotation of the lower extremity, permits a greater adducted knee positioning ($P = 0.009$) at the instance of initial ground contact in lateral jumps. Thus, for instance in EXD initial knee adduction in lateral landings measures $0.6° \pm 3.4°$, whilst in lateral jumps a greater initial knee adduction ($1.09° \pm 3.5°$) can be achieved. This influence of foot exorotation on initial frontal knee kinematics probably accounts for equal initial knee abduction moments in both tasks. The analysis of frontal knee displacements during the initial impact phase revealed greater knee adduction displacements in lateral jumps than in lateral landings. But with respect to lowering the injury risk of medial knee joint structures and the anterior cruciate ligament in high-loading lateral jumps, limiting initial knee abduction by a greater exorotated foot placement might be more relevant than higher frontal knee displacements caused by greater knee adductions. This assumption is supported by the fact that anterior cruciate ligament injuries which often occur in frontal plane movements are linked to abducted knee positions at the instant of injury (Krosshaug et al. 2007; Olsen et al. 2004).

Thus, foot exorotation seems to be a strategy to limit frontal ankle joint displacements and initial knee abduction in high-loading lateral movements. In addition to reducing frontal plane loading in these joints, a greater exorotated foot placement in lateral jumps might also favour an advantageous lower extremity alignment for the subsequent push-off action in this task.

In lateral jumps load compensation relies on sagittal joint displacements, in lateral landings on frontal joint displacements

Greater upper leg's knee and hip joint displacements in lateral jumps ensure the compensation of higher initial impact forces in this task. Those displacements ensure the deceleration of the motion and additionally provide a longer acceleration distance for the subsequent push-off phase. Thus, greater sagittal joint displacements in lateral jumps might contribute to jump performance. In lateral landings on the contrary, upper leg joint flexions are lower than in lateral jumps as initial impact forces are lower and no subsequent acceleration distance for a push-off is needed. The dependency of load compensation on knee and hip joint sagittal displacements, but not on ankle flexions could also be demonstrated in vertical landing tasks. Thus, the comparison of stiff and soft vertical landings revealed that soft landings are characterised by increased knee and hip flexions. Hence, the knee and hip joint encompassing muscles fulfilled more work in soft landings compared to stiff landings to compensate impact loading. But ankle dorsiflexion did not vary between the two tasks (Devita and Skelly 1992).

In contrast to lateral jumps, in which load compensation depends on upper leg sagittal joint displacements, in lateral landings load compensation seems to be achieved by increased frontal ankle and hip joint displacements. Those greater frontal joint displacements in lateral landings might allow keeping sagittal joint flexions low in that task. Increased frontal ankle and hip joint displacements in lateral landings result from the fact that lateral landings are associated with a greater lateral shift of the centre of mass in comparison to lateral jumps. The greater body's lateral translation and the associated increased frontal ankle and hip displacements probably cause the previously discussed lower frontal knee joint displacements in lateral landings in comparison to lateral jumps. Shifting load compensation into the frontal plane would be a disadvantageous strategy for lateral jumps. This strategy would impede short ground contact times, and would as discussed compromise lateral ankle joint stability in high-loading lateral jumps.

Higher upper leg joint flexions require an increased thigh muscle activity in lateral jumps

Increased muscle activity during the initial impact phase in lateral jumps is needed to compensate the higher impact forces and to control increased sagittal knee and hip joint flexions in comparison to lateral landing tasks. Consequently, during the initial post-impact phase (0–30 ms), in particular thigh muscle activity (BF, VL) is clearly enhanced in lateral jumps.

The initial post-impact amplitude pattern resembles the pre-activity pattern as muscle activity is rather continuously regulated (Santello 2005), and as the initial post-impact phase is too short to react upon sensory input generated at impact (Nigg and Liu 1999). Therefore, the initial post-impact muscle activity seems to be

initialized before impact as pre-activity amplitudes indicate, and thus seems to be depended on pre-programmed control.

In vertical jump and drop landing analysis it could also be shown that pre-activity in jumps is higher than in landings (Mrdakovic et al. 2008). But those results from sagittal jump and landing comparisons lack a clear distinction between thigh and shank muscle pre-activity characteristics. In this comparison of lateral jump and landing tasks, however, such a task-specific distinction between thigh and shank muscles could be observed for the mean pre-activity amplitude as well as for initial post-impact amplitude. Thus, the task comparison of this study confirms the findings from lateral stretch-load compensation in lateral jumps (Fleischmann et al. 2010), that initial pre-activity amplitudes are task- and hence load-dependently modulated in the thigh muscles (BF, VL), but less distinctively modulated in the shank muscles (SOL, PL).

Whereas a clear distinction between thigh and shank—except for TA—muscle amplitudes between the two tasks could be observed for pre-activity and the initial post-impact phase, during the reflex-induced phase EMG amplitudes in lateral jumps were enhanced in both thigh and shank muscles. In vertical jump and landing comparisons a reduced stretch reflex activity could be measured in the vertical landing tasks in SOL by Dyhre-Poulsen et al. (1991) and in SOL, m. gastrocnemius medialis and m. rectus femoris by Leukel et al. (2008). Besides lower stretch reflex activity in landings compared to jumps, Leukel et al. (2008) also observed lower background EMG activity during the early reflex response in SOL, but increased activity in TA. In the present study, in lateral landings lower EMG-activity during the reflex-induced phase has been measured in all muscles, but also not in TA.

In contrast to the probably pre-programmed EMG activity during the initial post-impact phase, the task comparison during the reflex-induced phase reveals clear stretch-load dependant differences in muscle activity characteristics between lateral jumps and lateral landings. Those differences affect in particular the shank muscles SOL and PL. Thus, the constantly high ankle joint loading in all stretch-load conditions in lateral jumps seems to cause a consistent PL and even a decreasing SOL ($P = 0.041$) activity during the reflex-induced phase in this task. In lateral landings, however, in which ankle joint moments are modulated according to stretch-loading, SOL ($P = 0.015$) and PL ($P = 0.008$) activity increased according to stretch- and hence according to ankle joint loading.

Thus, muscle activity during the reflex-induced phase is adjusted according to joint loading, whereas the tendency of decreasing SOL activity in lateral jumps seems to mark

an overload reaction to excessive ankle joint loading in this task.

Conclusion

Task-specificity impedes that initial impact forces in lateral jumps can be stretch-load adequately modulated in contrast to lateral landings. This inability results in lateral jumps in high ankle joint loading during the initial impact phase already in low stretch-load conditions. In order to limit lateral ankle and medial knee joint loading, a further exorotated foot placement seems to play a decisive role in movement control of lateral jumps. Therefore, focusing on the foot placement strategy in training routines of lateral movements could contribute to lower incidences of lateral ankle joint injuries, and possibly to those of the medial knee joint structures. Due to differences in neuromuscular and kinematic control of lateral landings and jumps, sports containing high rates of sideward motions, should include both types of movements under varying load conditions into training routine, to practise effectively task-specific load compensation strategies. Such training interventions might contribute to injury prevention in lateral movements.

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